CARBON AND NITROGEN SEQUESTRATION POTENTIAL OF BAMBOO FORESTS OF MIZORAM

THESIS
Submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY IN FORESTRY

By

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CERTIFICATE

We certify that the thesis entitled *"Carbon and Nitrogen Sequestration Potential of Bamboo Forests of Mizoram"* submitted by Mr. David C. Vanlalfakawma for the degree of Doctor of Philosophy in Forestry embodies the record of original investigations carried out by him under our supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the degree. This work has not been submitted for any degree of any other University.

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DECLARATION

I, Mr. David C. Vanlalfakawma, hereby declare that the subject matter of this thesis is the record of the work done by me, that the contents of this thesis did not form basis for the award of any previous degree to me or to anybody else, and the thesis has not been submitted by me for any research degree in any other University/Institution.

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

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Dated: Mizoram University (DAVID C. VANLALFAKAWMA)

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Chapter - I

INTRODUCTION

1.1 Ecology and socio-economy of bamboos

Bamboos belong to the family Poaceae represent one of the greatest natural renewable resources. Long slender stems of bamboos called ‘culms’ are characterized by well demarcated nodes and internodes. The species have an age old connections with the material needs of the common man and therefore called the poor man’s timber. This is the fastest growing and highest yielding renewable plant resources which has great socio-economic importance (Lessard and Chouinard, 1980). The versatility, high tensile strength, wide adaptability to range of climatic conditions and extensive availability of the bamboo make it extremely suitable for domestic and commercial consumption, and therefore the species occupy a prominent place in the progress of the people, particularly in the tropical countries (Sharma, 1980).

Besides multiple uses, the species is known for its high strength, straightness, lightness, easy propagation and abundant growth during short-interval of time. The species of bamboo has tremendous capacity to rapidly regenerate after disturbances and has been reported to grow well degraded areas under conditions of impoverished soil nutrients and water stress (Tripathi and Singh 1994, 1996). Bamboo also grows luxuriantly in secondary successional forests following shifting agriculture in northeast India and has been reported as one of the pioneer species in the succession of jhum fields (Deb and Dutta, 1987).

Bamboo, a multiuse species, is known for its high strength, straightness, lightness and easy propagation. It is used as construction materials, food and fodder, fishing poles, water pipes, handicrafts and tools. Moreover, some species of bamboos are also used as medicine in China (Dharmananda, 2004). Millions of tonnes of bamboos are utilized in different types of cottage industries such as agarbatti (incense stick), chopsticks, toothpicks, kite frames and cracker industry, ice-cream and match industry. It has been estimated that the combined value of internal and commercial consumption of bamboo resources in the world market will be approximated to US $ 10 billion (ca. 45,000.00 crores) every year (Anon. 2003).The total of revenue based products in India is estimated at ₹ 25,000.00 crores. Bamboo shoots account for about 35% of the International market for bamboo based products, to a sum of ₹ 1,750.00 crores, The Indian domestic market for bamboo shoots is valued at ₹ 4.8 crores only. In North Eastern region of India, where more than 50% of total bamboos of the country are available, the consumption of shoot is largely restricted to use of tribal families (Anon. 2003) so that the production of bamboo could be drastically enhanced.

There are about 10,000 units in the handmade sector of match industry in the country. The current size of the bamboo in agarbatti market is approximately ₹135 crores. Besides agarbatti industry, some other miscellaneous items such as lathis and fishing rods have an annual value of ₹ 186.00 crores (Anon. 2003). Bamboo craft sector generates about 250 million days of work by employing mainly women from the rural land tribal areas providing an income of ₹ 150.00 crores a year.

In 2007, the Mizoram State Environment and Forest Department, through the Bamboo Mahal systems, earned a revenue return of ₹ 3,634,694.00 (Anon. 2008). Within the state, bamboos are mainly utilized as raw materials for construction purposes and support beams. Bamboo houses are still prevalently used in remote areas. Jhum huts are constructed mainly by using bamboo structures. The state does not have major industry for processing and value addition of bamboo. The State has five units of Bamboo Plywood factory that produces excellent quality of long lasting plywood which are marketed in other states. There are several entrepreneurs producing bamboo charcoal and bamboo vinegar from their cottage industries. Bamboo based handicrafts occupy an important role in the Local economy.

Apart from the dietary consumptions and raw materials supply, the Socio-culture of the Mizo people is deeply influenced by bamboo. Amongst the many cultural dances, 'Cheraw' (Bamboo dance) is acknowledged by many across the world. The largest bamboo dance (Cheraw) was achieved by 10,736 dancers in Aizawl, on 12th March 2010 and was recorded in the Guinness Book of World Records (Anon. 2010b). The State Environment & Forest Department listed 59 different uses of bamboo and its products (Anon. 2010a) in which several parts of the plants are utilized.

In Mizoram, gregarious bamboo flowering was recorded during the last few years (i.e. 2006–2008) in different places. After the flowering the whole bamboo culms die and the seeds of bamboo fallen on the ground and regenerated vigorously during the rainy seasons. Bamboo seedlings exhibit fast growth and attain maturity within a short span of time. This property makes the bamboo different from the other species and has significant impact of the ecology and socio-economic properties of the region. Rapid re-growth of the bamboo after flowering has significantly affected the Carbon (C) and Nitrogen (N) cycling properties of the ecosystems.

There are few studies available on the regeneration, flowering and fruiting of bamboos (Lalnunmawia *et al.*, 2005; Lalnunmawia and Lalramnghinglova, 2010). However, studies on pools and fluxes of C and N in different bamboo growing areas in Mizoram are largely scanty. Therefore, this study was proposed to conduct the total biomass production (component wise), and the C and N dynamics in 5 major districts (covering >80% bamboo growing areas) of Mizoram. This study will have significant impact in offsetting the part of C emissions of industrialized nations by implementing emission reduction projects through forestation/reforestation programs in developing countries like India particularly in Mizoram to earn saleable certified emission reduction credits after the implementation of Kyoto Protocol (FAO, 2006).

1.2 Taxonomy and morphology of bamboo

Bamboo belongs to the sub-family Bambusoideae of the family Poaceae (earlier Gramineae). Bambusoideae is the giants of the family representing various species. Bambusoid grasses include not only the grasses whose culms are lignified but also herbaceous bamboos or bamboo allies (Anon. 2010a).Taxonomic position of Bamboo (Cronquist, 1988) is given as follows:

Class – Liliopsida; Subclass – Commelinidae; Order - Cyperales; Family – Poaceae; Subfamily – Bambusoideae.

Bamboos are the giant tree grasses showing various parts namely culms, rhizomes, nodes, branches, buds, roots. Bamboo seeds play an important role in propagation. However, some species of bamboo also propagate vegetatively.

The underground portion of the bamboo is known as the rhizome. Generally, bamboo bears two distinctly different forms of subterranean rhizomes (Liese, 2003). These two forms of rhizomes are characterized by a single stemmed "leptomorph type" which grows laterally under the soil surface extending the domain of the plant by enlarging and consolidated its area; and a densely clumped forming "pachymorph type" which grows vertically forming an interconnected rhizome systems (McClure,1961). Each individual segment of the rhizome tends to taper towards its end and forming a neck. Bamboos with single stemmed (leptomorph) are also called as monopodial bamboo (e.g. *Melocanna baccifera)* whereas, those with densely clumped (pachymorph) are also known as sympodial (e.g. *Dendrocalamus longispathus*).

Rhizome serves as storehouse of food and nutrients for the growth of bamboos which makes the bamboos different from other trees and facilitates rapid growth of bamboo species. The rhizome bears nodes and internodes which vary in length from species to species and occur between two nodes. The nodes of the bamboo rhizome produce extensive root systems through which various small lateral roots spread horizontally. Profuse root growth helps bamboo to exploit water and nutrients from larger soil volume. The cells in the internodes are arranged vertically along the culm and act as water pipes that help movement of water and nutrients. Whereas, the cell elements in the nodes are arranged horizontally, so as to enable the transverse movement of water and nutrients.

Stems of bamboo termed as "culm" are the most prominent, easily recognizable and widely used parts of bamboo developed from the rhizome. The culm of most bamboo species is a tall, woody and hollow cylinder. However, *Dendrocalamus strictus* of the drier regions generally has solid culms (Anon. 2010a). Each culm have distinct and solid nodes, which bears branch bud (pirmordium) which may later develop into branches and branchlets which bears leaves, flower, fruits and seeds. The juvenile culm or the shoots start emerging from the soil mostly at the beginning of rainy season. Shoot elongation continues both in the day and the night. The genus *Phyllostachys* in Japan grows more during the day (Ueda, 1960), whereas tropical bamboos grow more in the night (Osmaston, 1918).

Buds emerge from the alternate sides of the axes on the culm and rhizome of the bamboo. Culm buds are located marginally above the nodes and rhizome buds are seen adjacent to the nodes in the internodal portion. They are the key points from where new axes emerge. New rhizomes axes, as well as shoots that grow into culms emerge from buds on the rhizome. Culm buds occur varyingly across species.

The branches and the branchlets bear leaves. Most bamboos produce profuse leaves that fall on the ground annually, forming deep carpets of nutritious organic matter. The Culm sheaths which are attached at the nodes protect the developing bud from the axils of each culm. Culm sheaths are technically a modified leaves, having the same part as leaves, and fell off when it is old. Each species has distinctive features, and is the main key for morphological identification of bamboo.

Bamboo under good condition attains a height up to 46m (*Dendrocalamus giganteus)* in China (Guinness Book of World Records, 2006) and up to 30cm in diameter (*D. sinicus)*. However, the *Sinarundinaria densiflora* of South India is hardly a metre high and only few centimeters in diameter.

1.3 Distribution of bamboo

Bamboo occurs in different bio-climatically defined forest types ranging from tropical to sub-alpine zones. They are widely distributed all over the world except in Europe and Antartica, and 80% of the bamboo growing areas are confined to South and South-East Asia mainly in the countries like Burma, Cambodia, Ceylon, India, Indonesia, Laos, Malaya, New Guinea, Philippines, Thailand and Vietnam (Perez *et al.,* 1999; Zhengyi *et al.,* 2006; Newman *et al.,* 2007). In total, 75 genera and 1250 species of bamboos are distributed in the tropical, subtropical, mild temperate and alpine regions of the world (Sharma, 1980; Dransfield, 1992). According to Ohrnberger (1999), the subfamily Bambusoideae of the family Poaceae comprises 1575 species of woody and herbaceous bamboos. Various species of bamboos cover an area of 14 million ha worldwide (Dransfield and Widjaja, 1995).

India has the world largest bamboo reserves (Mauria and Arora, 1988), harbouring over 20 genera and 113 species (Naithani, 2008). The physical geography along with precipitation, temperature and altitudinal variation play a significant role in the diversity and richness of the forests of Indian Himalayan particularly bamboo flora of Northeastern and Eastern part of the country (Biswas, 1998). Biswas (1998) has classified the bamboo in India as per its occurrence in different bio-climatical regions of the country which are as:

(i) **Bamboos in tropical forests:**

Different bamboo species are found in moist and dry deciduous, evergreen and semi-evergreen forests and savannas which are both naturally occurring and cultivated. The main species are *Bambusa bambos, B. balcooa, B. pallida, B. tulda, B. burmanica, B. cacharensis, B. khasiana, B. longispathus, Dendrocalamus patellaris, D. sikkimensis, D. somdevai, D. strictus, Dinochloa compactiflora, Gigantochloa hasskarliana, Melocanna baccifera, Schizostachyum dullooa, S. latifolium, S. pergracile, S. polymorphum, Thamnocalamus aristatus* etc. The region experiencing shifting cultivation (jhuming) practice has promoted the regeneration of the species of bamboo like *Melocanna, Dendrocalamus hamiltonii, Schizostachyum dullooa, Bambusa khasiana* etc and forming bamboo brakes. The species of bamboo occurring on the outskirts of pine forests (*Pinus kesiya*) over Shillong Plateau are *Chimonobambusa callosa, Drepanostachyum khasianum, D. polystachyum, Racemobambos prainii, Schizostachyum polymorphum, S. dullooa, Dendrocalamus sikkimensis* etc. The sub-Himalayan and Siwalik tracts have very few bamboo taxa found as an admixture with tropical broadleaved species are *Dendrocalamus strictus* and *Bambusa bambos.*

(ii) **Bamboos in temperate forests:**

Temperate forests are composed of *Lauraceous* members, high level Oak-Hemlock, Coniferous and Birch-Rhododendron forests, are confined to elevations ranging from 1500 m to 3000 m. The main bamboo species represented by these forests are: *Chimonobambusa (Sinarundinaria) callosa, C. jaunsarensis, Drepanostachyum (Thamnocalamus) falcatum, D. hookerianum, D. intermedium, D. polystachyum, Himalayacalamus falconeri, Neomicrocalamus (Racemobambos) prainii, Arundinaria rolloana, Phyllostachys bambusoides, Semiarundinaria pantlingii, Sinobambusa elegans, Thamnocalamus aristatus* and *T. spathiflorus* etc.

(iii) **Bamboos in sub-Alpine and Alpine type of forests:**

The vegetation occurs at about 3000 m altitude and above is considered under this type. This type is represented by mainly firs (*Abies* spp.), birches (*Betula* spp.), *Rhododendron* spp., *Juniperus* spp. etc. Very few bamboo species are present in this zone and only nearer to the human settlements. Examples are *Pleioblastus simonii*, *Thamnocalamus aristatus*, *Arundinaria (Sinarundinaria) hirsuta*, *A. racemosa* etc.

1.4 Bamboo resource of India

Natural or planted bamboos are occurring in about 13% of the total forest area in India (Bahadur and Jain, 1983) and are an important source of commercial pulp and many utility products including fuel, fodder and small timber. The total growing stock of Bamboo in India is around 80.4 million tonnes from 8.96 million hectares of land (Anon 2010a). State wise growing stock and distribution of Bamboo in India is given in Table 1.1. The North East India, comprising of 8 states is the storehouse of bamboo in India; about 67% of the total growing stock of bamboo in the country is found in this region, harbouring 17 genera 87 species of bamboo (Anon 2010a).

Table 1.1: State wise number of estimated culms by Soundness in Recorded Forests Values are in millions.

State/UT	Green culms	Dry culms	Decaying culms	Total
Andhra Pradesh	837	198	63	1098
Arunachal Pradesh	2666	234	80	2980
Assam	2046	201	94	2341
Bihar	270	38	19	327
Chhattisgarh	458	123	20	601
Goa	10	4	0	14
Gujarat	114	50	7	171
Himachal Pradesh	161	103	27	291
Jharkhand	181	49	8	238
Karnataka	310	97	10	417
Kerala	115	37	5	157
Madhya Pradesh	1229	819	222	2270
Maharashtra	536	191	21	748
Manipur	2035	192	70	2297
Meghalaya	1109	104	38	1251
Mizoram	1953	185	67	2205
Nagaland	1077	102	37	1216
Orissa	720	169	54	944
Punjab	3	2	0	5
Rajasthan	500	404	122	1026
Sikkim	206	17	5	228
Tamil Nadu	367	86	33	485
Tripura	735	70	25	830
Uttar Pradesh	122	87	26	235
Uttarakhand	143	92	24	259
West Bengal	568	59	33	660
Dadra & Nagar Havelli	3	0	0	3
Total	18474	3713	1110	23297
%	**79**	**16**	**5**	**100**
Note: *Information for A&N Islands, Chandigarh, Delhi, D&D, Lakshadweep, J&K, Haryana and Puduchhery were not given due to inadequate data.*				

(SFR 2011)

1.5 Bamboo resource of Mizoram

The total bamboo cover of Mizoram is ~7,092 Km^2, which is about 33% of the total Geographical area of the state (Anon. 2010a). Bamboo is distributed thoroughly between 400m and 1520m a.m.s.l. Out of the 150 bamboo species in India, more than 58 species occur in the North-East India, of which 22 species have been recorded in Mizoram (Lalramnghinglova and Jha, 1997). Recent survey reported 35 species of bamboo in Mizoram including indigenous as well as introduced species (Anon. 2010a) which includes three newly discovered endemic species {*Bambusa mizorameana* (Naithani), *Bambusa dampaeana* (Naithani) and *Dendrocalamus manipureanus* (Naithani)} from the region. *Melocanna baccifera* is predominant and occupied about 95% of the total bamboo dominated land in the state. Other co-dominant bamboo species like *Dendrocalamus hamiltonii*, *D. longispathus* and *Bambusa tulda* are also found.

It has been reported that bamboos have resulted from jhumming system of cultivation (Deb and Dutta, 1987). The occurrence of Bamboo is rare in the Eastern region due to higher altitudes. Mostly, regeneration of bamboo in Mizoram takes place 3 to 4 years. The total number of culms for the entire state was estimated to be ~6,124millions (Anon 2010a). District wise distribution of bamboo in the state is given in Table 1.2.

As per the joint survey conducted by Mizoram Remote Sensing and Space Application Centre (MIRSAC) and the State Environment and Forest Department in 2009, a total growing stock of the State was estimated to be~24 million metric tonnes out of a total bamboo area of ~7092 Km^2 which constituted about 34% of the geographical area of the State. The average growing stock was assessed to be around 3,386 Mg Km^{-2}. The total number of culms for the entire state was estimated to be 6,124 million. In 2007, the state Environment and Forest Department, through the Bamboo 'Mahal system,' earned a revenue return of ₹ 3,634,694.00 (Anon. 2008b).

Table 1.2: District wise distribution of bamboo in Mizoram (MIRSAC 2009)

District	Area (Km^2)	Bamboo area (Km^2)	% Bamboo area to the district area	% Bamboo area to the total bamboo area of the state
Aizawl	3576.31	927.69	25.94	13.08
Champhai	3185.83	345.68	10.85	4.87
Kolasib	1382.51	661.80	47.87	9.33
Lawngtlai	2557.10	730.79	28.58	10.30
Lunglei	4538.00	1956.59	43.12	27.59
Mamit	3025.75	1598.00	52.81	22.53
Saiha	1399.90	432.04	30.86	6.09
Serchhip	1421.60	439.08	30.89	6.19
TOTAL	21087.00	7091.66	33.63	100.00

Mizoram has a mixture of 24 indigenous species and 15 introduced species of bamboo belonging to 9 genera. These species include 3 new bamboo species e.g. *Bambusa mizorameana* (Local name: Talan), *Bambusa dampaeana and Dendrocalamus manipureanus* discovered by Naithani *et al.*, (2009) whereas specimen for one pre-recorded species (*Sinarunidaria longispiculata* Chao & Renvoize) was unavailable (Anon. 2010a). Important bamboo species are *Melocanna baccifera* (Local name: Mautak), *Dendrocalamus hamiltonii* (Local name: Phulrua), *D. longispathus* (Local name: Rawnal) and *Bambusa tulda* (Local name: Rawthing); they are commonly found throughout the states, with an exception to the Eastern Districts of Mizoram. Some species like *Schizostachyum fuchsianum* (Local name: Rawngãl), *Sinarundinaria griffithiana* (Local name: Phar) and *Sinarundinaria falcata* (Local name: Lìk) are found in the high elevation areas (above 1500m a.m.s.l.) like Phawngpui (Blue Mountain), Chalfilhtlang, Sihphir Neihbawi etc.

Table 1.3: Indigenous bamboo species of Mizoram (Anon. 2010a)

Sl.No	Name of Species	Local Name
1	*Bambusa dampaeana*	Dampa Mau
2	*B. mizorameana*	Talan
3	*B. nagalandeana*	Rallengmau
4	*B. nutans*	Ankuang
5	*B. tulda*	Rawthing
6	*B. vulgaris*	Vairua
7	*Dendrocalamus hamiltonii*	Phulrua
8	*D. hookeri*	Rawpui/Rawlak
9	*D. longispathus*	Rawnal
10	*D. manipureanus*	Rawchhia/-changdam
11	*D. sikkimensis*	Rawmi
12	*D. strictus*	Tursing
13	*Melocalamus compactiflorus*	Sairil
14	*Melocanna baccifera*	Mautak
15	*Neomicrocalamus mannii*	Saiman
16	*Schizotachyum fuchsianum*	Rawngal
17	*S. mannii*	Rawte/Chalte
18	*S. munroi*	Nat
19	*S. ploymorphum*	Chal
20	*S. dulloa*	Rawthla
21	*Sinarundinaria falacata*	Lik
22	*S. griffithiana*	Phar
23	*S. longispiculata**	-
24	*Thyrsostachys oliveri*	Phungkirua

**Specimen unavailable*

At the advent of the gregarious flowering of *Melocanna baccifera* in 2004 – 2007, the State's Environment and Forest Department under the programme of the National Bamboo Mission set up several bamboo plantations, especially on degraded lands, through introducing several exotic species in addition to reclaiming the degraded bamboo forests. It seems that the search for a substitute species other than the indigenous species is a matter of interest to the authority. List of exotic species introduced in the states under authority are given in Table 1.4.

Table 1.4: Introduced Bamboo species of Mizoram (Anon. 2010a):

Sl.No	Name of Species	Local Name
1	*Bambusa balcooa*	-
2	*B. bambos*	Rawhling
3	*B. multiplex*	-
4	*B. vulgaris var. vittata*	*Vairaweng*
5	*B. vulgaris var. wamin*	*Vairua (chang zing)*
6	*Dendrocalamus asper*	-
7	*D. giganteus*	Vairaw-pui
8	*D. latiflorus*	-
9	*Phyllostachys edulis*	Moso (China mau)
10	*P. mannii*	-
11	*Schizostachyum pergacile*	Maudang

1.6 Global terrestrial carbon cycle and the forest

Net ecosystem production is the residual of two large fluxes that is the photosynthesis and the respiration. Carbon enters terrestrial ecosystem through a single process of photosynthesis, and is return back to the atmosphere through a variety of processes referred to as respiration. Globally, terrestrial photosynthesis and respiration (plus fire) represent enormous C fluxes that were approximately balance (Schimel, 1995). As per the reports, about 1/6th of atmospheric CO_2 (~115 Gt of C; Prentice *et al.,* 2001) passes through ecosystems every year. Because ecosystem respiration is one of the largest gross fluxes in the annual global C budget, ~18 times the rate of fossil fuel release in the 1990s (Prentice *et al.,* 2001), small imbalances in photosynthesis and respiration can lead to significant inter-annual variation in atmospheric CO_2.

Atmospheric CO_2 concentration has increased from ~ 280 ppm in pre-industrial era to ~ 385 ppm in 2008 and is increasing at the rate of ~ 2 ppm year^{-1} which is equivalent to 3.5 Gt yr^{-1}. This increase in atmospheric CO_2 concentration is the result of fossil fuel combustion, deforestation and biomass burning and soil cultivation, and all these factors are related to growing world population (i.e. ~7 billion in 2011 is increasing at 1.3% yr^{-1}, and is projected to be 9.5 billion by 2050). Fossil fuel combustion is increasing at the rate of ~ 2.5% yr^{-1}, particularly in upcoming economies like China, India and Brazil etc, because of increasing global energy demand to satisfy human need. Anthropogenic perturbation of the global C cycle has let two serious concerns about the risks of global warming and possible sea level rise. To overcome with the problem, there is an urgent to identify viable sinks for atmospheric CO_2 and sequester it into other C pools with long residence time such as geologic, oceanic, chemical transformations and terrestrial. In contrast to engineering technologies (like geologic), C sequestration in terrestrial ecosystems (mainly in above- and below-ground biomass and soil) is a natural process and cost-effective with many additional benefits (Lal, 2008). The bamboo with its high capacity to produce huge biomass in a short time which is widely occurring in India particularly northeaster part has high potential to sequester large amount of atmospheric C each year if quantified and managed efficiently.

World forests cover ~ 4 billion ha or 30% of the Earth's surface. The total amount of C stored in these forests is 750 Gt, of which 230 Gt C stored in the aboveground biomass, 60 Gt C in the belowground biomass (excluding fine root <2 mm diameter), 60 Gt C in litter including dead wood, and 400 Gt C in forest soils (Kindermann *et al.*, 2008; FAO, 2005). The amount of C incorporated in the tree roots, accounts between 14 and 27 Mg C ha^{-1} (Brunner and Godbold, 2007). This amount is small compared to the amount of C which is included in the forest soil as soil organic matter but because bulk amount of roots in the forest are belonging to fine roots having short life span (turnover time<1year), which return significant amount of C $year^{-1}$ to forest soil (Jackson *et al.*, 1997; Tripathi and Singh, 1996, 2008; Singh and Singh 1981).

Soils contain about 70% of terrestrial organic C, and belowground processes regulate fluxes to the atmosphere that are approximately 10 times the current anthropogenic CO_2 loading rate (Chapin *et al.*, 2002). Soil organic matter is a complex of large and amorphous organic molecules and particles derived from the humification of aboveground and belowground litter, and incorporated into the soil, either as free particles or bound to mineral soil particles, which includes organic acids, dead and living microorganisms, and the substances synthesized from their breakdown products (IPCC, 2003). It represents the largest terrestrial C pool, being almost 3 times as large as that of the plant biomass.

Tropical forest constitute about half of the World's forest area and plays an important role in the global cycles of carbon (C) by storing significant fractions in the world's vegetation and soil pools (Brown and Lugo, 1982; Brown *et al.,* 1993). Among terrestrial ecosystems, forests are playing significant role in the global carbon (C) cycling by sequestering ~ 60 - 80% of the global terrestrial C pool, of which bulk (~70%) of C is stored in the soil (Dixon *et al.*, 1994; Schimel, 1995) and remaining in vegetation. Forest soils have been reported to accumulate considerably higher C than other land uses such as savannas and agro-ecosystems and thus a small alteration in soil may lead to a considerable change in atmospheric CO_2 concentration (Bouwmann and Germon, 1998; Hagedorn *et al.*, 2001). Geographically, tropical forests are among the dominant forest ecosystems constituting about half of the world's forest area and storing 46% of the world's living terrestrial C pool and 11% of the world's soil C pool (Brown and Lugo, 1982). Because of huge potential to sequester and store large quantities of C, these forests are considered as the major resource for climate change mitigation (Canadell and Raupach, 2008)

In Indian tropical regions, the occurrence of extensive landscape transformations from natural forests to degraded landforms is accompanied by changes in soil structure and quality (Tripathi *et al.*, 2008) due to opening up of crown cover, decreased soil organic matter content and reduced efficiency of nutrient cycling (Singh, 1989; Tripathi and Singh, 1994, 1996). The plantations of bamboo followed by its periodical harvest makes the bamboo ecosystem highly dynamic from the point of view of its structure and functioning (Tripathi and Singh, 1996). Because of very rapid growth, this species has immense capacity to sequester C from the atmosphere and effectively recycle C within the system.

Northeastern part of India is characterized by shifting cultivation practice where the piece of forest land is slashed and burned after drying and cultivated for various crops for 1 – 2years followed by a fallow period. Earlier fallow period was sufficiently prolonged (20 – 30 years) to sequester huge C in the system, however, as a result of increasing population fallow period has been considerably decreased (<5 years) and thus leading fragile ecosystem characterized by less C stock in the vegetation and soil. Various species of bamboos are widely distributed in northeastern part of the country. Bamboos are occurring in pure patches and mixed with natural forests. The species of bamboo also grows well on degraded lands or fallow lands.

Due to high growth rate the species has considerable ability to sequester C in soil and vegetation. Different forest management systems and activities such as crop rotation, harvesting practices, site preparation, fertilization etc interfere more or less strongly with soil organic carbon (Liski *et al.,* 2001; Johnson and Curtis, 2001).Thus, bamboos in this region could be a great resource to manage efficiently to sequester significant amount of C in soil and vegetation pool that may be beneficial for offsetting the C emissions of the developed countries through aforestation program in developing countries defined in Article 12 of the Kyoto Protocol.

1.7 Global terrestrial nitrogen cycle

The nitrogen cycle represents one of the most important nutrient cycles found in terrestrial ecosystems and is used by living organisms to produce a number of complex organic molecules like amino acids, proteins and nucleic acids (Pidwirny, 2006).The largest pool of N is present in the Earth's atmosphere, contributing up to 78%.The atmospheric N, however, can't be used in biological process unless it is converted into reactive form. N cycles through air, water and soil and plays a significant role in the synthesis of complex N compounds in all forms of life on the earth by combining with carbon, hydrogen and oxygen. Besides, natural fixation of N by microorganisms, advertent and inadvertent fixation of N by human activities (e.g. landscape transformations, fossil fuel burning and production of N through Haber-Bosch process and its use in agriculture) are altering the global cycle of N (Tripathi, 2009).

Global annual conversion rate of un-reactive N to its reactive forms is about 145 Tg, of which 55% is associated with fertilizer production, 31% is derived from legume and rice cultivation, and the remaining14% from fossil fuel combustion (Mellilo, 1996). It is estimated that these practices are now releasing more combined N into the terrestrial environment than the N-fixation by micro-organisms in natural and semi-natural ecosystems (Galloway *et al.,* 1995). It is estimated that a doubling of the natural rate of N-fixation and an increase of atmospheric N-deposition rates by > 10 fold over the last 40 years to the current values of 5–25 kg N ha^{-1} yr^{-1}in eastern USA and 5–60 kg N ha^{-1} yr^{-1} in Northern Europe (Wedin and Tilman, 1996).

Further increase in fossil fuel burning and fertilizer use is projected to lead to a 60% increase in combined annual N-release by the year 2020. About two-thirds of the increase will occur in Asia which will account for more than half of the global anthropogenic nitrogen fixation by 2020 (Singh and Tripathi 2000).

During mineralization of N, organic N contained in decaying plants and animals (proteins, nucleic acids etc) is converted to various forms of N like ammonia (NH_3), ammonium (NH_4^+), NO_2 and NO_3 through the process of ammonification and nitrification. The resultant NO_3 and partly ammonia can be taken up by microbes and plants for their metabolism. After the death of plants and microbial exudation the N is converted to organic N (Corbin, 1998). During the process of denitrification N goes back to the environment.

Nitrate is a highly water soluble anion which is repelled by most soils and therefore very mobile (Martin *et al.,* 1999). Since denitrification takes place during anaerobic conditions and therefore under low oxygen tension, NO_3^- is used by denitrifying bacteria in place of O_2as terminal electron acceptor for energy production (Watts and Seitzinger, 2000). As a result of bacterial metabolic reduction, NO_3^-gets converted into di-nitrogen (N_2) or nitrous oxide gas (N_2O). Both of these gases then diffuse in the atmosphere and the N concentration in the soil is constantly reduced. Plants consume N in the form of NO_3. The major source of N in the soil is through rice-legume cultivation and anthropogenic conversion of N through Haber-Bosch process. The NO_3 used by the plant is brought back to the soil after the plant death. Denitrification and nitrification are the main sources of NO_3gas; however, it is also produced during numerous N transformations in soils. In a study conducted by Simek *et al.* (2003) denitrification rate was found to be significantly related to N_2O.

Nitrogen is essential for many processes and is crucial for any life on Earth. It is a component in all amino acids. In plants, much of the Nis used in chlorophyll molecules, which are essential for photosynthesis and further growth. The abundance or shortage of fixed form of N determines the productivity of a piece of land. Development of a sufficient organic matter pool to serve as an N source and sufficient N-mineralization potential resulting into nutrient release rates that are adequate for plant growth are essential for sustaining vegetation at an acceptable level of production (Bradshaw *et al.*, 1986).

Vegetation contributes to the accumulation of soil organic matter and plant nutrients. Development of a sufficient organic matter pool serve as N source through the process of N-mineralization that sustain plant growth at an acceptable level of production (Bradshaw *et al.*, 1986).

1.8 Role of bamboo in climate change mitigation

Climate change is considered to be one of the greatest threats facing humanity. According to the IPCC, global warming is unequivocal, with evidence from increases in average air and ocean temperatures, melting of snow and ice and sea level rise (IPCC, 2007). If global emissions continue down the Business as

Usual (BAU) trajectory, the scientific evidence points to increasing risks of serious, irreversible impacts (Stern, 2006). In order to avoid the most damaging effects of climate change, it is estimated that global levels of atmospheric greenhouse gases (GHGs) need to be stabilized at approximately 445-490 parts per millionCO_2e (CO_2 equivalent) or less. To achieve this target, it is essential that urgent international action is taken. Forests will have a central role in meeting this target (Eliasch, 2008).

The effects of climate change and climate variability on forest ecosystems are evident around the world and further impacts are unavoidable, at least in the short to medium term. Addressing the challenges posed by climate change will require adjustments to forest policies and changes to forest management plans and practices (FAO, 2013). Since the late 1980s, much of the interest in C sequestration has been prompted by suggestions that sufficient lands are available to use sequestration for mitigating significant shares of annual CO_2 emissions (Marland, 1988; Lashof and Tirpak, 1989) and related claims that this approach provides a relatively inexpensive means of addressing climate change (Sedjo and Solomon, 1989; Dudek and LeBlanc, 1990).

The global environment debate, which has intensified considerably 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, has seen international action being taken through the Framework Convention on Climate Change to reduce carbon dioxide in the ambient temperature of the earth A focus of this climate change debate has been centered around the role of the forests, especially tropical forests (primary, logging and regenerating, secondary, or plantation forests) in sequestering atmospheric CO_2. In terrestrial ecosystem, forest is the largest C inventory and it deposits 1146 × 1015 g C which occupies 56 % of the C inventory of the total terrestrial ecosystem. Bamboo forest ecosystem is an important part of forest ecosystem and an important source and sink of C on the earth (Li *et al.*, 2003).Tropical forests have the largest potential to mitigate climate change amongst the world's forests through conservation of existing C pools (e.g. reduced impact logging), expansion of C sinks (e.g. reforestation, agroforestry), and substitution of wood products for fossil fuels (Brown *et al.*, 2000).

In 1997, during the Third Conference of Parties (COP-3) of the UNFCCC, the Kyoto Protocol was drafted which is the first international agreement that places legally binding limits on GHG emissions from developed countries (UNFCCC, 1997). The Kyoto Protocol proposed that C reduction could take place by decreasing fossil fuel emissions, or by accumulating C in vegetation and in the soil of terrestrial ecosystems. The Kyoto Protocol was, in fact, the first legal binding agreement to reduce GHG emissions, which aimed to curb GHGs by 5% of 1990 levels (Boyd, 2009).

Adaptation and mitigation are the two main issues related to climate change addressing the causes of climate change and adaptation of its impacts. In the forest sector, adaptation encompasses changes in management practices designed to decrease the vulnerability of forests to climate change and interventions intended to reduce the vulnerability of people to climate change. Mitigation strategies in the forest sector can be grouped into four main categories: reducing emissions from deforestation; reducing emissions from forest degradation; enhancing forest C sinks; and product substitution (FAO, 2013).

The Kyoto Protocol has incorporated the Agroforestry system as an environmental service for C sequestrating and trading. Agroforestry is one means by which farmers could benefit from C investment projects (Sampson and Scholes, 2000; Smith and Scherr, 2002). Reliable estimates of C inputs in temperate and tropical agroforestry systems are essential for national C inventories used in the Conferences of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) (Watson *et al.,* 2000). Bamboos occur extensively in the managed ecosystems of India—both as plantations (Chandrashekara, 1996) and in agroforestry (Kumar, 1997; Divakara *et al.*, 2001).

Human beings are fundamentally dependent upon the ecosystem services (MEA, 2005). Enhanced protection and management of natural ecosystems and more sustainable management of natural resources and agricultural crops can play a critical role in climate change adaptation strategies (World Bank, 2010; TEEB, 2009). Bamboo's ability to provide global environmental services through C sequestration is now receiving high levels of interest, and is the subject of research by INBAR and partners. Due to its fast growth rate, bamboo has long been supposed to be a plant with a high sequestration capability, and the research to date indeed confirms that bamboo outperforms fast growing trees in its rate of C accumulation (Yiping *et al.*, 2010).

Sustainable management and appropriate utilization of bamboo resources can increase the amount of C sequestered, through management changes which increase storage capacity within the ecosystem in the short-term, and through transformation of C into durable products in the long-term (Yiping *et al.*, 2010). The total C stock in bamboo forests is obviously affected by climatic factors. The C stock of bamboo in Fujian province, China (Qi, 2009), where the climate is more suitable for bamboo growth than in Zhejiang province (Zhou *et al.*, 2004), surpassed *Pinus elliottii* in its 19th year, Chinese Fir in its 15^{th} year, and showed comparable C stock to broad-leaved forest (262.5 Mg ha^{-1}) and tropical forest (230.4 Mg ha^{-1}).

After studying the effects of management regimes on C storage, Yiping *et al.* (2010) suggested that, intensive management of *Moso* bamboo seems to be able to increase the C storage capacity in above ground biomass; the role of management practices on C sequestration by bamboos needs further study. Magel *et al.* (2005) argue that growth of the new shoots in a bamboo forest occurs as a result of transfer of the energy accumulated in culms through photosynthesis in the previous year; as such, the growth of a bamboo culm is not driven by its own C sequestration, but by sequestration in previous seasons in other parts of the bamboo system, and as such growth of new shoots is not an indicator of sequestration rate.

On the other hand, Zhou *et al.* (2009) argues that as the bamboo system requires more inputs in the shooting season of young culms (when new shoots grow), high growth in bamboo shoots can be equated with a high rate of C sequestration. It can be argued of course that as long as C sequestration is determined by measuring the difference in standing C between Year (t+1) and Year (t) (a stock exchange approach), it doesn't matter whether and how the relocation of C between old and new culms occurs (Yiping *et al.*, 2010).

Bamboo culms of most species attain maturity after approximately 7 – 10 years, after which they deteriorate rapidly, releasing C from the above-ground biomass back into the atmosphere (Liese, 2009). Therefore in a natural state, bamboo reaches a stable level of above ground C relatively quickly, where C accumulation through sequestration is offset by C release through deterioration of old culms. In order for the bamboo system to continue to be a net sink, C has to be stored in other forms, so that the total accumulation of C in a solid state exceeds the C released to the atmosphere.

Scientists have raised the issue of C sinks' permanence within the terrestrial biosphere (Schlamadinger and Marland, 2000), since C storage in forests is finite and therefore not permanent, whereby after a period of time, C locked in vegetation and soil is released into the atmosphere through respiration, decomposition, digestion, or fire (Locatelli and Pedroni, 2004). Nevertheless, C sequestration through forestry is commonly considered to contribute to mitigating climate change. Apart from the C sequestration obtained through ecosystem services, value added bamboo products prolonged the duration of C being sequestered.

1.9 Scope of the study

According Mizoram Remote Sensing and Space Application Centre (MIRSAC) and the State Environment and Forest Department, in 2008, a total growing stock of bamboo in the State was estimated to be 24.0 million metric tonnes. The average growing stock was assessed to be around 3,386 metric tonnes Km^{-2}. According to the Forest Survey of India inventory carried out in 1988 – 89, bamboo stock of Mizoram was 12,950 metric tonnes with annual yield of 3237 metric tonnes. The annual consumption of bamboo for domestic purpose was around 28 metric tonnes, leaving an annual surplus of 3209 metric tonnes for Industry. In this way Mizoram alone contributes significantly to the country's growing stock of bamboo (Bamboo Policy of Mizoram 2002).

In recent years (2006 – 2007), due to gregarious flowering of bamboo (*M. baccifera)* all culms including rhizomes die and produce huge amount of seeds that grow profusely and attain maturity within short span of time due to high growth rates. Such changes make the bamboo community dominated by this species a highly dynamic ecosystem in its structural and functional changes. These changes are also affected from one area to the other because of changing biotic variables. There are few studies available on regeneration, flowering and fruiting of bamboos in different locations. However, our knowledge on the comparative study of C and N cycling of bamboo ecosystems in Mizoram is extremely limited. Considering the bamboo wealth of Mizoram, it is presumed that bamboo would be playing a considerable role in the C and N sequestration and recycling within the system would be tremendous.

Therefore, this study was carried out to fulfill the gap of knowledge on the C and N sequestration potential of different bamboo forest of Mizoram by quantifying the pools and fluxes of C and N in different components of bamboo and soil, and to find out the major variables affecting the C and N cycling properties in bamboo forests. Further, this study will have significant impact in offsetting the part of C emissions of industrialized nations by implementing emission reduction projects through forestation/reforestation programs of bamboos in Mizoram, through which the state could earn saleable certified emission reduction credits after the implementation of Kyoto Protocol (FAO 2006). In return, the different stakeholders of the region will get monetary benefits for their sustenance.

1.10 Objectives

The present study aims to understand the comparative analysis of the C and N dynamics of bamboo forests of Mizoram. This investigation aims to achieve the following major objectives:

(1) To estimate standing crop biomass (above and below-ground) and net primary production in major bamboo forests.

(2) To measure the magnitude of recycling and sequestration of C and N in Soil-Vegetation compartment of major bamboo forests.

(3) To understand the role of fine roots in uptake, recycling and transfer of C and N in different bamboo forests of Mizoram.

Chapter - II

REVIEW OF LITERATURE

2.1 Pools and fluxes of carbon and nitrogen in forest ecosystems

2.1.1 Carbon cycling in forest ecosystem

Forests play a major role in the natural global C cycle by capturing C from the atmosphere through photosynthesis, converting it to forest biomass, and releasing it into the atmosphere through plant respiration and decomposition (Shah *et al.,* 2009). Activities that increase the biomass accumulation in a forest or in forest products increase carbon sequestration (Obersteiner *et al.,* 2005). As increase in greenhouse gasses in the atmosphere contributes to concerns over climate change and thus, interest in the role of forests in the global C cycle is growing as a public policy issue. In various parts of the world, changes in climate (temperature and precipitation) and non-climatic factors such as increasing atmospheric CO_2, forest age effects (Schimel *et al.,* 2000; Karnosky 2003; Churkina *et al.,* 2007), increased nitrogen deposition reduced acid deposition and ozone concentration have been reported as driving productivity changes (de Vries *et al.,* 2008, 2009). CO_2 concentration has continuously increased globally (Keeling *et al.,* 1995) and increasing nitrogen deposition rates in Europe have been evident since the early 1960s (Katzensteiner and Glatzel, 1997; de Vries *et al.,* 2009).

The role of forests in temporal C dynamics is characterized by long periods of gradual build-up of biomass (a sink) alternating with short periods of massive biomass loss (Grace *et al.,* 1995 and Sedjo *et al.,* 2001). Deforestation transfers C directly to the atmosphere and badly affects the mechanism to hold C in soil (Chambers *et al.,* 2001). Widespread deforestation for fuelwood, timber and forage is an on-going process in the south-east Asian countries (Islam, 1997), which is of great concern and needs reforestation of degraded lands for reversing the process of C sequestration (Wallace, 1994; Islam, 1997).

Soil plays an important role in the global C cycle. Scholars like Eswaran *et al.* (1993), Jobbágy and Jackson (2000) etc reported that the C stock of soil equals some 1,500 Pg in the topmost 1m soil layer, and approximately 506 Pg (32 percent) of this is in the tropics (Eswaran *et al.,* 1993) and 160 Pg in Africa (Henry *et al.,* 2009). The global C stock in the soil is nearly three times the amount in the above-ground biomass and about twice as large as the C stock of the atmosphere (e.g. Eswaran *et al.,* 1993). In Africa, the soil organic C stock corresponds to 68 percent of the terrestrial C stock (Henry *et al.,* 2009).

C dioxide emissions resulting from the decomposition of organic C compounds in soil amount to 60–80 Pg C per year (Thum *et al.,* 2011). A somewhat similar amount of C is brought annually to soil in the form of plant residues. These C fluxes from and to the soil are seven to nine times as large as the current anthropogenic fossil C dioxide emissions to the atmosphere, equal to 9.1 Pg in 2010 (Peters *et al.*, 2012).

Changes in soil C result from an imbalance between the C fluxes into and out of the soil. When C brought to the soil is more than that is released, C accumulates in the soil, and vice versa. Increments in plant productivity and input of plant residues to soil thus have an increasing effect on soil C stock, whereas more favourable conditions for decomposition have a decreasing effect. Land-use change may induce quite rapid changes in soil C as a result of altered C input to the soil or decomposition conditions or both (Post and Kwon, 2000; Vågen, Lal and Singh, 2005; Zingore *et al.*, 2005).

Studies on C sequestration have been carried out in different ecosystems. Bijayaand Bhandari (2010) estimated the above- and below-ground net C sequestration potential of *Dendrocalamus strictus* forest of Sigana VD in Nepal. Yang *et al.* (2008) and Zhou *et al.* (2000) carried out C estimation of the forests of China. Xiangang *et al.* (2009) estimated the C stocks of bamboo stands in China, during the last 100years, and reported that the C stock in another 50 years i.e., 2050 would be 1017.64 Tg.

Studies are available for various species of bamboos like *Arundinaria, Bambusa, Thryostachys, Gigantochola, Oxytenanthera, Dendrocalamus* and *Meloccana* in different countries with respect to flowering and few studies on regeneration status (Janzen, 1976; Kao and Wang 1988; Loh *et al.*, 2000). Some studies were conducted on the biomass and productivity of bamboo from China, India and South Central Chile (Veblen *et al.*, 1980; Taylor and Zhiseng 1987; Rao and Ramakhrishnan, 1989).

In bamboo forest ecosystem, through the mechanism of photosynthesis, bamboo turn C dioxide into organic C and store it as their structure, part of which will store in the litters or in forest soil (Zhou Ben-Zhi *et al.*, 2005). According to an estimate, one quarter of the biomass in tropical regions and one-fifth in subtropical regions comes from bamboo (Anon. 1997).

In India, C sequestration potential assessment of different ecosystem is on the way. Chavan and Rasal (2012) reported that *Annona reticulate* and *A. squamosa* can sequester 83.1 kg ha^{-1} and 73.5 kg ha^{-1} in the University campus of Aurangabad, India. Dey (2005) estimated the C sequestration potential of rubber plantations of North-East India. The C sequestration potential of medicinally important tree plantation in Haryana ranged from 3.1 – 11.0 Mg ha^{-1} yr^{-1} (Gera and Chauhan, 2010). Nath and Das (2012) reported that the rate of above ground C sequestration by bamboos in the land managed by farmers in Cachar district, Assam, Northeast India was 18.93 – 23.55 Mg ha^{-1} yr^{-1} with a mean sequestration potential of 21.36 Mg ha^{-1} yr^{-1}.

2.1.2 Pools and fluxes of N in forest ecosystems

N being an essential nutrient for the vegetation plays an important role in the ecosystem. Soil C and N contents play a crucial role in sustaining soil quality and environmental quality. The conversion of annually cultivated land to forage grasses has potential to increase C and N sequestration (Yong, 2007). Nutrient concentration in various tree components varies in accordance to their utilization for regulating different physiological processes. These nutrients are also translocated to various components as and when required. Most of the macronutrients (N, P, K, Mg, S and Na) are highly mobile and leachable except for Ca. Ca being an immobile element can be used as indicator of C content in different tree components (Negi *et al.,* 2003). Increase in litterfall resulted in the increment of N (Zhou Ben-zhi *et al.,* 2005).

Humans have altered global N cycling such that more atmospheric N_2 is being converted (fixed) into biologically reactive forms by anthropogenic activities than by all natural processes combined (Vitousek *et al.,* 1997). In particular, N oxides emitted during fuel combustion and ammonia volatilized as a result of intensive agriculture has increased atmospheric N inputs (mostly NO_3 and NH_4) to temperate forests in the Northern Hemisphere (Galloway *et al.,* 1995; Townsend *et al.*, 1996; Holland, 1997).

The tree growth in northern temperate regions of Europe is typically N-limited (Vitousek and Howarth, 1991), increased N deposition could have the effect of attenuating rising atmospheric CO_2 by stimulating the accumulation of forest biomass. Apps and Kurz (1994) reported that the C contents of northern forests have increased concurrently with N deposition since the 1950s. In addition, variations in atmospheric CO_2 indicate a globally significant C sink in northern mid-latitude forest regions (Tans *et al.,* 1994; Ciais *et al.*, 1995; Schimel 1995; Houghton *et al.,* 1998).

It is however unclear whether elevated N deposition or other factors are the primary cause of C sequestration in northern forests (Nadelhoffer, 1999).Although northern temperate forests might now function as significant CO_2 sinks, estimates of the effects of N deposition on forest C sequestration (Peterson and Melillo, 1985; Schindler and Bayley, 1993) vary from 0.1 to 2.3 Pg yr^{-1}.

Nutrient status of some Himalayan and other forests have been estimated by Duvigneaud and Denaeyer De-Smet (1970), Johnson and Risser (1974), Pandey and Singh (1981a, b), Toky and Ramakrishnan (1982, 1983), Negi *et al.* (1983), Chaturvedi and Singh (1987), and Rawat and Singh (1988). However, there is little knowledge on the functional role of bamboo species in tropical humid forests (Numata, 1965, 1970; Janzen, 1976; Rao and Ramakrishnan 1989). Estimation of the nutrient dynamics of a lower Siwalik bamboo forest in the Garhwal Himalaya, India reported that about 63 k*g* ha^{-1} of N was recorded in the standing biomass, out of which 5 kg ha^{-1} was returned to the soil (Joshi *et al.,* 1991).

Tripathi and Singh (1995) recorded an annual nutrient return through litterfall amounting to 28 – 49 kg N ha^{-1} from recently harvested and mature bamboo savannas in a dry tropical region in India, whereas the mean annual content of N by the forest floor was 29 – 40 kg ha^{-1}. Singh and Singh (1998) reported that the nutrient deposition through leaf litter, in the bamboo plantations of the dry tropical region in India, was 45 – 79 kg N. The proportion of mineralized-N converted into nitrate decreased with age. Soil microbial C increased from 127 – 319 µg g^{-1}, microbial-N from 19–38 µg g^{-1} soil between 3 to 5 years. With increasing age of plantation, a greater proportion of soil C, N and P tended to be immobilized in soil microbial biomass. Net primary production and the soil redevelopment process exhibited a positive feed-back relationship.

Further, a studies on the role of active components (viz., leaves, fine roots and herbs) of the bamboo ecosystems reflected that in the nutrient limited bamboo ecosystem, the active components play a significant role in maintaining a fairly high net production within a short span of time, despite substantial periodical (5 – 7yrs) export of nutrients, through harvesting, from the ecosystem (Tripathi and Singh, 2008).

2.1.3 C and N cycling in forest litters

Litter accumulation during succession has been traditionally considered an ecosystem process with significant impact on C (Odum, 1960; Golley, 1965; Mellinger and McNaughton, 1975) and nutrient cycles

(Stinner *et al*., 1984; Holland and Coleman, 1987). The amount and seasonal pattern of litterfall are important determinants of overall recycling of nutrients and maintenance of soil fertility in different ecosystems (Tripathi and Singh, 1995).

Vegetation contributes to the accumulation of soil organic matter and plant nutrients. Development of a sufficient organic matter pool to serve as an N source and sufficient N-mineralization potential resulting into nutrient release rates that are adequate for plant growth are essential for sustaining vegetation at an acceptable level of production (Bradshaw *et al.,* 1986). Microorganisms contribute to the re-establishment of biogeochemical processes, and play an important role in soil re-development and in the maintenance of soil fertility.

The amount and seasonal patterns of litterfall and decomposition are important determinants of overall recycling of nutrients and maintenance of soil fertility in terrestrial ecosystems (Upadhyay and Singh 1989; Tripathi and Singh 1992a, b; Tripathi and Singh 1995; Singh *et al.,* 1999; Fioretto *et al.,* 2003). Moreover, the impact of tree species on soil fertility depends on their litter chemical quality and decomposition rate. The decomposition of litter is primarily influenced by the physical environment in which decay takes place, the nature and abundance of decomposing organisms and the chemical quality of litter (Facelli and Pickett 1991; Heal *et al.,* 1997; Sariyildiz *et al.,* 2005). Plant litter of varying substrate quality has been found to exhibit different mineralization potential and decomposition behavior (Mtambanengwe and Kirchman, 1995). Litter decomposition is mainly governed by two factors, i.e., the climate and the initial substrate quality of the litter (Swift *et al.,* 1979).

Among the climatic variables, actual evapo-transpiration (AET) is reportedly the major determinant of decomposition in a range of climatic conditions (Berg *et al.* 1993). However, in Indian dry tropical regions, precipitation and associated variables such as soil and litter moisture have also been found to be major factors influencing the rate of litter decomposition (Tripathi and Singh 1992a). Among the initial litter substrate quality variables, water or ethanol soluble substances, cellulose, lignin and N content, and ratios of C/N and lignin/N have been shown to play a crucial role at different stages of litter decomposition (Taylor *et al.*, 1989; Tripathi and Singh 1992a). Generally, the labile fraction of litter, which includes water soluble substances and free unshielded cellulose, decomposes rapidly within a few months (Berg *et al.*, 1997), and as a result, the concentrations of lignin and nutrients like N increase in later stages (Berg and Staaf, 1980; Berg, 2000).

2.2 C and N cycling in bamboo ecosystems

Information on C and nutrient relations of bamboo is scarcer and if available mostly limited to aboveground parts (Rao and Ramakrishnan, 1989). Tripathi and Singh (1994) could not locate any significant information on the belowground production and nutrient relations of bamboos. With respect to fine-root production and nutrient dynamics, the bamboo savanna ecosystem is still unexplored. Tripathi *et al.* (1999) have reported the effects of harvesting of bamboo culms on the production, mortality and the seasonal changes in nutrient concentrations of fine roots which are poorly known.

With a series of papers Tripathi and Singh (1992 a, b; 1994, 1995, 1996) conducted intensive research on the ecological aspects of the *Dendrocalamus strictus* of the bamboo savanna of the Dry Tropical India, prior to which, no information on the primary productivity and nutrient cycling on *D. strictus* was available in neither India nor elsewhere (Tripathi and Singh, 1994). Authors have reported considerably higher root/shoot production ratio in bamboo (*Dendrocalmus strictus*) compared with the ratio reported in the natural (*Shorea robusta*) dry tropical forest (0.4 - 1.0) in India (Sharma *et al.,* 1990). Typical fenced grass dominated savanna also showed lower root/shoot ratio of 0.6 – 1.0; however, grazing increased the ratio significantly to 2 – 3 (Pandey and Singh, 1981).

Bamboo savanna growing under low availability of N and P (Singh *et al.,* 1990) and reflects lower levels of nutrient storage compared to the dry deciduous forests (Tripathi and Singh, 1994). Nevertheless, the bamboo savanna supports fairly high net production inspite of relatively oligotrophic soil nutrient conditions (Tripathi and Singh, 1994) thereby attracting more attention to the significant role of fine roots. Large organic matter and nutrient export occurs during periodical (5 – 7 yrs cycle) harvesting of Bamboo. Bamboo attains maturity within a short interval of 5 – 7 yrs after each harvest.

Bamboo produces large biomass annually through litter fall that varied from 3-10 Mg ha^{-1} in different ecosystems of the world. This figure can be roughly converted to 1.5-5 Mg C ha^{-1}. Ueda (1960) pointed out that bamboo leaves usually fall when they are between 12 and 18 months old, and they are quickly replaced with new leaves. The total aboveground litterfall (litter, sheath, and branches) was estimated to be 4.7 Mg ha^{-1} at 72 months. Fu *et al.* (1989) observed the seasonal dynamic of litterfall of *Phyllostachys pubescens*. They suggested that *Phyllostachys pubescens* produces the most litterfall during two periods, i.e. during April to May and November, although the litterfall occurs around the year.

Rozanov and Rozanov (1964) reported the values for total aboveground litterfall for bamboo plantation of 6.6 Mg ha^{-1} yr^{-1} for bamboo forest under thinned tropical forest, and of 10.6 Mg ha^{-1} yr^{-1} for bamboo forest under thinned monsoonal forest. For the mature bamboo savannas in the Indian Dry tropics, Tripathi and Singh (1994) reported that the aboveground litter values ranging from 4.1 to 7.2 Mg ha^{-1} yr^{-1}. Seth *et al.* (1963) reported the aboveground leaf litter production of 3.2 Mg ha^{-1} in a bamboo plantation in India. A 4-year-old *Bambusa longispiculata* forest can accumulate to 2−10 cm mulch in Puerto Rico (White and Childers 1945). Wu *et al.* (1992) suggested that the litterfall amount varies with the composition of the mixed forest, the stand density and human activity. The pure *Phyllostachys pubescens* forest accumulated litterfall of 5.8 Mg ha^{-1} yr^{-1}, while the bamboo forest mixed with broadleaf and with *Cunninghamia lanceolata* produced litterfall of 7.2 Mg ha^{-1} and 9.4 Mg ha^{-1} yr^{-1} respectively. The annual litterfall of *Dendrocalamus latiflorus* forest, with a density of 825 culms ha^{-1} is measured to 3.6–3.9 Mg ha^{-1} (Xie, 1999).

A significant portion of the net production in forests is allocated for the formation of fine roots which are large and dynamic components of these ecosystems (Harris *et al.,* 1997; Santantonio *et al.,* 1977; Vogt *et al.,* 1986). Fineroots mortality transfers considerable amounts of organic matter and nutrients into the forest soil (Shugart *et al.,* 1977; Srivastava *et al.,* 1986). Yet of all components of a forested ecosystem, roots have received the least attention so far (Powell and Day, 1991). Although a significant role of fine roots in the functioning of dry tropical forest ecosystems has been recognized (Singh and Singh 1981; Srivastava *et al.,* 1986), information on fine roots in these ecosystems is highly limited due to methodological and logistic problems associated with their study (Singh *et al.*, 1984).

In North-east India, bamboos constitute the major vegetation after slash and burn agriculture (Ramakrishnan *et al.*, 1981; Toky and Ramakrishnan, 1983). Due to their adaptability (Rao and Ramakrishnan, 1987; 1988a, b) and nutrient conservational role (Toky and Ramakrishnan, 1982; Rao and Ramakrishnan, 1989), they play a special role in succession. Bamboos are one community that colonizes disturbed lands in the tropics (Drew, 1974; Soderstrom and Vidal, 1975). Troup

(1921) and Haig *et al.* (1958) also stated that as a result of shifting agriculture, huge expanses of grass and bamboo forests have been established in Asia.

Bamboo growing in Indian dry tropical forests was reported as a productive compared to adjoining forest with lower accumulation of C and N stocks. The reasons cited for this high production was the efficient utilization of meager soil resources by bamboo through strong nutrient retranslocation, immobilization and transfers considerable amount of organic matter and nutrients into soils and through rapid turnover rate that regenerate available soil nutrient to support plant growth in this ecosystem (Tripathi and Singh, 1994).

The plant litter production and decomposition are the two important processes which provide the main input of organic matter in soil and regulate the patterns of nutrient cycling in forest ecological systems (Facelli and Pickett, 1991; Singh *et al.*, 1999; Weltzin *et al.*, 2005). Decomposition of organic detritus provides 70 – 90% of nutrient annually needed for forest growth (Vogt *et al.*, 1986) and is a complex microbe fauna mediated process, which is accelerated by favourable environmental conditions that enhance faunal and microbial activity (Swift *et al.*, 1979). In tropical environment, the climatic seasonality characterized by alternating wet and dry period plays a vital role in regulating the rates of litter decomposition (Tripathi and Singh, 1992) by changing the population of microbial community on decomposing organic matter (Arunachalam *et al.*, 1997).

Chapter - III

MATERIALS AND METHODS

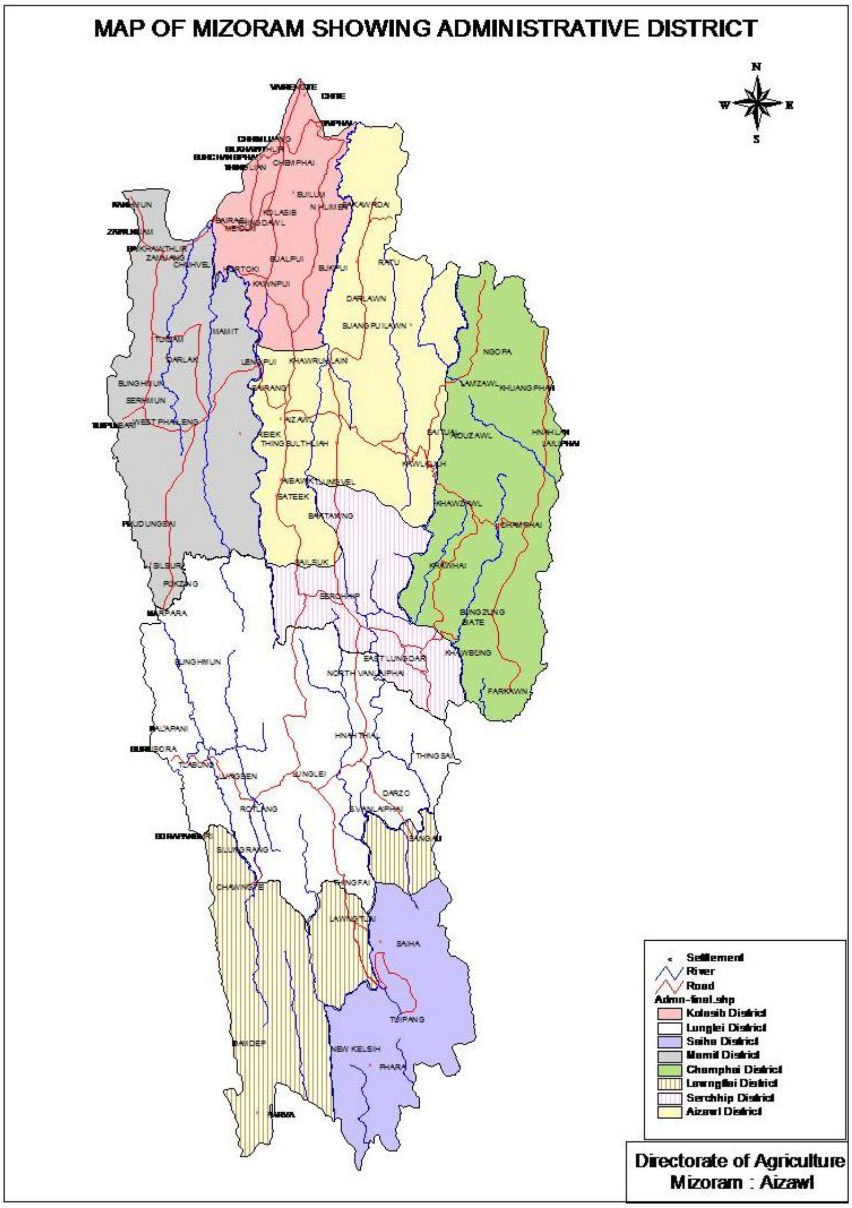
3.1 Location of Mizoram

Mizoram is a hilly state located in the North eastern part of India, sandwiched between Myanmar and Bangladesh. It lies between 92° 15´and 93° 29´ East Longitudes and 21°58´ and 24° 35´ North Latitudes and shares a common International boundary of 404 Kms with Myanmar and 318 Kms with Bangladesh. Mizoram is bounded on the north by Assam and Manipur, on the east and south by Chin and Arakan Hills of Myanmar, on the west by the Chittagong hill tracts of Bangladesh and on the north-west by the state of Tripura. The tropic of cancer, *i.e.* 23°30´N latitude cuts across the region in the undivided Aizawl District; traversing places like Champhai, Chhawrtui, Darlung and Phuldungsei etc. This imaginary line divides the region into two almost equal parts (Pachuau, 1994).

The state is divided into eight administrative districts, *viz.*, Aizawl, Champhai, Kolasib, Mamit, Lunglei, Serchhip, Lawngtlai and Saiha (Fig. 3.1). About 57.8 percent of the populations depend on agricultural products and practice jhum or shifting cultivation (Anon., 2004a). The total geographical area of Mizoram is 21,087 Km^2 and as per 2011 census, Mizoram has recorded as a population of 1,091,014 consisting of 552, 339 males and 538, 675 females, a sex ratio of 975 females to 1000 males.

Mizoram enjoys a moderate and pleasant climate. The temperature varies from 9°C to 24°C during winter and 24°C to 32°C during summer. The climate is pleasant in the months of October and November (19°C to 25°C). The entire Mizoram comes under the direct influence of the south west Monsoon receiving an annual average rainfall of 2095 mm in the year 2009 (Anon., 2011).

Fig. 3.1: Map of Mizoram showing the administrative districts



3.2 Physiography of Mizoram

The whole state is composed of several ranges of hills of tertiary rocks; the ranges are separated from one another by narrow deep river valleys. The elevation ranges from 20 m at Tlabung to Phawngpui Mountain where the height of its peak is 2157 m above mean sea level. There are a few and small patches of plains found in North Vanlaiphai, Thenzawl, Serchhip, Champhai and Serchhip. Most of these flats are now covered under permanent rice cultivation (Anon., 2003a). The state of Mizoram is drained by a numbers of rivers, streams and rivulets. Most of the drainage line originated in the Central part either towards North and South. All the rivers in Mizoram are fed by monsoon rain and their volume is very limited during dry season.

The soils of Mizoram are dominated mainly by loose sedimentary formation. They are young, immature and sandy (Pachuau, 1994). Analysis of soil samples from different places in Mizoram indicates that available manganese, copper, iron are adequately available except zinc. The pH and organic C content mostly decrease with depth (Anon., 2004b).

The main rivers that drain the northern part of Mizoram includes Langkaih, Teiret, Tut, Tlawng, Tuivawl, Tuivai and their tributaries ultimately join the Barak river further north. The river such as Tiau, Chhimtuipui (Kolodyne), Mat, Tuipui, Khawthlangtuipui (Karnaphully) and their tributaries drain the southern part.

3.3 Forest and vegetation

The state is divided into 12 forest divisions falling under three territorial circles. The forests of Mizoram are governed by the Mizoram (Forest) Act, 1955. Commercial utilization of the forests is prohibited but small felling is permitted for the use of *bona fide* locals to meet their needs (State of Forest Report, 2006). Mizoram falls under temperate zone having sub-tropical climatic condition with short and dry winter.

The sub-tropical humid climate favours luxuriant growth of vegetation and forests. The forests are divided into Protected Areas, reserve forests and unclassified forest. According to State of Forest Report, open forest occupies 61.18%, scrub 0.01%, moderately dense 28.87%, very dense 0.64% and non-forest 9.3% to the total geographical area of the state. Area under recorded Forest is 16,717 Km^2 (ISFR 2011). The reserved–forest covers 6465 Km^2 and the protected forest covers 941 Km^2 (Anon., 2008a). The practice of shifting cultivation, uncontrolled fire, felling of trees, agricultural expansion and road building have resulted in deforestation.

The forests of Mizoram have been classified into the following categories:

3.3.1 Adoption of Champion and Seth's classification (1968):

According to Champion and Seth (1968), the forest of Mizoram has been classified into three types, mainly based on the altitudinal ranges -

(1) Tropical wet-evergreen forests (up to 900 m)

(2) Tropical semi-evergreen forests (900-1500 m)

(3) Montane Sub-tropical Pine (above 1500m)

3.3.2 The Forest Survey of India (Forest Survey of India, 1992)

The Forest Survey of India classified the forests of Mizoram into six types, based on the altitudinal ranges and composition of species:-

(1) Eastern Himalaya wet temperate forest

(2) Cachar tropical semi-evergreen forests

(3) Assam tropical pine forests

(4) Secondary moist bamboo brakes

(5) Tropical wet evergreen forests and

(6) Montane sub-tropical forest

3.3.3 Classification by the Indian Institute of Remote Sensing (2002)

The Indian Institute of Remote Sensing, Dehra Dun classified the forest of Mizoram as follows:

(1) Tropical wet evergreen forest

(2) Sub-tropical broadleaved forest

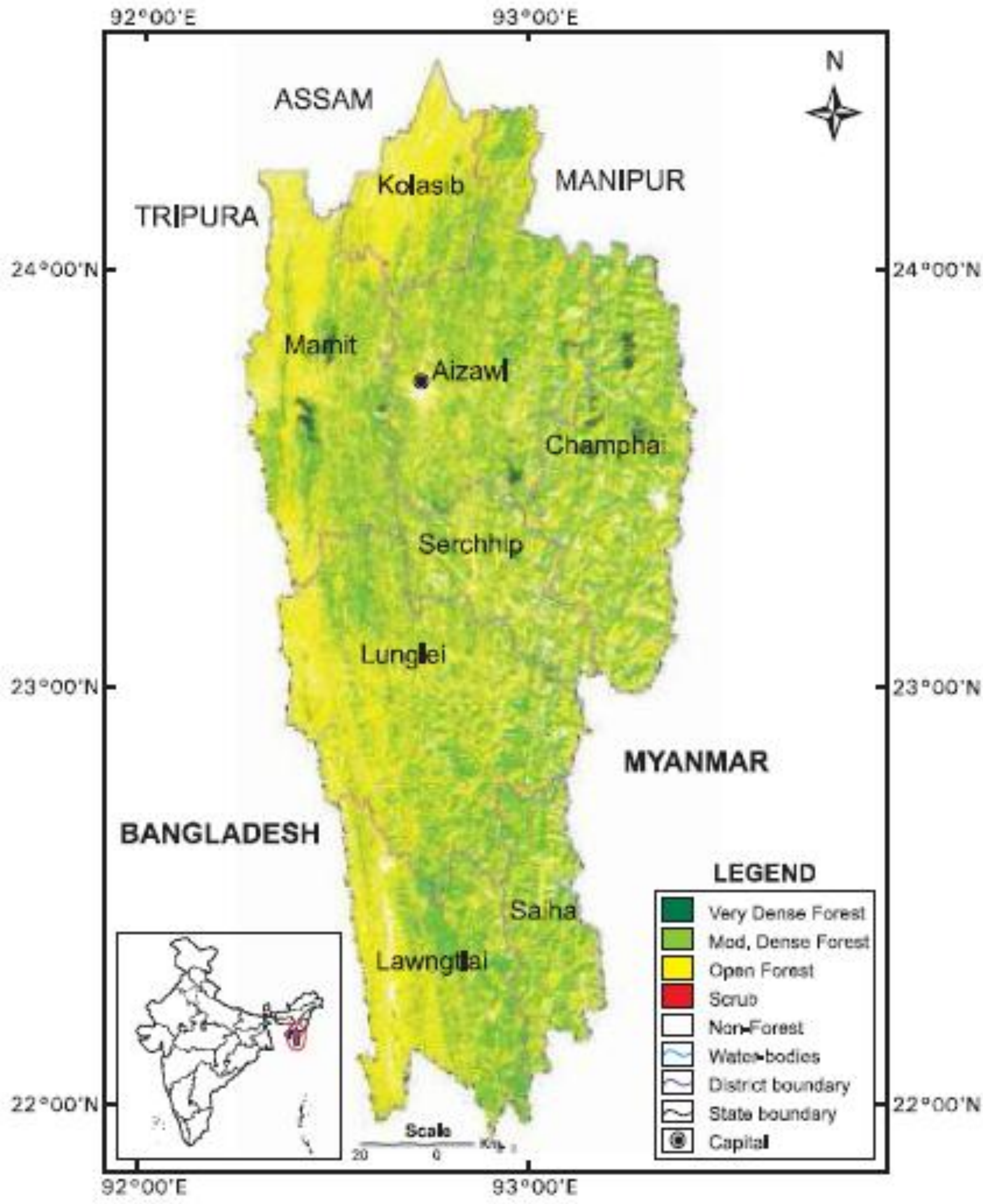
(3) Tropical semi-evergreen forest

(4) Temperate evergreen forest

(5) Degraded forest and

(6) Bamboo forest

Fig. 3.2: Forest cover map of Mizoram (ISFR 2011)



3.4 Description of the study sites

Extensive field work in bamboo forests was carefully conducted periodically for two years (2011 – 13) in five administrative districts (namely Aizawl, Lunglei, Kolasib, Mamit and Serchhip) representing approx. 78.7% of total bamboo area

(7091.66 Km²) of Mizoram(Anon., 2010).In each district, replicated permanent plots were established for periodical measurements.

Geographically, five selected districts of the study sites cover a total of ~ 12944 Km² areas which is ~61% of the geographical area of the state. In addition, these districts represented ~ 79% of the bamboo growing areas of the state covering an area of ~5583 Km² comprising~78% of the total growing stock of the state. All selected districts were dominated by three species of bamboos namely-*Melocanna baccifera* (Roxb.) Kurz, *Dendrocalamus longispathus* (Kurz) Kurz and *Bambusa tulda* Roxb.

3.4.1. Aizawl District

Aizawl is the largest city as well as the capital of the state of Mizoram. The City is located north of the Tropic of Cancer in the northern part of Mizoram and is situated on ridge 1132 m (3715 ft) a.m.sl., with the Tlawng river valley to its west and the Tuivawl river valley to its east. Summer temperature ranges from 20 – 30°C, and winter 11 – 21°C. The geographical area of the district is 3,576 Km² and as per the 2011 census a population of 404,054 souls.

The district has a bamboo area of 927.69 Km² which is 25.94% of the total geographical area of the district. Major species of bamboo of the state are found in the district. The study sites were located at Maubuang – Damdiai and Sateek. (Table 3.1)

3.4.2. Lunglei District

Lunglei District, the biggest District in Mizoram is bounded on the north by Mamit and Serchhip Districts, on the south by Lawngtlai and Saiha Districts, on the east by Myanmar and on the west by Bangladesh. It has area of 4,538 $Km^2$with a population of 154,094 (Census 2011) and 186 villages.

The district has the largest area under bamboo covering i.e. 1956.59 Km^2 which is 43.12% of the total geographical area of the district, and 27.59% of the total bamboo area of the state. The study sites were located at Haulawng – Mausen areas. (Table 3.1)

3.4.3 Kolasib district

The Kolasib district is sandwiched between Mamit on the west and Aizawl district in the east, bounded on the north and northwest by Hailakandi district of Assam state and on the south the Aizawl district. The geographical area of the district is 1382.51 Km^2 and has a population of 83,054 (Census 2011). Kolasib town is the administrative headquarters of the district.

Out of the total geographical area of the district, 47.87% is under bamboo growing area which is 661.80 Km^2, contributing 9.33% of the total bamboo growing area of the state. The study sites were located at Kolasib and Lungdai (Table 3.1)

3.4.4 Mamit District

The Mamit District is bounded on the north by Hailakandi district of Assam state, on the west by North Tripura district of Tripura state and Bangladesh, on the south by Lunglei district and on the east by Kolasib and Aizawl districts. The district occupies an area of 3025.75 km².It is the 4th largest district in the state. Mamit town is the administrative headquarters of the district. According to the 2011 census Mamit district has a population of 85,757.

In terms of bamboo area to the geographical area of the district, Mamit has the largest area under bamboo, extending to an area of 1598Km², which is 52.81% of the total geographical area of the state, which is as much as 22.53% of the total bamboo growing area of the state. The study sites were located at Lengpui and Dialdawk.

3.4.5 Serchhip District

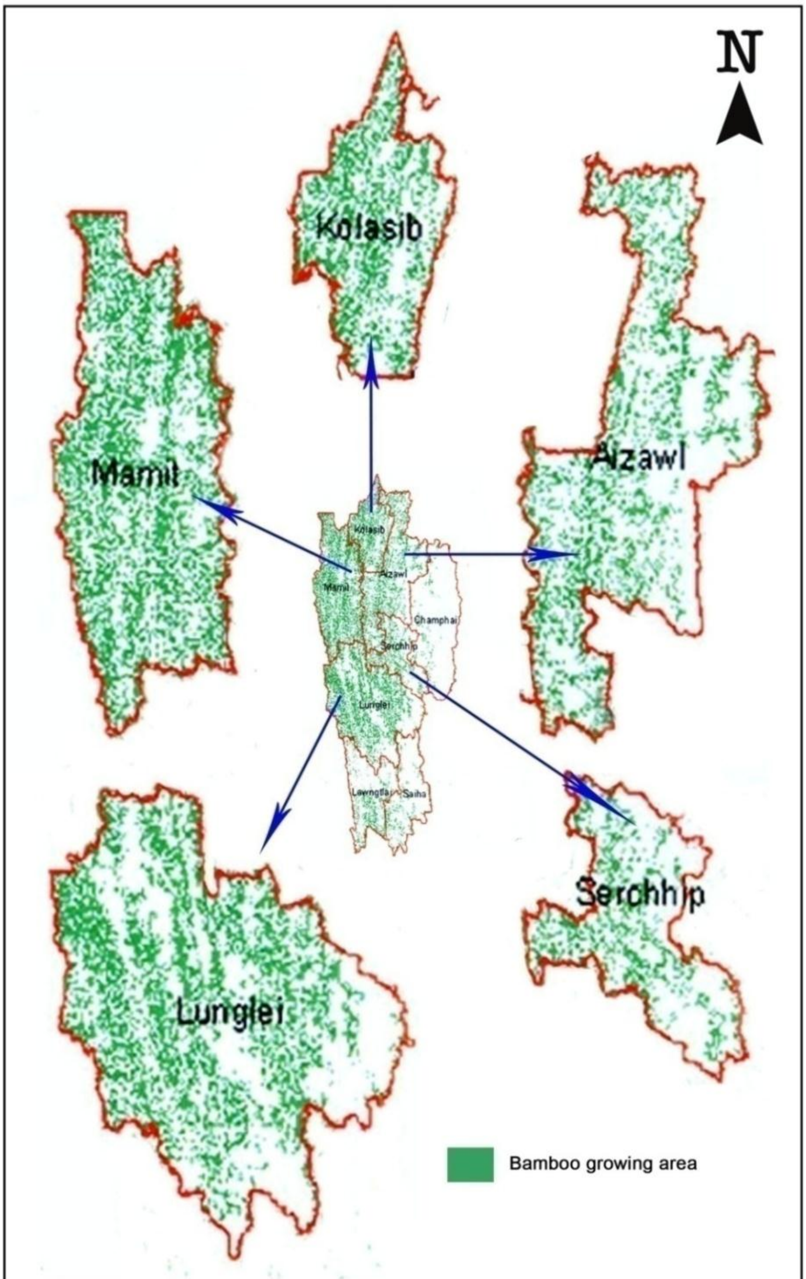
Serchhip District is the smallest district in the state having an area of 1421.60 Km² and a population of 64875 (Census 2011). The Tropic of Cancer passed through the District and is located in the central of the state of Mizoram. Serchhip is adjoined by Champhai District in the East, Aizawl in the North and North West and Lunglei District in the South. The average elevation (altitude) is 888m. Serchhip town is the administrative headquarters of the district.

Geographically the smallest district has a bamboo area of 439.08 Km² which is 30.89% of the total geographical area of the district. The district has uniqueness. There are bamboo forests dominated by the *Melocanna baccifera*, which doesn't flower during the recent gregarious flowering of the same. The study sites were located at Serchhip and Chhingchhip (Table 3.1)

Table 3.1: Geo-coordinates of the study sites.

District	Study Sites	Geo-Coordinates	Elevation	Dominant species
Aizawl	Sateek	N 23°32.068' E 092°41.950'	915	*Bambusa tulda*
	Damdiai	N 23°31.119' E 092°42.066'	818	*Bambusa tulda*
Lunglei	Mausen	N 23°01.105' E 092°4.326'	572	*Bambusa tulda*
	Haulawng	N 23°02.983' E 092°46.324'	972	*Bambusa tulda*
Mamit	Lengpui	N 23°48.018' E 092°36.080'	338	*Dendrocalamus longispathus*
	Dialdawk	N 23°49.029' E 092°36.228'	443	*Dendrocalamus longispathus*
Kolasib	Kolasib	N 24°12.696' E 092°41.000'	675	*Dendrocalamus longispathus*
	Lungdai	N 23°52.729' E 092°44.465'	1012	*Dendrocalamus longispathus*
Serchhip	Chhingchhip	N 23°28.608' E 092°52.148'	965	*Melocanna baccifera*
	Serchhip	N 23°17.406' E 092°51.725'	853	*Melocanna baccifera*

Fig. 3.3 Bamboo Distribution Map of Mizoram showing the study sites



Bamboo Distribution Map of Mizoram
Showing the Study sites
(Map courtesy of MIRSAC 2009)

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3.5 Experimental layout

For the present study, bamboo forest from each five districts was selected through literatures as well as GIS mapping, which were then verified on the spot for further studies. In each study area, 10 permanent plots of 10m × 10m were established and the number of culms per plot was counted and converted to per ha. Further, culm diameters of each bamboo within the permanent plots were recorded. In total, 1000m² areas were covered in each district.

3.6 Measurement of plant biomass

The bamboo shoots were separated by categories, namely current year shoot and >1 year live shoots and standing dead shoot. All categories were sub-divided into several diameter classes (<1cm, 1 – 2cm, 3 – 4cm, 4 – 5cm). In each diameter class, 10 – 30culms with a total of 120 culms were harvested. After measuring the basal diameter of the culm, the fresh weights for each component (leaves, branches and culms) were recorded and sub-samples were collected from each component and diameter class of the harvested bamboo shoots. The sub-samples of each component were dried at 80°C for 24 hours in a hot air oven and the fresh weight was converted into dry mass. Regression equation was developed relating dry weight of culms component wise to culms diameter.

The above ground biomass in each diameter class was determined from the mean diameter and regressions. The biomass of culms was multiplied with the density of culms to obtain the total aboveground bamboo biomass. The rhizome biomass of the sampled bamboo species were measured by excavating the adequate number of rhizomes and then weighed. The fine root biomass was estimated in 10 soil monoliths (each measuring 15 × 15 × 30 cm).

- The aboveground biomass of bamboo was determined with the help of regressions relating diameter (dbh) with biomass. (Tripathi and Singh, 1994)
- The dry matter values for standing crop biomass, net production, litterfall and roots were converted to C equivalent.
- Fine roots (<1mm diameter) and coarse roots (1 – 2 mm diameter) were collected at bimonthly interval from each site. For collecting roots soil monoliths of 15cm × 15cm × 30cm was excavated at random from all sites and brought to the laboratory. Soil containing the root materials was washed over a sieve system to recover the roots. Recovered roots were then over dried to constant weight and sorted out in different diameter classes.
- Litter traps measuring 100 cm × 100 cm was established in each site. Litterfall was collected at bi-monthly interval. The litter materials were brought to the laboratory, dried and sorted out to different categories.

3.7 Estimation of bamboo biomass production

Aboveground biomass production in bamboo was estimated as the difference of two years biomass (final – initial) as: $\Delta B = B_2 - B_1$, where, ΔB is the production Mg ha^{-1} yr^{-1}, B_2 = final biomass, B_1= initial biomass. Culm biomass was calculated by developing an allometric equation relating DBH to total dry weight. Biomass of culms recruited in a year was added to the production value. In addition, total litter fall and root production as the sum of difference between annual maximum and minimum standing crop mass for each size class (Edwards and Harris, 1977; Singh and Singh, 1981) was also added to the total biomass production.

3.8 Sampling of soil

Soil samples were collected from three horizons at 10 cm intervals (0 – 10, 10 – 20 and 20 – 30 cm) up to 30cm depth from each site. The collected samples from each horizon were then packed in an airtight plastic bag and brought to the laboratory for further analysis. The samples were oven dried at 80°C, ground and passed through 2mm mesh sieve. The soil bulk density of each study site was measured using a soil corer.

3.9 Chemical analysis of plant and soil samples

The oven dried samples of plant (component wise) and soils were grounded and sieved through 2mm sieve. The C and N concentrations of the sieved soil and plant samples were determined by CHN-OS Auto-Analyser (EURO EA) using Sulphanilamide ($C_6H_8N_2O_2S$) as a standard at the Central Instrumentation Laboratory, Mizoram University, Aizawl.

3.10 Computations

3.10.1 Calculation of Soil C pool

Equation for Soil C Pool (Guo and Gifford 2002):

$$C_{stock}(kg\mathrm{m}^{-2}) = \frac{BD \times C_c \times D}{10}$$

Where:

BD – bulk density (g cm^{-3})

C_c – percent soil C

D – sampling depth in cm

3.10.2 Estimation of total C and N stock in the bamboo forest of Mizoram

The total C and N stock of the bamboo forest of Mizoram was estimated using the primary data collected in the present study, the bamboo area, growing stock (green weight) and number of culms, obtained from the Mizoram Remote sensing and Space Application Centre (2009). The green weight of the primary data was converted to dry weight and was multiplied by the mean concentration of C and N in the vegetation, which was then computed to per unit area.

3.10.3 Calculation for C and N sequestration in bamboo

The productivity values of bamboo (component wise) were multiplied by C and N concentrations to calculate the sequestration of C and

N in different components of bamboo. Total ecosystem stock and sequestration was calculated by summing up component wise values.

3.10.4 Turnover of litter

The turnover rate (k) of organic matter, C and N on the bamboo floor was calculated by the expression adapted from Jenny *et al.,* (1949):

$$k = A/(A+F)$$

Where, A is the amount of organic matter, C and N annually added to the bamboo floor by litter fall and F is the organic matter, C and or N content of the minimum litter layer in the annual cycle. In the present study, A is the annual increment of in litter (i.e. litterfall) and F is the biomass of litter at steady states. Turnover time is the reciprocal of the turnover rate (k), expressed as $1/k$.

The turnover of C and N in the standing vegetation was computed as the ratio of standing crop of C and N to annual sequestration/uptake.

3.11 Statistical analysis

IBM's SPSS 16.0 and SigmaStat 32 software were used to determine the significant differences by analyzing it through the one-way analysis of variance (ANOVA). Statistical tools of the Mircosoft Excel 2007 were also used; graphs and regression co-efficient were generated through it.

3.12 Meteorological data

The meteorological data for different districts of the state was obtained from the Directorate of Science and Technology, Gov't of Mizoram, Aizawl (Table 3.1).

3.13 Growing stock

The growing stock of bamboo of the state was adapted from a joint survey organized by Mizoram Remote Sensing and Space Application (MIRSAC) and the State's Environment and Forest Department (Table 2.1).

3.14 Conversion of dimensions used

The following mathematical conversions were used:

1Giga gram (Gg)	=	10^3 Mega gram (Mg)	=	10^9 gram (g)
1 Tera gram (Tg)	=	10^6 Mega gram (Mg)	=	10^{12} gram (g)

1 hactare (ha)	=	10^4 m^2		
1 Km^2	=	100 ha	=	10^6 m^2

Table 3.2: Annual Rainfall and Temperature data of Mizoram

Months	2007 - 2010		2011		2012		2013	
	Mean Temp.	Mean Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall
	°C	mm	°C	mm	°C	mm	°C	mm
January	18.2125	11.35	16.85	8.8	18.02	15.3	16.69	0
February	19.1875	18.05	19.55	0.7	20.14	7.3	21.15	3.3
March	22.875	32.1	22.25	52.75	22.84	46.9	23.71	4.7
April	23.9875	158.05	23.35	88	22.23	277.5	23.34	64.9
May	23.825	215.3	22.75	369.3	23.98	201.1	21.88	458.4
June	23.725	290.175	23.86	302.2	23.21	505.5	24.01	301.8
July	23.475	315.15	23.72	235.9	23.68	260.1	23.55	316.8
August	23.475	391.175	23.87	412	23.89	432.8	22.79	371.9
September	23.975	388.55	24.01	348.1	23.66	328.9	22.96	301.9
October	23.6	202.3	23.5	82.3	21.9	288	22.03	126.4
November	21.2375	58.375	21.85	0	19.41	121.1	21.7	0
December	18.55	11.85	19.07	0	18.05	0	17.58	0
MEAN/Total	**22.1875**	**2092.425**	**22.05**	**1900.05**	**21.75**	**2484.5**	**21.78**	**1950.1**

[Courtesy of Department of Science & Technology, Gov't of Mizoram]

Chapter - IV

RESULTS

4.1 Physico-Chemical characterization of Soil

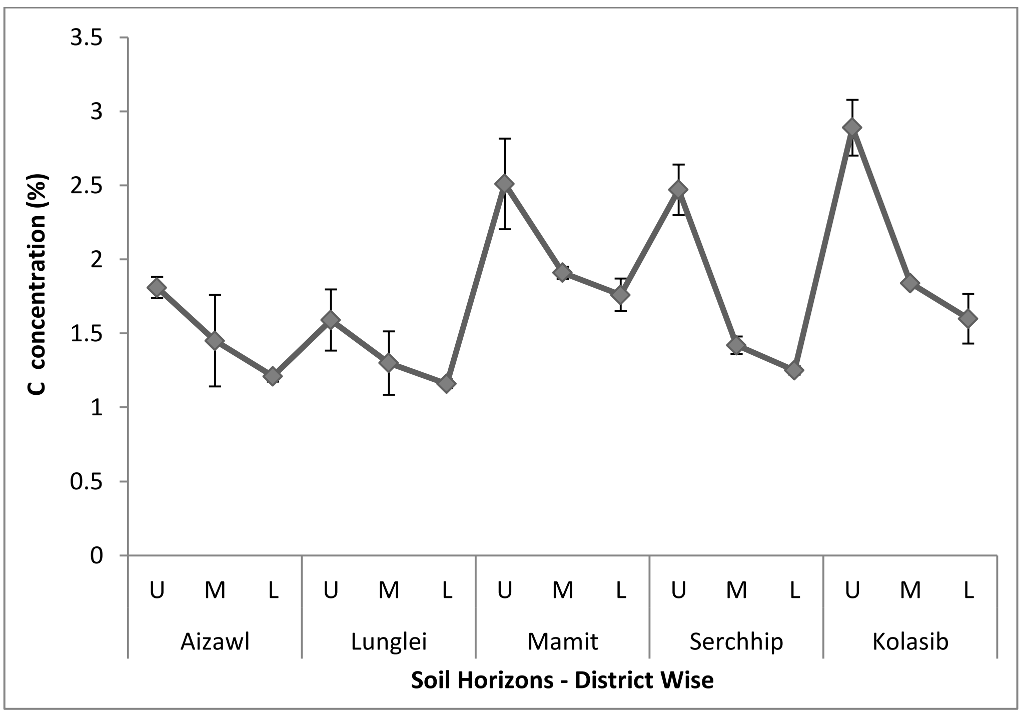
The total soil C concentration ranged from 1.59–2.89% in the upper (0 – 10cm), 1.3 – 1.9% in the middle (10–20cm) and (1.2–1.8%) in the lower soil depth (20-30 cm). Remarkably, upper soil depth reflects significantly greater C compared to lower depths. The decrease of C concentration with the increase in depth was statistically significant ($p<0.05 – 0.01$). Bulk density ranges from 1.01 g cm^{-3} to 1.3 g cm^{-3} (Fig. 4.1). Minimum was recorded in Mamit district and maximum in Aizawl District (Table 4.1).

The total soil N concentration ranged from 0.14 – 0.36% in upper, 0.20 – 0.25% in middle and 0.13 – 0.24% in the lower depths (Table 4.2). Decrease in soil N concentration with increase in depth was statistically significant ($p<0.05 – 0.01$).

4.1.1 Soil C Pool

The soil C-pool (product of percent organic C and bulk density) ranges from 51.9 Mg ha^{-1} to 69.2 Mg ha^{-1} in the five studied districts of Mizoram. Maximum soil C pool was recorded in Mamit district and minimum in Serchhip district. The difference in C accumulations in different district was mainly because of the higher concentration of C in the soil and not because of the bulk density. The upper horizon (0 – 10cm) of the soil contributed 40.5%, 39.3%, 40.6%, 48.1% and 45.7% of the total C-pool in Aizawl, Lunglei, Mamit, Serchhip and Kolasib districts respectively; whereas the middle and the lower horizons contributed 27.6% - 32.4% and 25.3% - 28.7% respectively in each sites. The C pool decreases with the increase in depth ($p < 0.05 – 0.01$).

Fig. 4.1: District wise soil C concentration (%) in different soil depths. Upper (U), middle (M) and lower (L) depths are representing 0–10cm, 10–20 cm and 20–30cm, respectively. Values are in % ± SE.



The C-pool in the upper horizon in each districts were in the range of 20.67 Mg ha^{-1} to 30.1 Mg ha^{-1}, maximum in the Kolasib district and minimum in the Lunglei district; the middle layer were in the range of 14.34 Mg ha^{-1} to 21.13

Mg ha^{-1}; minimum in Serchhip district and maximum in the Mamit district. The lower layer was in the ranges of 12.63 Mg ha^{-1} to 19.75 Mg ha^{-1}, where maximum was recorded from Mamit district and minimum from Serchhip district (Table 4.1).

Table 4.1: District wise changes in the values of soil bulk density, C concentrations and soil C pool. U, M and L represent upper (0 – 10 cm), middle (10 – 20 cm) and lower depths (20 – 30 cm) respectively. Values are in ± 1SE.

Sl. No.	Site	Horizon	C (%)	BD (g cm^{-3})	C (Mg ha^{-1})
1	**Aizawl**	**U**	1.81 ± 0.1	1.3	23.53 ± 1.7
		M	1.45 ± 0.3	1.3	18.85 ± 0.6
		L	1.21 ± 0.04	1.3	15.73 ± 0.3
		Total			**58.11 ± 1.34**
2	**Lunglei**	**U**	1.59 ± 0.2	1.3	20.67 ± 2.7
		M	1.30 ± 0.2	1.3	16.90 ± 2.8
		L	1.16 ± 0.03	1.3	15.08 ± 0.4
		Total			**52.64 ± 1**
3	**Mamit**	**U**	2.51 ± 0.3	1.12	28.1 ± 3.4
		M	1.91 ± 0.04	1.12	21.4 ± 0.5
		L	1.76 ± 0.1	1.12	19.7 ± 1.24
		Total			**69.22 ± 1.47**
4	**Serchhip**	U	2.47 ± 0.2	1.01	24.95 ± 0.9
		M	1.42 ± 0.1	1.01	14.34 ± 4.14
		L	1.25 ± 0.01	1.01	12.63 ± 0.49
		Total			**51.91 ± 2.22**
5	**Kolasib**	**U**	2.89 ± 0.2	1.04	30.06 ± 1.9
		M	1.84 ± 0.01	1.04	19.14 ± 0.1
		L	1.6 ± 0.2	1.04	16.4 ± 1.7
		Total			**65.83 ± 2.4**

The total soil C pool in the Aizawl district up to 30 cm soil depth was 58.1 Mg ha^{-1}. Maximum soil C accumulation (24.3 Mg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of higher C concentration (1.8%), as compared to the lower depth (Table 4.1).

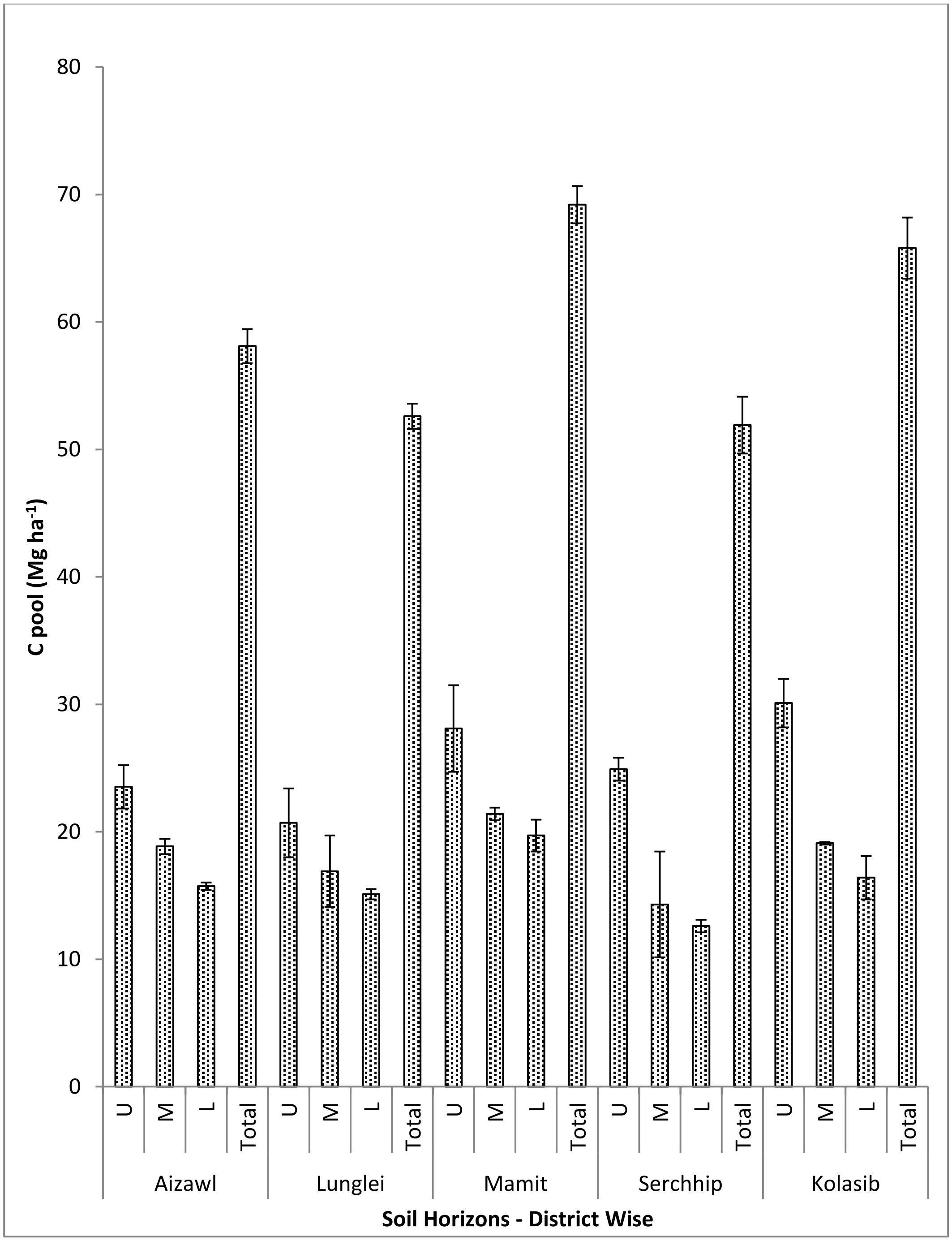
The total soil C pool in Lunglei district up to 30 cm soil depth was 52.6 Mg ha^{-1}. Maximum soil C accumulation (20.7 Mg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of high C concentration (1.6%), as compared to the lower depth (Table 4.1).

The total soil C pool in Mamit district up to 30 cm soil depth was 69.2 Mg ha^{-1}. Maximum soil C accumulation (28.1 Mg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of high C concentration (2.5%), as compared to the lower depth (Table 4.1).

The total soil C pool in Serchhip district up to 30 cm soil depth was 51.9 Mg ha^{-1}. Maximum soil C accumulation (24.9 Mg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of high C concentration (2.5%), as compared to the lower depth (Table 4.1).

The total soil C pool in Kolasib district up to 30 cm soil depth was 65.8Mg ha^{-1}. Maximum soil C accumulation (30.1 Mg ha^{-1}) was found in the upper layer (0 – 10 cm) which was mainly because of high C concentration (2.9%), as compared to the lower depth (Table 4.1).

Fig. 4.2: District wise soil C pool (Mg ha^{-1}± 1 SE) in upper (0 – 10 cm), middle (10 – 20 cm) and lower depths (10–20cm), which are represented by U, M and L respectively.



4.1.2 Soil N Pool

The total soil N pool ranges from 52.1 kg ha^{-1} to 88 kg ha^{-1} in 5 studied districts of Mizoram. Maximum soil N pool (88 kg ha^{-1}) was recorded in Kolasib district and minimum in Lunglei district (52.1 kg ha^{-1}). The total N concentration was found to be the highest in Kolasib District (0.28%), whereas 0.13% was the lowest and was recorded from Lunglei District. Soil total N pool was mainly affected by the concentration of soil N and thus the upper horizon of the soil represented a mean percentage of 40% of the total N-pool followed by middle (32%) and lower depths (28%) in each site.

Fig. 4.3: District wise soil N concentration (%) of soil in three depths - upper (0-10 cm), middle (10-20 cm) and lower depths (10-20cm), which are represented by U, M and L., respectively. Values are mean ± 1SE

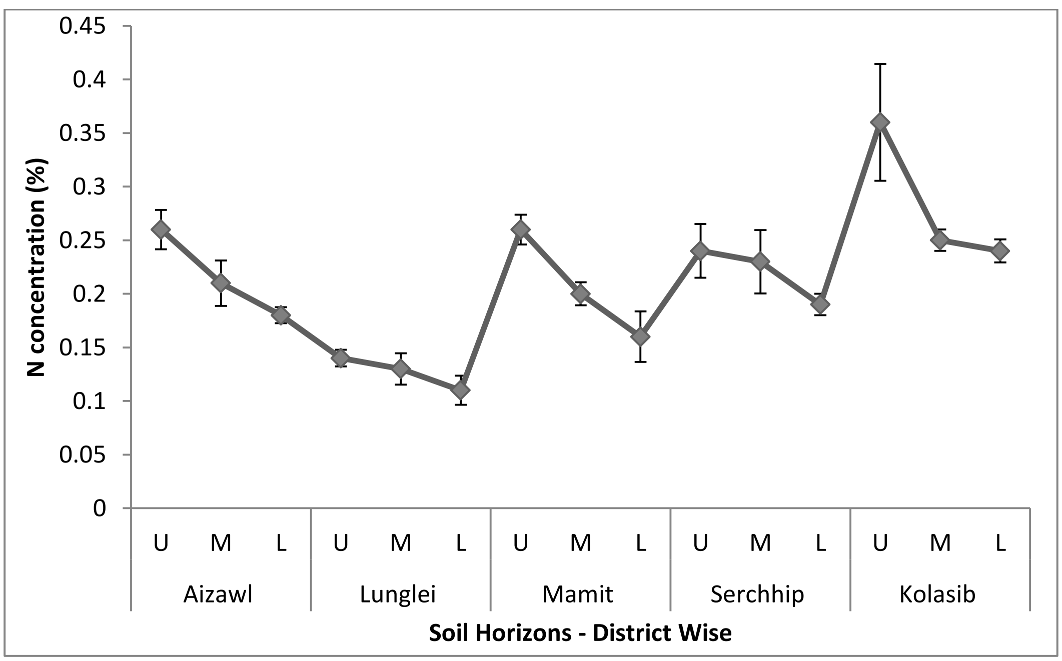


Table 4.2: District wise soil bulk density, N concentration and N-pool in 5 studied sites of Mizoram. U, M and L letters represent upper (0-10cm), middle (10-20cm) and lower depths (10-20 cm). Values are means ± 1 SE

Sl. No	Site	Horizon	N (%)	BD ($g\ cm^{-3}$)	N ($kg\ ha^{-1}$)
1	**Aizawl**	**U**	0.26 ± 0.02	1.3	35.2 ± 0.11
		M	0.21 ± 0.02	1.3	27.6 ± 0.36
		L	0.18 ± 0.01	1.3	24.2 ± 0.43
		Total			**87.0 ± 1.9**
2	**Lunglei**	**U**	0.14 ± 0.01	1.3	18.2 ± 0.14
		M	0.13 ± 0.01	1.3	16.9 ± 0.27
		L	0.11 ± 0.01	1.3	14.3 ± 0.18
		Total			**49.4 ± 0.3**
3	**Mamit**	**U**	0.26 ± 0.01	1.04	28.9 ± 0.03
		M	0.2 ± 0.01	1.04	22.8 ± 0.01
		L	0.16 ± 0.02	1.04	18.1 ± 0.02
		Total			**69.9 ± 1.8**
4	**Serchhip**	**U**	0.24 ± 0.03	1.12	24.1 ± 0.03
		M	0.23 ± 0.03	1.12	23.3 ± 0.26
		L	0.19 ± 0.01	1.12	18.9 ± 0.14
		Total			**66.3 ± 0.9**
5	**Kolasib**	**U**	0.36 ± 0.05	1.01	37.7 ± 0.11
		M	0.25 ± 0.01	1.01	25.8 ± 0.07
		L	0.24 ± 0.01	1.01	24.5 ± 0.01
		Total			**87.9 ± 2.4**

The N pool in the upper horizon in each districts were in the range of 14.2 kg ha^{-1} to 37.7 kg ha^{-1}, maximum in the Kolasib district and minimum in the Lunglei district; the middle layers were in the range of 16.6 kg ha^{-1} - 27.6 kg ha^{-1}; minimum in Lunglei district and maximum in the Aizawl district. The lower layers were in the ranges of 14.2 kg ha^{-1} to 24.5 kg ha^{-1}, where maximum was recorded from Kolasib district and minimum from Lunglei district (Table 4.2).

The total soil N pool in Aizawl district up to 30 cm soil depth was 88 kg ha^{-1}. Maximum soil N accumulation (35.2 kg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of high N concentration (0.26%) in this depth (Table 4.2).

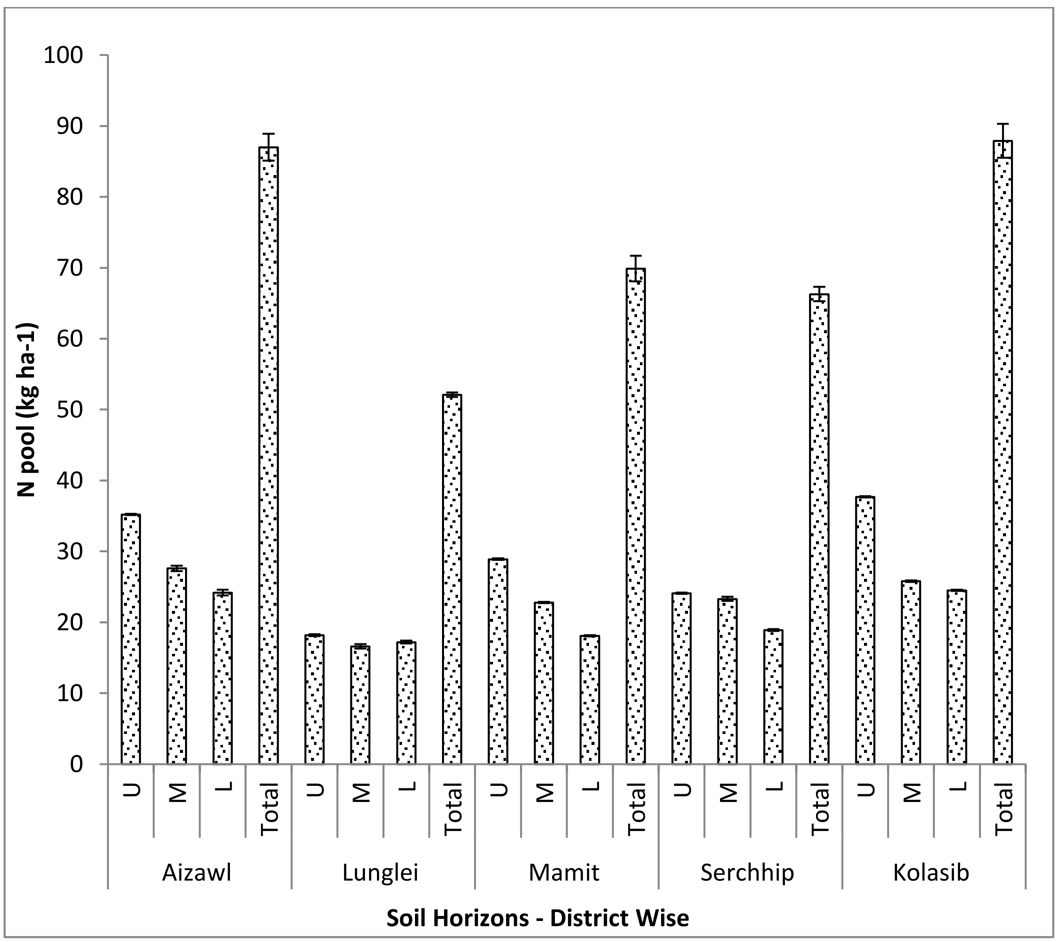
The total soil N pool in Lunglei district up to 30 cm soil depth was 49.4 kg ha^{-1}. Maximum soil N accumulation (18.2 kg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of high N concentration (0.14%), as compared to the lower depth (Table 4.2).

In Mamit district, the total soil N pool up to 30 cm soil depth was 69.9 kg ha^{-1}. Maximum soil N accumulation (28.9 kg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of high N concentration (0.26%), as compared to the lower depth (Table 4.2).

The total soil N pool in Serchhip district up to 30 cm soil depth was 66.3 kg ha^{-1}. Maximum soil N accumulation (24.04 kg ha^{-1}) was found in 0 – 10 cm soil depth which was mainly because of high N concentration (0.24%), as compared to the lower depth (Table 4.2).

The total soil N pool in Kolasib district up to 30 cm soil depth was 87.9 kg ha⁻¹. Maximum soil N accumulation (37.7 kg ha⁻¹) was found in 0 – 10 cm soil depth which was mainly because of high N concentration (0.36%), as compared to the lower depth (Table 4.2).

Fig. 4.4: District wise soil N-pool per horizon (0-10, and 20-30 cm). Upper (0-10 cm), middle (10-20 cm) and lower depths (10 – 20cm) are represented by U, M and L respectively. Values are mean ± 1 SE



4.2 Allometric equation relating culm dimensions and biomass

The culm diameter, height, number of internodes and product of diameter and height of three major bamboo species (*M. baccifera, D. longispathus and B. tulda)* had been correlated. It was found that the diameter at breast height (dbh) was the best predictor of biomass of bamboo components (culm, branch, leaf and total biomass). Therefore, regression equations have been developed between culm diameter and the biomass of culm, branch, leaf and total bamboo biomass to estimate the total stand biomass and production of different bamboo at various locations (Fig. 4.5 – 4.7).

Fig. 4.5 Regression equations relating diameter at breast height (DBH) and biomass of *Melocanna baccifera*.

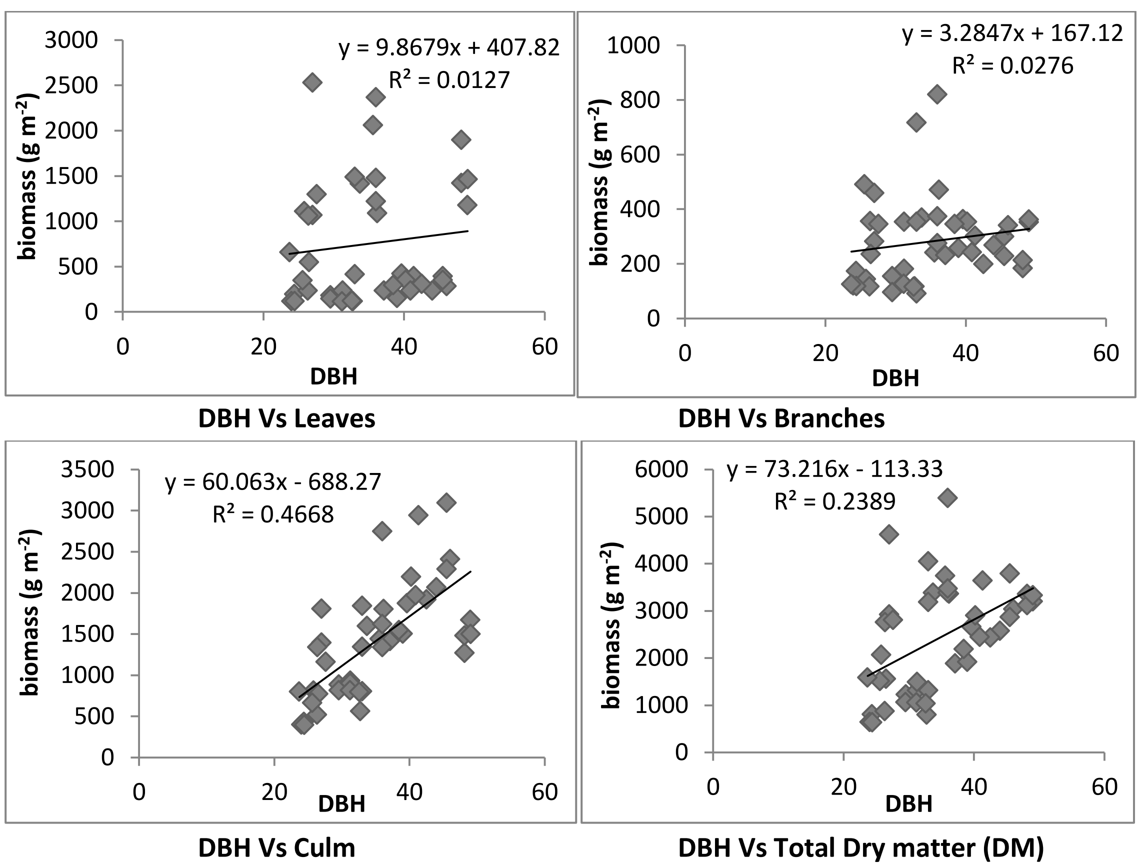
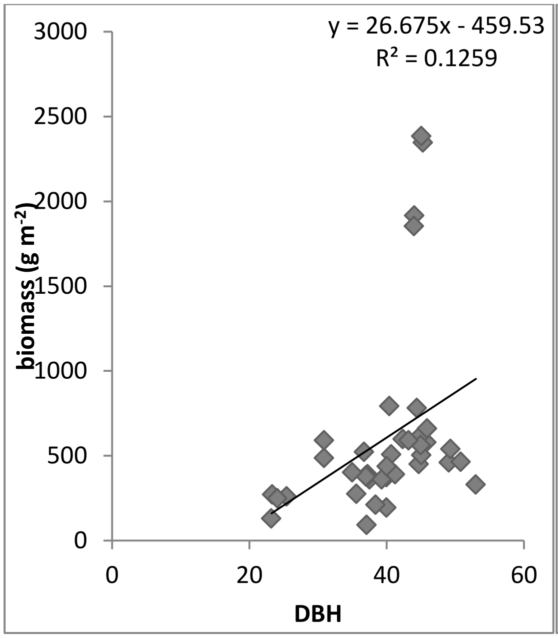
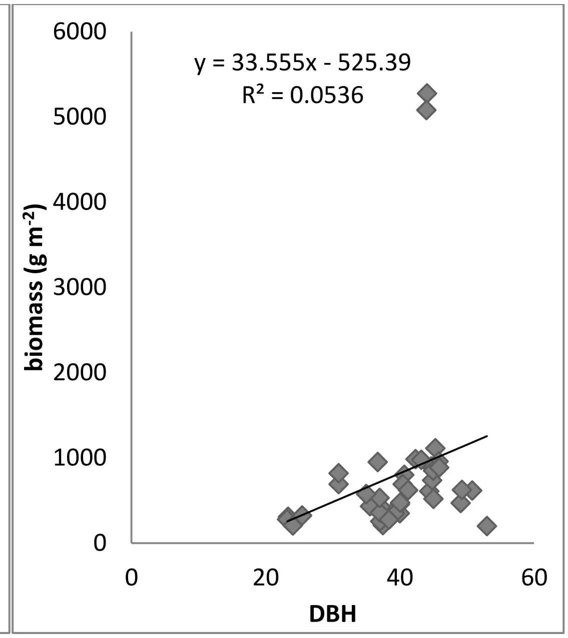


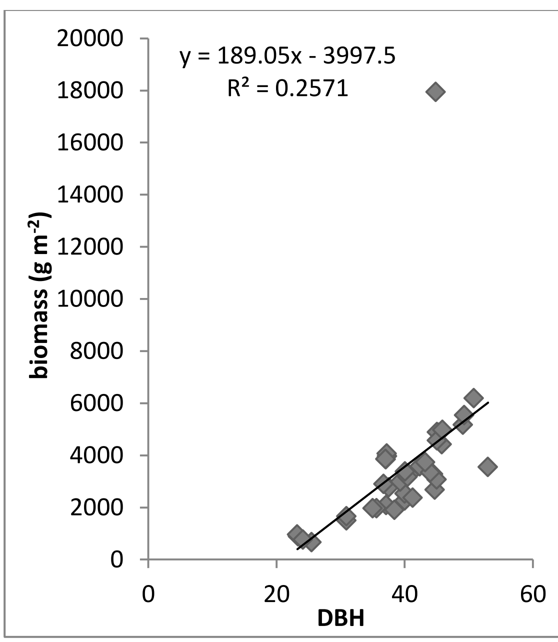
Fig. 4.6 Regression equations relating diameter at breast height (DBH) and biomass of *Bambusa tulda*



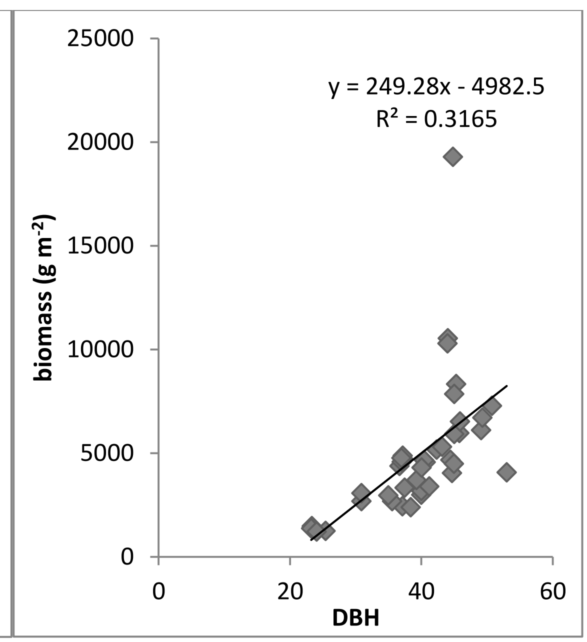
DBH Vs Leaves



DBH Vs Branches

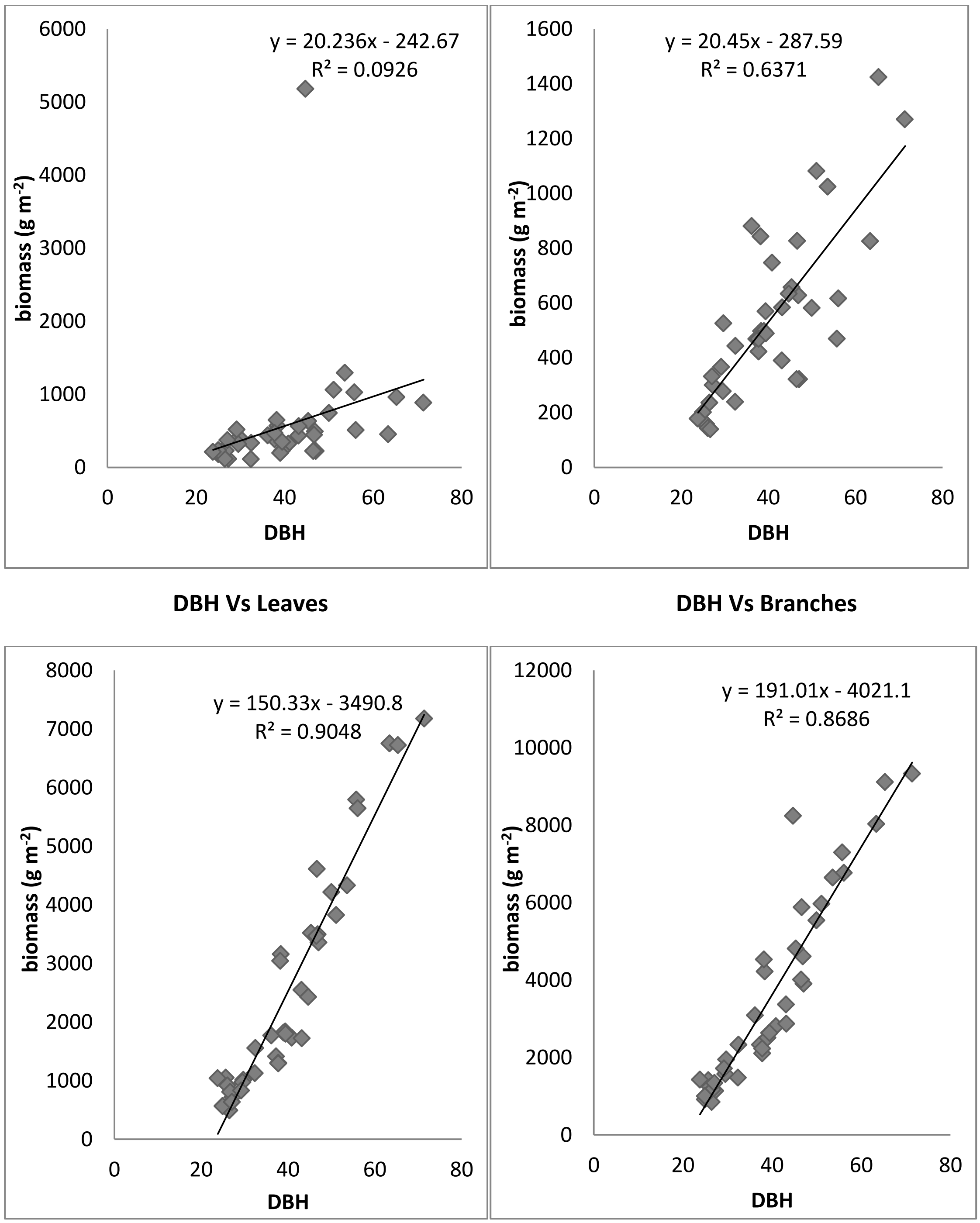


DBH Vs Culm



DBH Vs Total DM

Fig. 4.7 Regression equations relating diameter at breast height (DBH) and biomass of *Dendrocalamus longispathus*

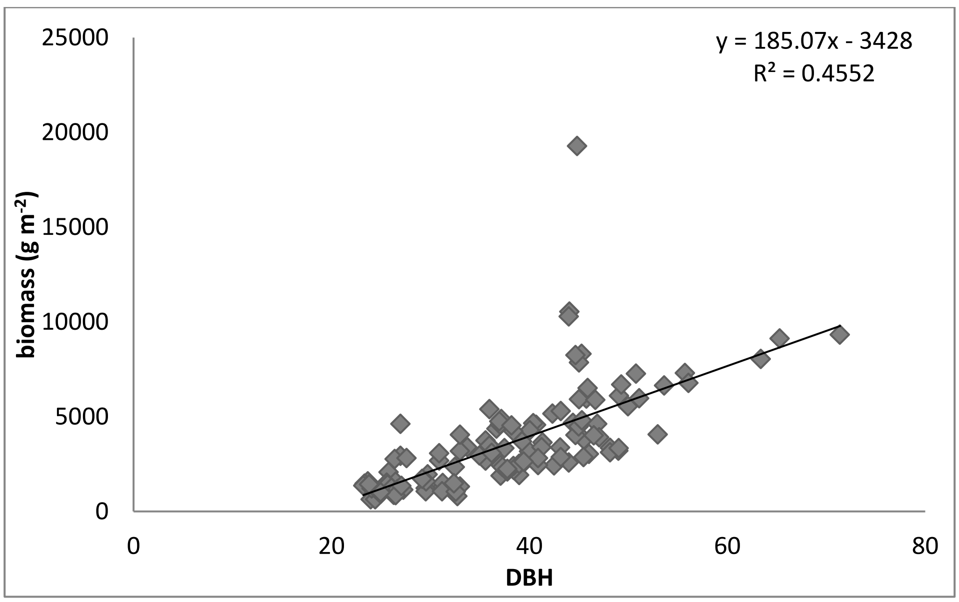


DBH Vs Leaves **DBH Vs Branches**

DBH Vs Culm **DBH Vs Total DM**

The regression equation for species pool/common species taking into account the diameter and biomass of different component has also been developed to estimate the stand biomass and the production. The culm dimension at the breast height was again found to be the best predictor (p< 0.05) for biomass of different components of bamboo namely – leaves, culms, branches and total (Fig. 4.8).

Fig. 4.8 Regression equations relating diameter at breast height (DBH) and biomass all species of bamboo (common species/species pool).



DBH Vs Total DM

4.3 Plant biomass and production

The total plant biomass (above- and below-ground) of the study sites ranged from 42.96 – 84.08 Mg ha^{-1}. Since bamboo attains its maturity within a year, the annual biomass production depends upon the amount of new shoots recruited and thus the density of total number of culms in the sites is one of the factors affecting the productivity of new culms.

Table 4.3: Standing crop biomass and production of three major bamboo species of Mizoram in plant component wise (Mg ha^{-1} ± SE)

District →	Aizawl	Lunglei	Mamit	Serchhip	Kolasib
Components	**Biomass (Mg ha^{-1})**				
Leaf	8.18 ± 0.01	6.38 ± 0.01	3.27 ± 0.01	3.79 ± 0.01	2.27 ± 0.01
Branch	9.37 ± 0.01	8.19 ± 0.01	3.36 ± 0.01	1.26 ± 0.01	0.97 ± 0.01
Culm	36.19 ± 0.06	44.67 ± 0.08	22.68 ± 0.01	22.44 ± 0.01	20. 5 ± 0.04
Shoot	7.64 ± 0.01	15.27 ± 0.01	11.45 ± 0.01	15.01 ± 0.01	11.45 ± 0.01
Fine root	2.70 ± 0.01	5.45 ± 0.01	3.67 ± 0.01	4.41 ± 0.01	4.35 ± 0.01
Coarse roots	1.91 ± 0.01	4.13 ± 0.01	3.19 ± 0.01	3.35 ± 0.01	3.46 ± 0.01
Total	**65.99 ± 5.2**	**84.08 ± 6.3**	**47.63 ± 3.2**	**50.25 ± 3.4**	**42.96 ± 3.0**
Components	**Production (Mg ha^{-1} yr^{-1})**				
Leaf	1.43 ± 0.01	0.55 ± 0.01	0.62 ± 0.01	0.68 ± 0.01	0.28 ± 0.01
Branch	3.83 ± 0.01	3.75 ± 0.01	1.82 ± 0.01	0.71 ± 0.01	0.47 ± 0.01
Culm	24.21 ± 0.01	29.51 ± 0.01	14.25 ± 0.01	16.68 ± 0.01	11.52 ± 0.01
Shoot	7.63 ± 0.01	15.27 ± 0.01	11.45 ± 0.01	10.00 ± 0.01	7.63 ± 0.01
Fine root	0.33 ± 0.01	0.26 ± 0.01	0.41 ± 0.01	0.33 ± 0.01	0.16 ± 0.01
Coarse roots	0.30 ± 0.01	0.15 ± 0.01	0.34 ± 0.01	0.13 ± 0.01	0.15 ± 0.01
Total	**37.73 ± 3.8**	**49.49 ± 4.9**	**28.89 ± 2.6**	**28.52 ± 2.8**	**20.21 ± 2.0**

Of the total biomass of the plant, 57.6% was contributed by the culms. The leaves, the branches and the new shoots contributed 23.9%, 23.15% and 23.9% respectively to the total biomass. The total belowground biomass of the study sites was 36.62 Mg ha^{-1}. Out which 56.2% were shared by the fine roots and the remaining 43.8% was contributed by the coarse roots (Table 4.3)

Fig. 4.9: Mean biomass in different components of bamboo. Values are mean ± 1SE

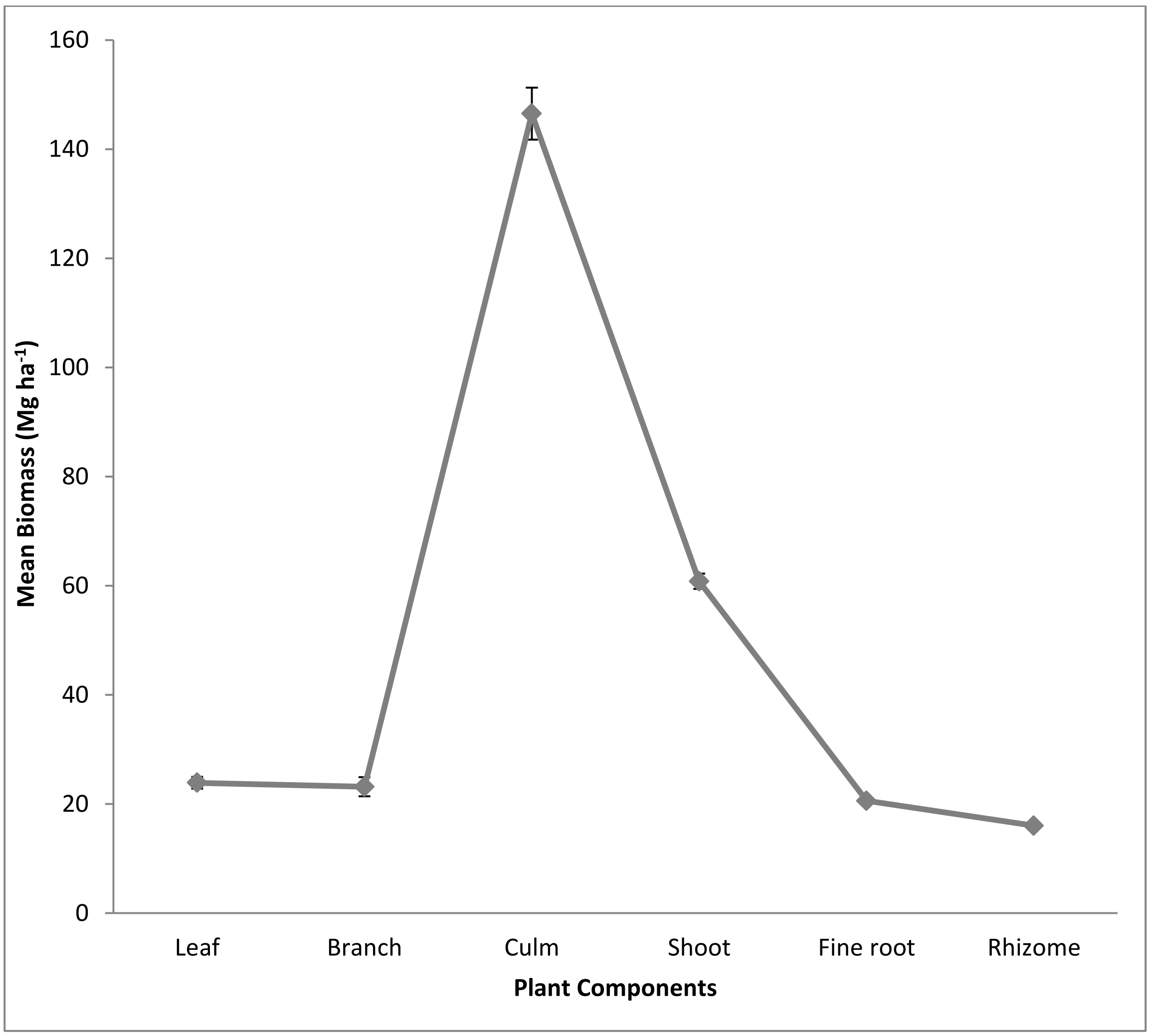
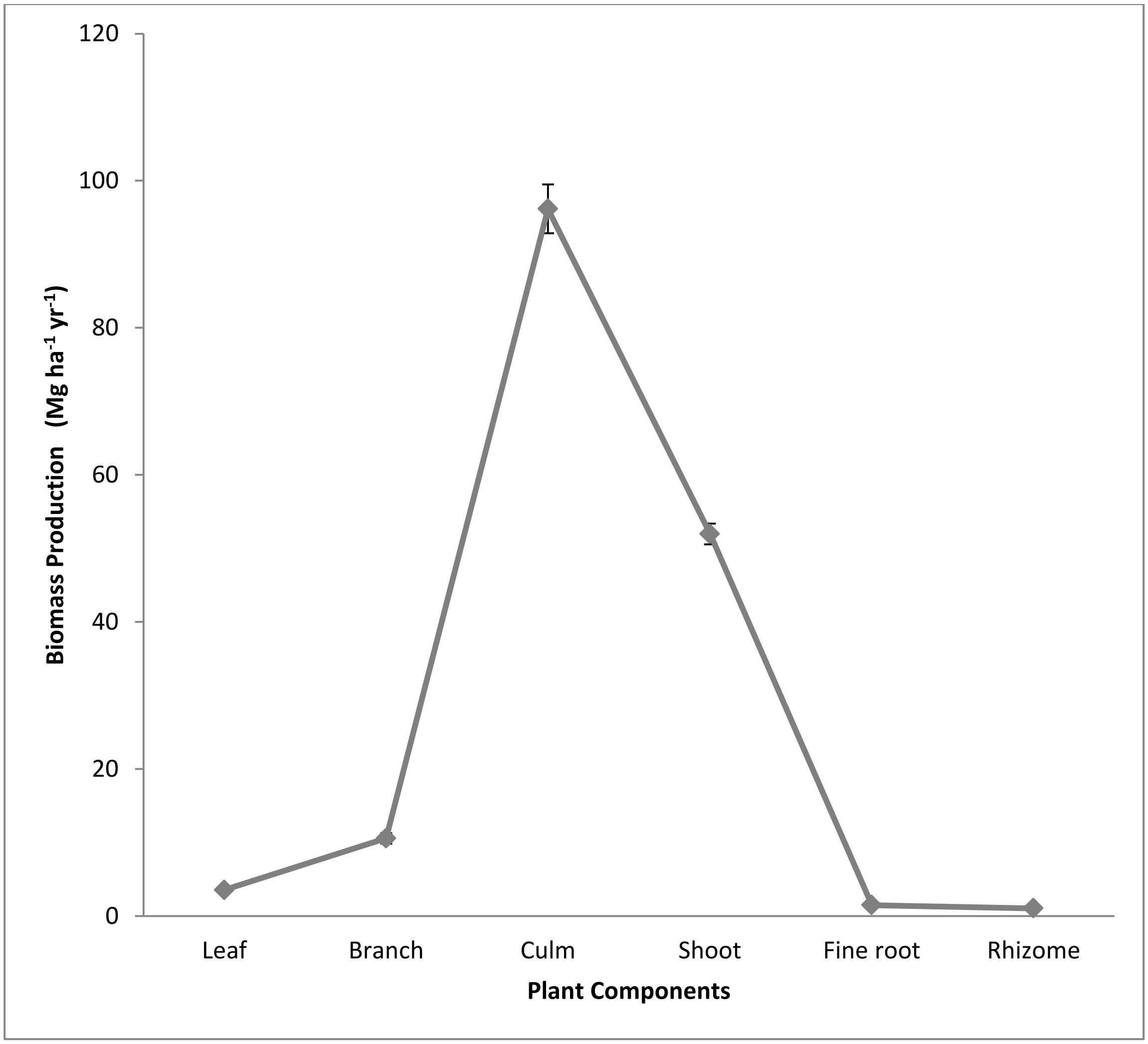


Fig. 4.10 Mean annual biomass production in different components of bamboo. Values are mean ± 1SE



4.4 C Sequestration in bamboo ecosystems

The C sequestration potential of 5 studied districts ranged from 8.9 Mg ha^{-1} yr^{-1} – 22.07 Mg $ha^{-1}yr^{-1}$ with a mean of 14.67 Mg ha^{-1} yr^{-1}. The bamboo forests of the Lunglei district have the highest C sequestration potential (22.07 Mg ha^{-1} yr^{-1}), whereas the lowest 8.98 Mg ha^{-1} yr^{-1} was recorded from the Kolasib district. The C sequestration potential of the bamboo forest (in district wise) is given in table 4.5. The mean difference between each district per plant component wise was significant at 5% ($p < 0.05$).

Fig. 4.11: District wise total C-sequestration in bamboo

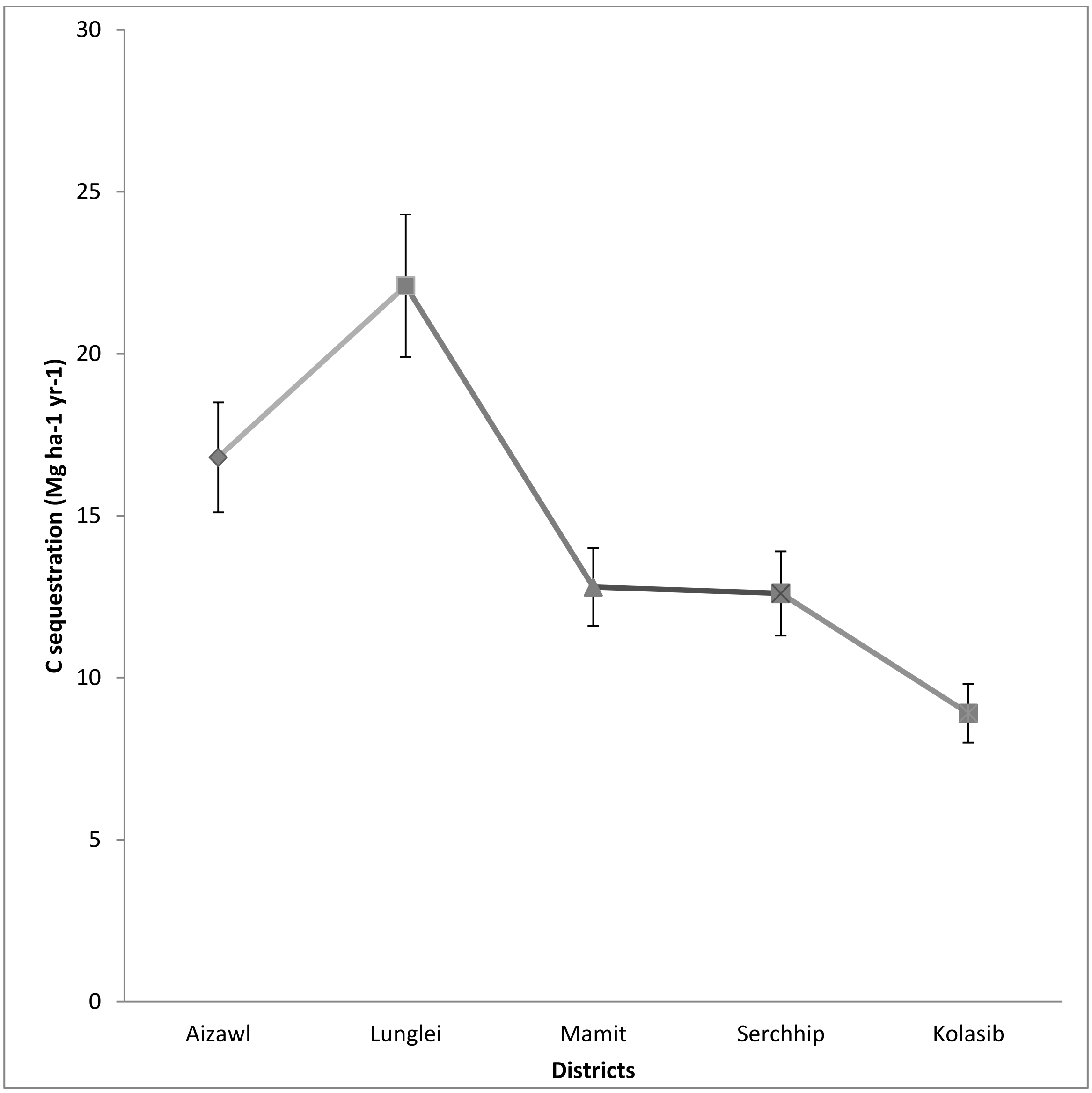


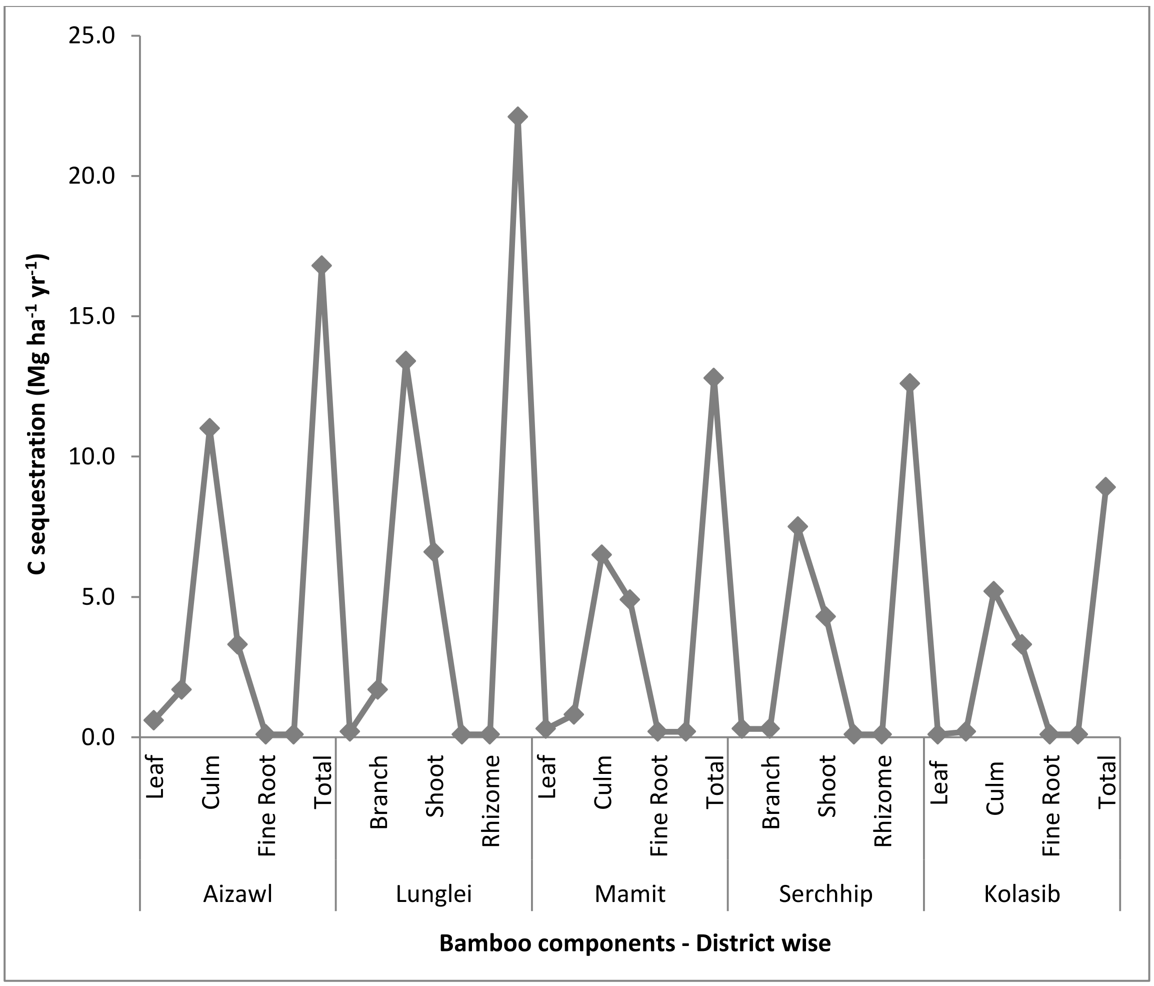
Table 4.4: District wise C-stock and C-sequestration rates of bamboo (Mean ± SE)

District	Components	Biomass (Mg ha^{-1})	Production (Mg ha^{-1} yr^{-1})	C (%)	C Stock (Mg ha^{-1})	C Seqs. (Mg ha^{-1} yr^{-1})
Aizawl	**Leaf**	8.2 ± 0.01	1.4 ± 0.01	40.3	3.3 ± 0.01	0.6 ± 0.01
	Branch	9.4 ± 0.01	3.8 ± 0.01	45.2	4.2 ± 0.01	1.7 ± 0.01
	Culm	36.2 ± 0.06	24.2 ± 0.01	45.26	16.4 ± 0.01	11 ± 0.06
	Shoot	7.6 ± 0.01	7.6 ± 0.01	43.42	3.3 ± 0.01	3.3 ± 0.01
	Fine Root	2.7 ± 0.01	0.3 ± 0.01	41.66	1.1 ± 0.01	0.1 ± 0.01
	Coarse roots	1.9 ± 0.01	0.3 ± 0.01	43.16	0.8 ± 0.01	0.1 ± 0.01
	Total	**65.9 ± 5.2**	**37.73 ± 3.8**	**43.28**	**28.56 ± 2.4**	**16.84 ± 1.7**
Lunglei	**Leaf**	6.4 ± 0.01	0.5 ± 0.01	40.34	2.6 ± 0.01	0.2 ± 0.01
	Branch	8.2 ± 0.01	3.6 ± 0.01	45.15	3.7 ± 0.01	1.7 ± 0.01
	Culm	44.7 ± 0.08	29.5 ± 0.01	45.26	20.2 ± 0.01	13.4 ± 0.08
	Shoot	15.3 ± 0.01	15.3 ± 0.01	43.42	6.6 ± 0.01	6.6 ± 0.01
	Fine Root	5.4 ± 0.01	0.7 ± 0.01	41.66	2.3 ± 0.01	0.1 ± 0.01
	Coarse roots	4.1 ± 0.01	0.1 ± 0.01	43.16	1.8 ± 0.01	0.1 ± 0.01
	Total	**84.1 ± 6.3**	**49.34 ± 4.9**	**43.28**	**36.39 ± 2.9**	**22.1 ± 2.2**
Mamit	**Leaf**	3.3 ± 0.01	0.6 ± 0.01	40.34	1.3 ± 0.01	0.3 ± 0.01
	Branch	3.4 ± 0.01	1.8 ± 0.01	45.15	1.5 ± 0.01	0.8 ± 0.01
	Culm	22.7 ± 0.01	14.2 ± 0.01	45.26	10.2 ± 0.01	6.5 ± 0.01
	Shoot	11.4 ± 0.01	11.5 ± 0.01	43.42	4.9 ± 0.01	4.9 ± 0.01
	Fine Root	3.7 ± 0.01	0.4 ± 0.01	41.66	1.5 ± 0.01	0.2 ± 0.01
	Coarse roots	3.2 ± 0.01	0.3 ± 0.01	43.16	1.4 ± 0.01	0.2 ± 0.01
	Total	**47.6 ± 3.2**	**28.9 ± 2.6**	**43.28**	**20.61 ± 1.5**	**12.8 ± 1.2**
Serchhip	**Leaf**	3.8 ± 0.01	0.7 ± 0.01	40.34	1.5 ± 0.01	0.3 ± 0.01
	Branch	1.3 ± 0.01	0.7 ± 0.01	45.15	0.6 ± 0.01	0.3 ± 0.01
	Culm	22.4 ± 0.01	16.7 ± 0.01	45.26	10.2 ± 0.01	7.5 ± 0.01
	Shoot	15.1 ± 0.01	10 ± 0.01	43.41	6.5 ± 0.01	4.3 ± 0.01
	Fine Root	4.4 ± 0.01	0.3 ± 0.01	41.1	1.9 ± 0.01	0.1 ± 0.01
	Coarse roots	3.3 ± 0.01	0.1 ± 0.01	43.64	1.5 ± 0.01	0.1 ± 0.01
	Total	**50.2 ± 3.4**	**28.5 ± 2.8**	**43.276**	**21.7 ± 1.6**	**12.6 ± 1.3**
Kolasib	**Leaf**	2.3 ± 0.01	0.3± 0.01	40.337	0.9 ± 0.01	0.1 ± 0.01
	Branch	1 ± 0.01	0.5 ± 0.01	45.148	0.4 ± 0.01	0.2 ± 0.01
	Culm	20.5 ± 0.04	11.5 ± 0.01	45.258	9.3 ± 0.01	5.2 ± 0.04
	Shoot	11.5 ± 0.01	7.6 ± 0.01	43.415	4.9 ± 0.01	3.3 ± 0.01
	Fine Root	4.4 ± 0.01	0.2 ± 0.01	41.664	1.8 ± 0.01	0.1 ± 0.01
	Coarse roots	3.5 ± 0.01	0.1 ± 0.01	43.160	1.5 ± 0.01	0.1 ± 0.01
	Total	**43 ± 3.05**	**20.2 ± 2.02**	**43.276**	**18.6 ± 1.4**	**8.9 ± 0.9**

4.5 C Sequestration by different bamboo components

Among the different components of the plant, maximum amount of C is being sequestered by the culms (59.31%), whereas the leaves accounted for 1.96% of the sequestration which is lower than that by the branches (6.51%). Current year shoots sequestered 30.7%. The belowground components (fine roots and coarse roots) were accounted for 1.5% of the sequestration (Fig. 4.12).

Fig. 4.12: District wise C-sequestration of bamboo components. Values are mean ± SE

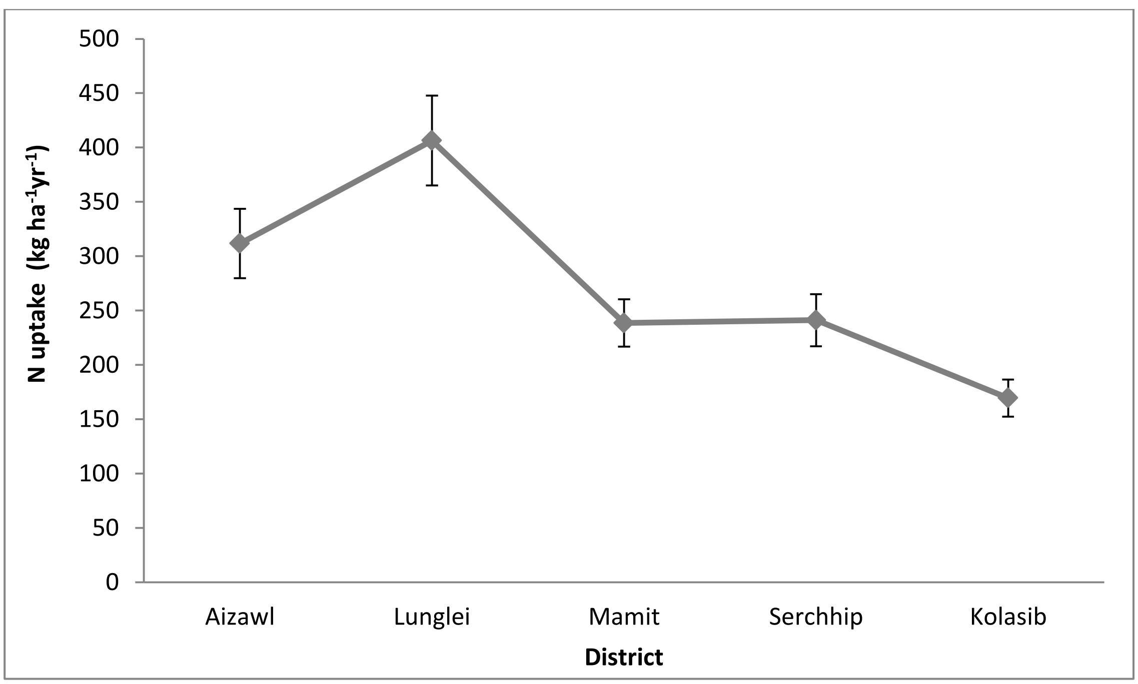


4.6 N Sequestration

The N uptake of the bamboo forests of the studied sites were in the range of 169.5 – 406.4 kg ha^{-1} yr^{-1} with a mean of 273.5 kg ha^{-1} yr^{-1}. The Bamboo forests of the Lunglei district have the highest N sequestration potential (406.4 kg ha^{-1} yr^{-1}), whereas 169.5 kg ha^{-1} yr^{-1} was the lowest recorded from the Kolasib district.

Lunglei district has the maximum potential of N sequestration, accounting to 29.7% of the total followed by Aizawl district 22.8% and Serchhip district 17.7%. The bamboo forests of Mamit district contributed 17.5%; the lowest was recorded from Kolasib district 12.4% (Fig. 4.13)

Fig. 4.13: District wise N-sequestration in different components of bamboo. Values are in kg ha^{-1} yr^{-1} ± SE



4.7 Distribution of N in different bamboo components

Of the total N-uptake by the different component of the plants, maximum amount of N is being sequestered by the culms (59.6%) followed by the branches (8.58%) and the leaves (3.83%). The new shoots or the current year shoots contributed 31.8% of the total N uptake. The belowground components accounted for 1.53% of the total N uptake (Fig. 4.14). The differences in the mean values among the different components of each sample are greater than would be expected by chance; there is a statistically significant difference ($p < 0.05$).

Fig. 4.14: Total N-uptake in different bamboo components. Values are mean ± SE.

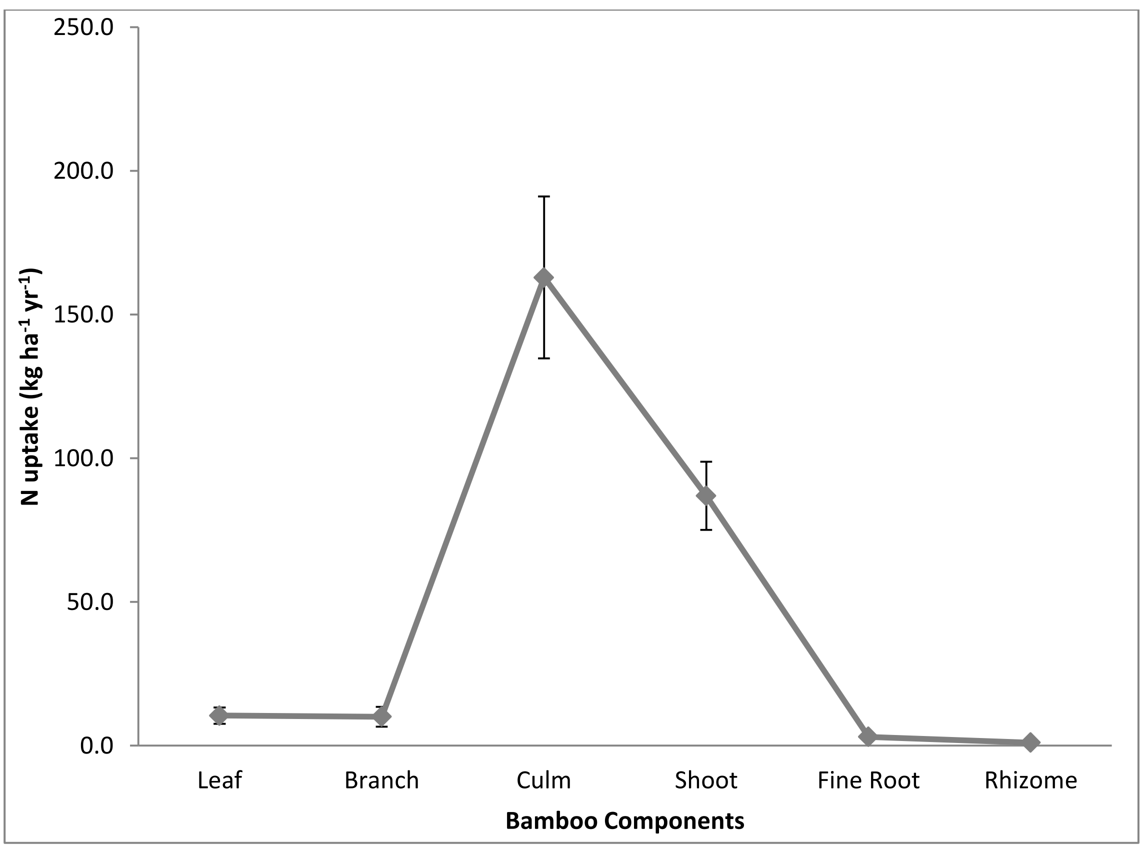


Table 4.5: District wise N-uptake of bamboo in 5 districts of Mizoram (Mean ± SE)

District	Components	Biomass (Mg ha^{-1})	Production (Mg ha^{-1} yr^{-1})	N %	N Stock (Kg ha^{-1})	N uptake (Kg ha^{-1} yr^{-1})
Aizawl	**Leaf**	8.2 ± 0.05	1.4 ± 0.01	1.47	21.1± 0.01	21.1 ± 0.01
	Branch	9.4 ± 0.05	3.8 ± 0.01	0.48	18.3 ± 0.01	18.3 ± 0.01
	Culm	36.2 ± 0.06	24.2 ± 0.01	0.85	205.1 ± 0.06	205.1 ± 0.06
	Shoot	7.6 ± 0.05	7.6 ± 0.01	0.84	63.8 ± 0.01	63.8 ± 0.01
	Fine Root	2.7 ± 0.04	0.3 ± 0.01	1.07	28.9 ± 0.01	3.5 ± 0.01
	Coarse roots	1.9 ± 0.0	0.299 ± 0.01	0.51	9.70 ± 0.01	1.52 ± 0.01
	Total	**65.9 ± 5.2**	**37.7 ± 3.8**	**1.33**	**337.1 ± 30.4**	**311.7 ± 31.9**
Lunglei	**Leaf**	6.4 ± 0.01	0.5 ± 0.01	1.47	8.1 ± 0.01	8.1 ± 0.01
	Branch	8.2 ± 0.01	3.7 ± 0.01	0.48	17.9 ± 0.01	17.9 ± 0.01
	Culm	44.7 ± 0.08	29.5 ± 0.01	0.85	249.9 ± 0.08	249.9 ± 0.08
	Shoot	15.3 ± 0.01	15.3 ± 0.01	0.84	127.7 ± 0.01	127.7 ± 0.01
	Fine Root	5.5 ± 0.01	0.3 ± 0.01	1.07	58.3 ± 0.01	2.8 ± 0.01
	Coarse roots	4.1 ± 0.01	0.1 ± 0.01	0.51	20.9 ± 0.01	0.8 ± 0.01
	Total	**84.1 ± 6.3**	**49.3 ± 4.9**	**1.33**	**461.8 ± 38.4**	**406.4 ± 41.4**
Mamit	**Leaf**	3.3 ± 0.01	0.6 ± 0.01	1.47	9.1 ± 0.01	9.1 ± 0.01
	Branch	3.4 ± 0.01	1.8 ± 0.01	0.48	8.7 ± 0.01	8.7 ± 0.01
	Culm	22.7 ± 0.01	14.2 ± 0.01	0.85	120.7 ± 0.01	120.6 ± 0.01
	Shoot	11.5 ± 0.01	11.5 ± 0.01	0.84	95.7 ± 0.01	95.7 ± 0.01
	Fine Root	3.7 ± 0.01	0.4 ± 0.01	1.07	39.3 ± 0.01	4.4 ± 0.01
	Coarse roots	3.2 ± 0.01	0.3 ± 0.01	0.51	16.2 ± 0.01	1.7 ± 0.01
	Total	**47.6 ± 3.2**	**28.9 ± 2.6**	**1.33**	**273.5 ± 19.7**	**238.6 ± 21.8**
Serchhip	**Leaf**	3.8 ± 0.01	0.7 ± 0.01	1.47	10.1 ± 0.01	10.1 ± 0.01
	Branch	1.3 ± 0.01	0.7 ± 0.01	0.48	3.4 ± 0.01	3.4 ± 0.01
	Culm	22.4 ± 0.01	16.7 ± 0.01	0.85	141.2 ± 0.01	141.2 ± 0.01
	Shoot	15.1 ± 0.01	10 ± 0.01	0.84	125.5 ± 0.01	83.6 ± 0.01
	Fine Root	4.4 ± 0.01	0.3 ± 0.01	0.93	41.1 ± 0.01	3 ± 0.01
	Coarse roots	3.3 ± 0.01	0.1 ± 0.01	0.53	17.9 ± 0.01	0.7 ± 0.01
	Total	**50.2 ± 3.4**	**28.5 ± 2.8**	**1.33**	**321.2 ± 24.9**	**241.3 ± 24.01**
Kolasib	**Leaf**	2.3 ± 0.01	0.3± 0.01	1.47	4.1 ± 0.01	4.1 ± 0.01
	Branch	0.9 ± 0.01	0.5 ± 0.01	0.48	2.2 ± 0.01	2.2 ± 0.01
	Culm	20.4 ± 0.04	11.5 ± 0.01	0.85	97.6 ± 0.04	97.6 ± 0.04
	Shoot	11.5 ± 0.01	7.6 ± 0.01	0.84	95.7 ± 0.01	63.8 ± 0.01
	Fine Root	4.4 ± 0.01	0.2 ± 0.01	1.07	46.6 ± 0.01	1.7 ± 0.01
	Coarse roots	3.5 ± 0.01	0.1 ± 0.01	0.51	17.6 ± 0.01	0.7 ± 0.01
	Total	**42.9 ± 3.05**	**20.2 ± 2.02**	**1.33**	**246.2 ± 17.9**	**169.5 ± 17.12**

Fig. 4.15(a): N-stock in different components of bamboo in 5 districts of Mizoram. Values are means ± 1SE

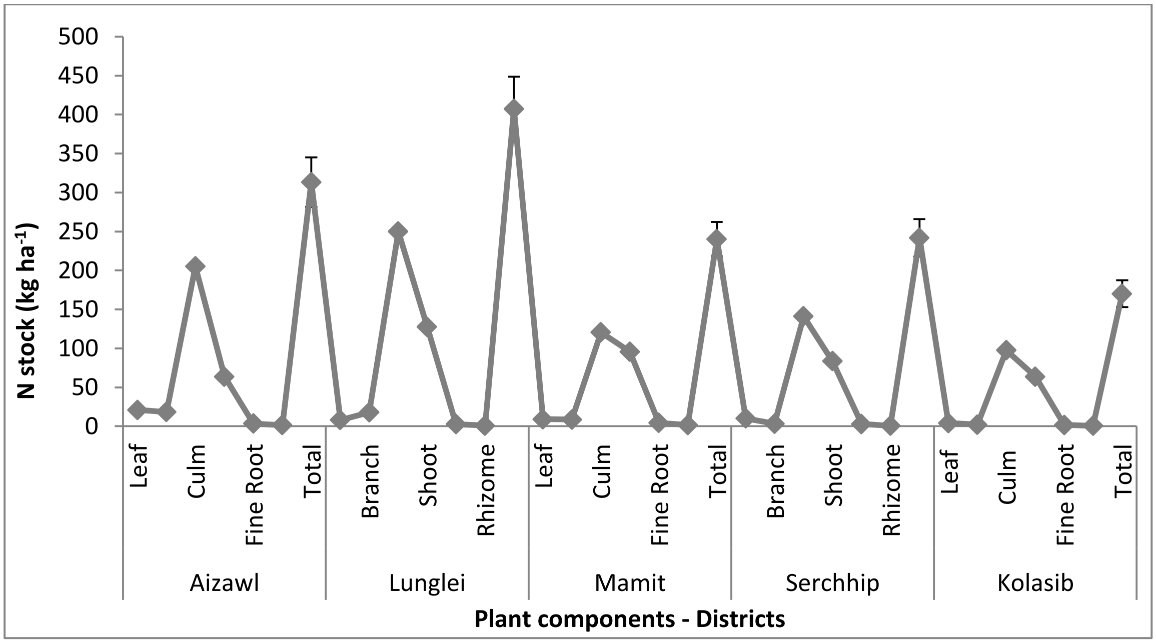
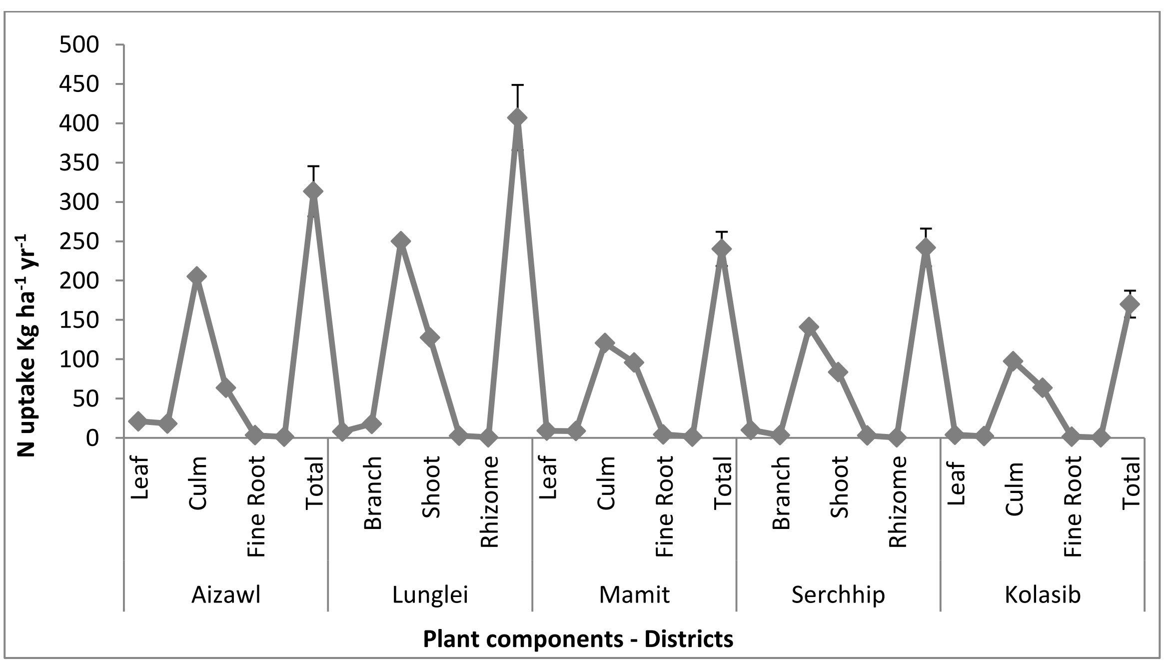


Fig. 4.15(b): N-uptake in different components of bamboo in 5 districts of Mizoram. Values are means ± 1SE



4.8 Species wise C and N sequestration

In the present study, three dominant indigenous bamboo species of the state viz., *Melocanna baccifera, Bambusa tulda* and *Dendrocalamus longispathus* were given more priority. As compared to other indigenous species, their distribution in the state is wider, and more cosmopolitan. Their versatility in different aspects plays a major role in the ecology as well as the socio-cultural lives of the people. The *Melocanna baccifera* alone occupies 90% of the total growing stock of the state.

Biomass estimation of the three elite species showed that thick walled bamboo has higher biomass accumulation. *Bambusa tulda* has the highest biomass (75.03 Mg ha^{-1}) followed by *Melocanna baccifera* (50.2 Mg ha^{-1}) and *Dendrocalamus longsipathus* (45.3 Mg ha^{-1}).

Table 4.6: Total stocks (kg ha^{-1}) and annual uptake (kg ha^{-1} yr^{-1}) of C and N in three major species of bamboo of the state. Values are ± SE

Species	*B. tulda*	*D. longispathus*	*M. baccifera*	Mean
C %	43.3	43.2	42.3	42.9 ± 0.3
C Stock (Mg ha^{-1})	33.2	19.9	22.1	25.1 ± 4.1
C uptake (Mg $ha^{-1}yr^{-1}$)	19.5	10.9	12.7	14.3 ± 2.6
N %	1.3	1.3	1.3	1.3 ± 0.01
N Stock (kg ha^{-1})	646.1	389.3	436.2	490.5 ± 78.9
N uptake (kg $ha^{-1}yr^{-1}$)	360.2	205.3	242.0	269.2 ± 46.7

The most common species of bamboo in the state, *Melocanna baccifera* has the potential of sequestering 12.7 Mg ha^{-1} yr^{-1} of C and 242.03 kg ha^{-1} yr^{-1} of N, which accounted for 29.46% and 29.9 % of the total C and N sequestration by the three species, respectively. *Bambusa tulda* has the highest potential for sequestering C and N, 45.2% and 44.6% respectively. *Dendrocalamus longispathus*, another common species, sequester 25.3% and 25.41% C and N respectively (Table 4.6).

Fig. 4.16: C sequestration and C stock – Species wise. Line diagram represents C-uptake (Mg ha^{-1} yr^{-1}), bar diagram represents C stock (Mg^{-1} ha^{-1}).

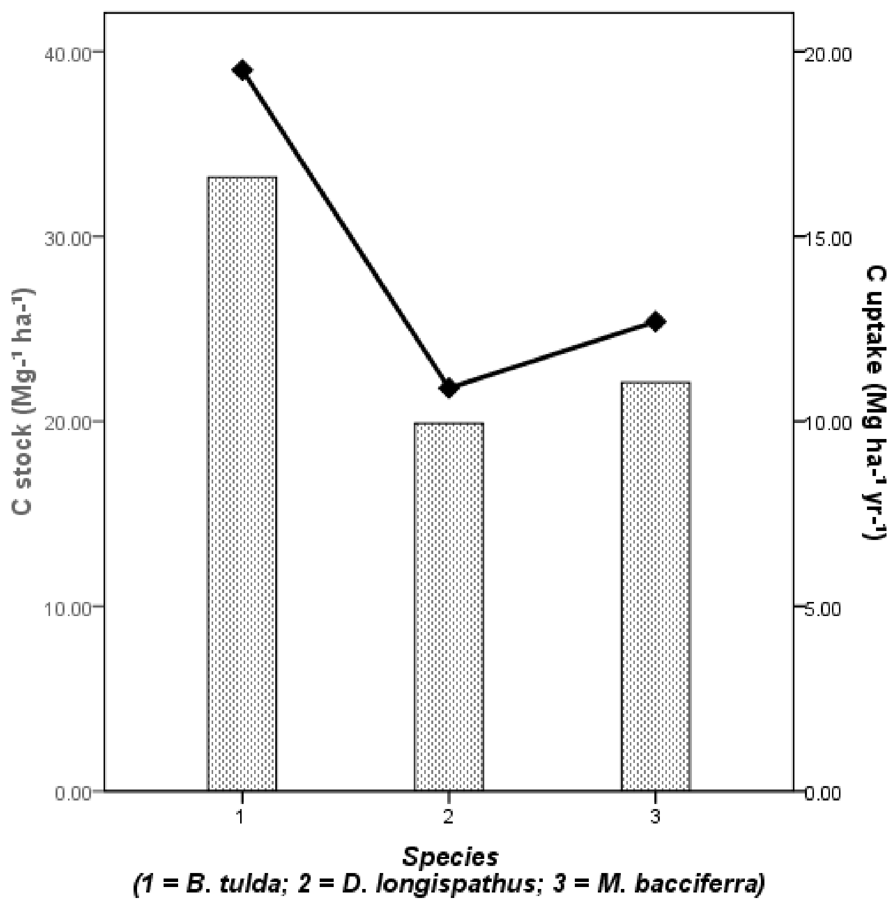
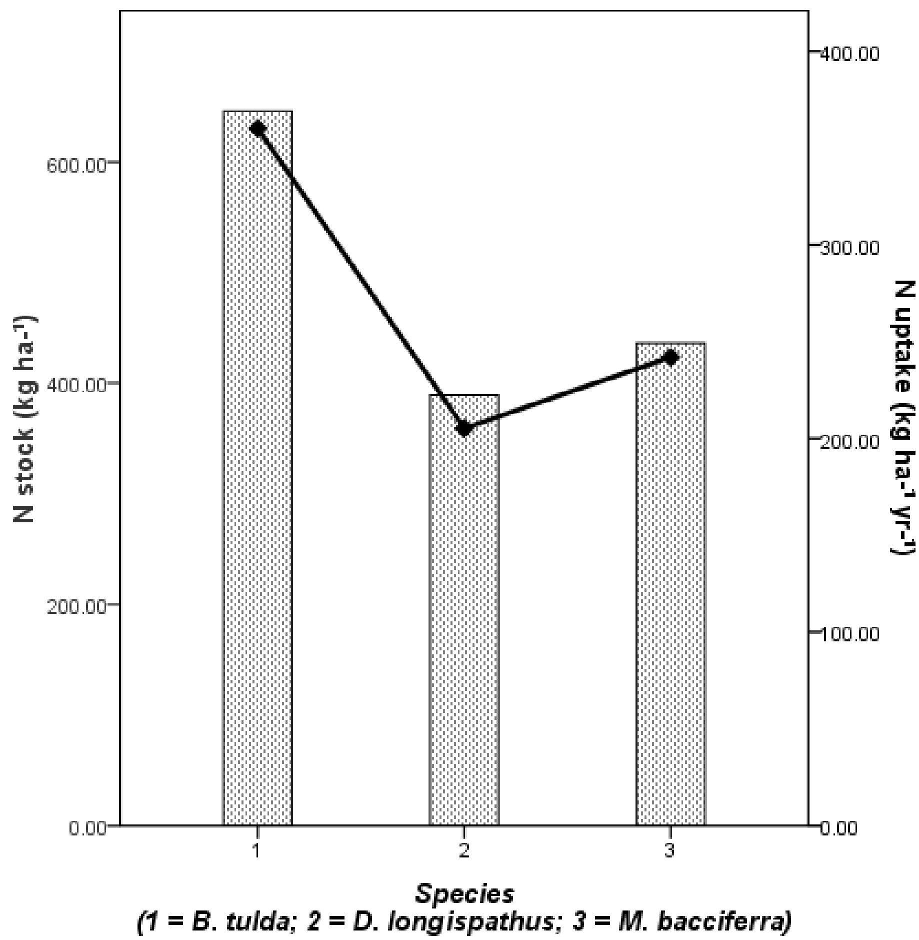


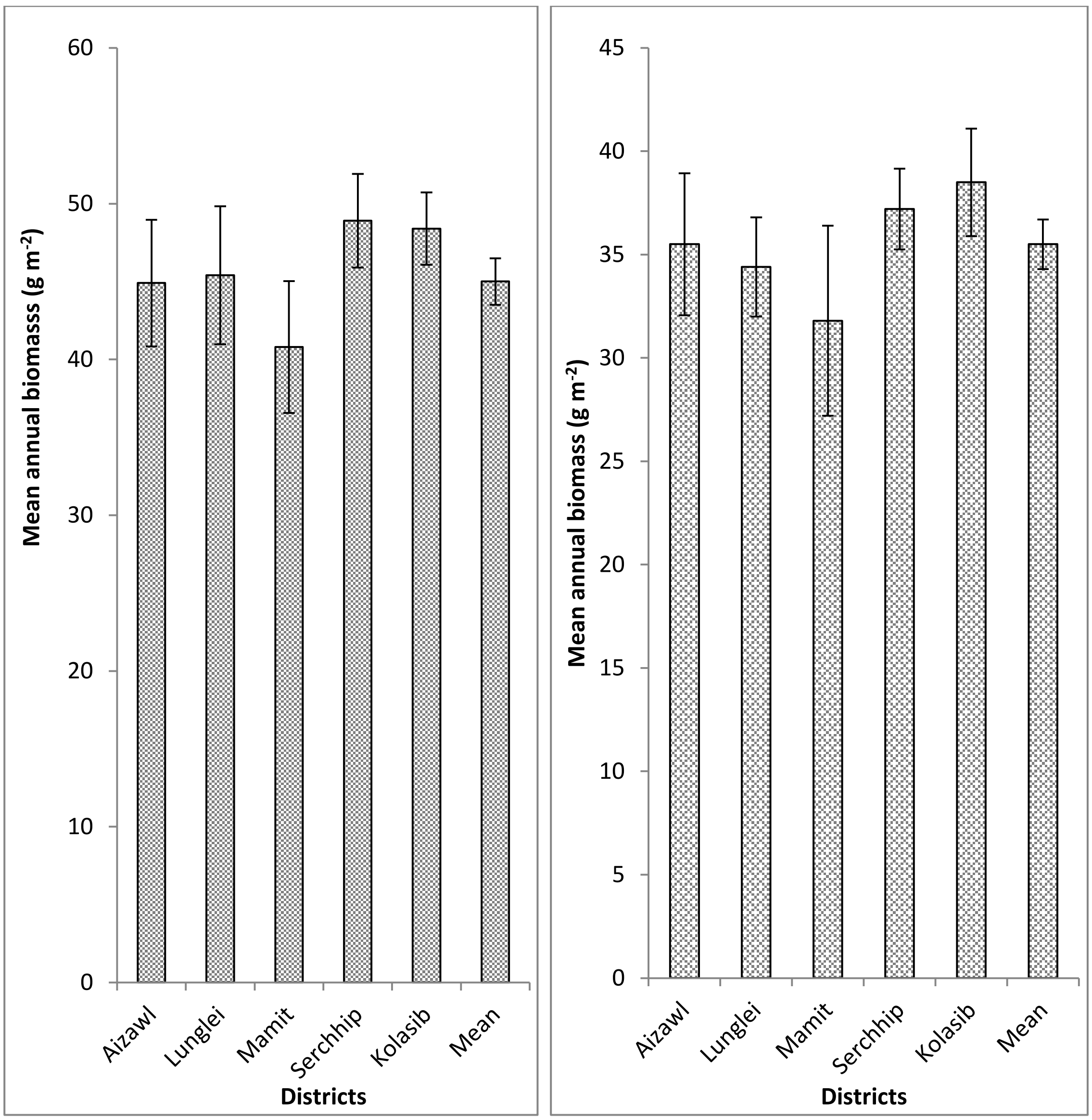
Fig. 4.17: N sequestration and N stock – Species wise. Line diagram represents N-uptake (kg ha^{-1} yr^{-1}), bar diagram represents N stock ($kg^{-1}ha^{-1}$).



4.9 Fine roots and coarse roots dynamics in bamboo ecosystems

The total belowground biomass of the study sites was 24.36 Mg ha^{-1}. They were collected bi-monthly from the study sites, up to a depth of 30 cm. The net production of the fine roots in the studied area is 23.1 gm^{-2} yr^{-1}, whereas the net production of the coarse root is 19.1 gm^{-2} yr^{-1}. The production ranges from 39.4 gm^{-2} yr^{-1} to 58.0 gm^{-2} yr^{-1} throughout the year, in the case of fine roots. Mean annual coarse roots production were in the range 29.9 gm^{-2} yr^{-1} to 45.2 gm^{-2} yr^{-1}. Wide seasonal variation was observed in the production of roots ($p < 0.05$). The decline of production in the dry period was mainly due to the decrease in live roots fraction.

Fig. 4.18**:** Mean annual biomass of fine roots (gm^{-2} yr^{-1}) in the studied areas



(A) Fine Roots **(B) Coarse Roots**

Table 4.7: Seasonal variation and annual mean values of fine root and coarse biomass ($gm^{-2}\ yr^{-1}$) in the studied areas.

FINE ROOTS (gm^{-2} ± SE)						
	Aizawl	**Lunglei**	**Mamit**	**Serchhip**	**Kolasib**	**Mean**
Jul-12	37.83 ± 0.6	35.82 ± 1.3	32.06 ± 0.5	45.84 ± 1.2	45.39 ± 0.01	39.4 ± 2.7
Sep-12	61.22 ± 0.3	62.08 ± 0.8	59.44 ± 0.9	49.12 ± 1.0	58.07 ± 2.2	58.0 ± 2.3
Nov-12	47.89 ± 0.1	52.19 ± 0.01	40.69 ± 1.3	62.63 ± 0.3	51.27 ± 0.01	50.9 ± 3.6
Jan-13	37.36 ± 0.6	37.27 ± 0.01	34.27 ± 1.7	43.22 ± 0.2	41.85 ± 0.2	39.3 ± 1.6
Mar-13	49.89 ± 0.2	49.16 ± 2.2	44.94 ± 0.1	50.31 ± 0.2	45.38 ± 0.1	39.1 ± 1.2
May-13	35.52 ± 0.01	35.78 ± 0.4	33.52 ± 0.4	42.61 ± 0.2	48.31 ± 0.01	38.8 ± 2.8
Mean	**44.9 ± 4.06**	**45.4 ± 4.43**	**40.8 ± 4.23**	**48.9 ± 3.01**	**48.4 ± 2.33**	**45.0 ± 1.5**
COARSE ROOTS (gm^{-2} ± SE)						
	Aizawl	**Lunglei**	**Mamit**	**Serchhip**	**Kolasib**	**Mean**
Jul-12	38.84 ± 0.3	36.67 ± 0.22	33.69 ± 0.74	46.51 ± 1.32	40.28 ± 0.07	39.2 ± 2.1
Sep-12	49.78 ± 0.42	44.23 ± 0.24	53.12 ± 0.7	33.70 ± 0.51	44.95 ± 0.12	45.2 ± 3.3
Nov-12	34.95 ± 0.4	36.34 ± 0.4	30.72 ± 0.04	33.52 ± 0.4	46.32 ± 0.04	36.4 ± 2.7
Jan-13	28.17 ± 0.45	30.02 ± 0.32	23.23 ± 0.1	36.40 ± 0.41	31.81 ± 0.18	31.3 ± 2.2
Mar-13	34.71 ± 0.24	29.88 ± 0.03	23.49 ± 0.35	36.93 ± 1.12	31.85 ± 0.36	30.9 ± 2.3
May-13	26.41 ± 0.35	29.40 ± 0.15	27.05 ± 0.3	36.01 ± 0.7	35.66 ± 0.4	29.9 ± 2.1
Mean	**35.5 ± 3.43**	**34.4 ± 2.4**	**31.8 ± 4.6**	**37.2 ± 1.95**	**38.5 ± 2.6**	**35.5 ± 1.2**

Maximum fine roots production was observed in the post-rainy season i.e. September; during which 21.15% of the annual mean production was achieved; whereas, minimum fine roots were produced during the dry season. The production during the month of March 149.6 g m^{-2} was merely 14.1% of the annual mean production (Table 4.8).

The same trend goes with the coarse roots as well. Maximum coarse roots were produced during month of September, 21.2% of the annual mean production was attained, whereas the production was minimum during the dry season. The production during the month of March was 14.05% of the annual mean production.

The mean annual production is the highest in the forests of Mamit district, for both the fine roots and the coarse roots, accounting up to 21.2% and 21.7% respectively. The production in the Aizawl district amounted to 19.7% fine roots and 19.9% coarse roots.

Table 4.8: Root production (fine root and coarse root) of bamboo (gm^{-2} yr^{-1}) in the different bamboo forests.

Components	Fine roots (gm^{-2} yr^{-1})	Coarse roots (gm^{-2} yr^{-1})	Total (gm^{-2} yr^{-1})
Aizawl	25.7	23.37	49.07
Lunglei	26.3	14.83	41.13
Mamit	27.38	29.89	57.27
Serchhip	20.02	12.99	33.01
Kolasib	16.22	14.51	30.73
Mean	**23.124**	**19.118**	**42.2**

4.10 Litterfalls:

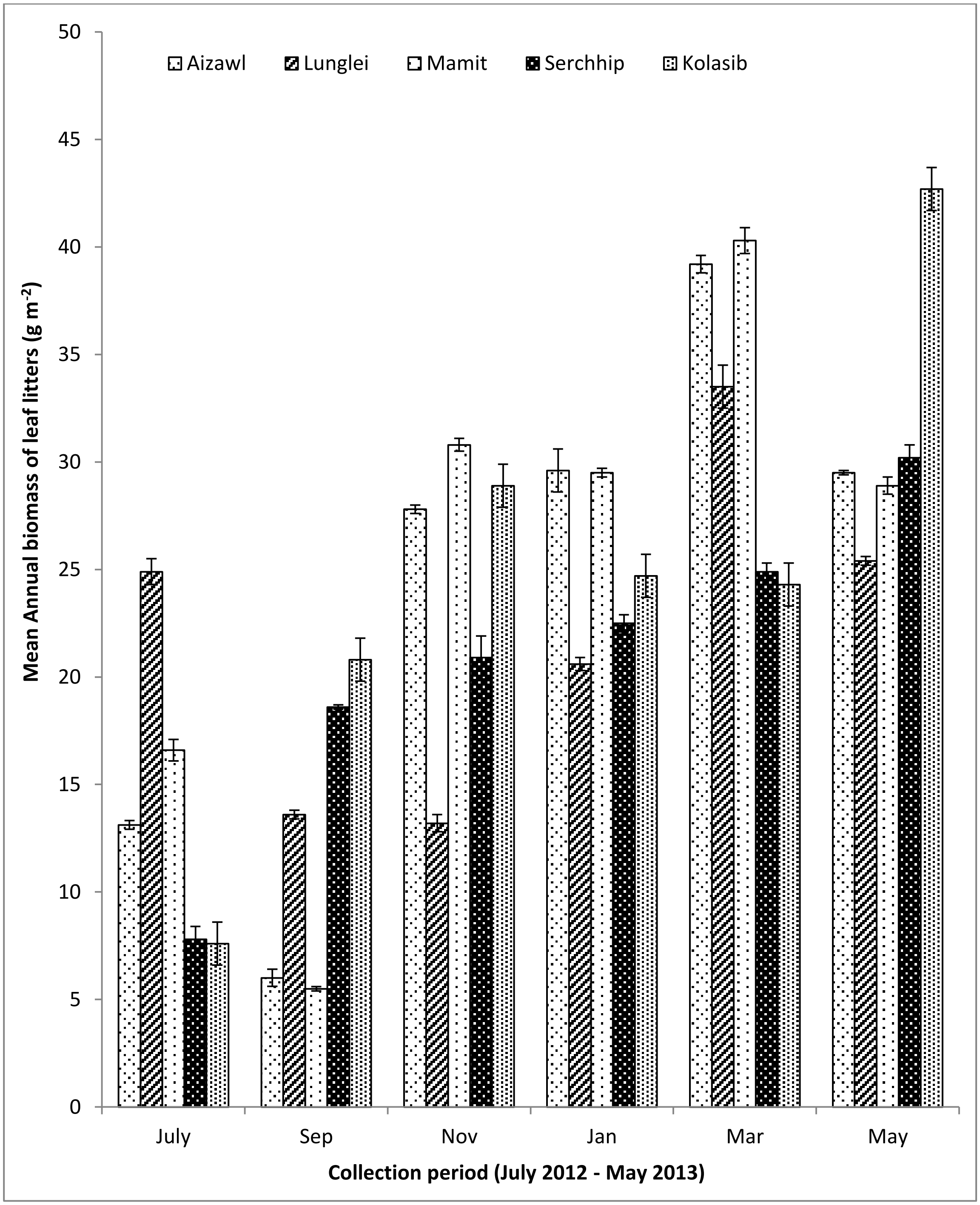
The total annual organic matter input to the soil through litterfall in the five districts was 702.12 gm^{-2}. Out of the five districts, the bamboo forests of the Lunglei district contributed 21.59% of the litterfalls, followed by the Kolasib district accounting to 21.24%. Aizawl, Mamit and Serchhip contributed 20.68%, 18.69% and 17.79% respectively. Data's were collected bi- monthly from each site.

The total leaf fall at each site peaked at the dry season i.e., March to May; maximum litterfalls were observed in these two months (Fig. 4.18). The mean seasonal values of leaf-fall in each district was statistically significant ($p < 0.05$).

Table 4.9: Bi-monthly changes in the amount (g m^{-2} yr^{-1}) of litterfalls in bamboo forests of five districts of Mizoram. Values are means ± SE.

Date	Aizawl	Lunglei	Mamit	Serchhip	Kolasib
Jul-12	13.12 ± 0.2	24.9 ± 0.6	16.57 ± 0.5	7.78 ± 0.6	7.61 ± 0.4
Sep-12	6.01 ± 0.4	13.56 ± 0.2	5.52 ± 0.1	18.6 ± 0.13	20.81 ± 0.2
Nov-12	27.8 ± 0.2	13.22 ± 0.4	30.79 ± 0.3	20.92 ± 1.0	28.9 ± 1.2
Jan-13	29.61 ± 1.0	20.57 ± 0.3	29.53 ± 0.23	22.52 ± 0.4	24.7 ± 0.61
Mar-13	39.16 ± 0.4	33.48 ± 1.0	40.27 ± 0.6	24.9 ± 0.4	24.31 ± 0.8
May-13	29.5 ± 0.1	25.43 ± 0.2	28.87 ± 0.4	30.16 ± 0.6	42.7 ± 1.0
Total	**145.2 ± 5.0**	**131.16 ± 3.2**	**151.55 ± 0.5**	**124.88 ± 3.1**	**149.03 ± 4.7**

Fig. 4.19: Bimonthly variations in the amount ($gm^{-2}yr^{-1}$) of leaf litterfall (from July 2012 - June 2013) in different bamboo forests. Values are means ± SE.



4.11 Turnover rate (*k*)

The turnover rate (*k*) of the litter mass on the floor was 0.90 and 0.58, respectively, for leaves and woods. Annual turnover rate (*k*) was 0.79 in Kolasib district followed by Aizawl (0.75), Serchhip (0.73), Lunglei (0.72), Mamit districts (0.71) of Mizoram. Litter turnover time (year) ranged between 1.05 and 1.26 for leaves and 1.61 and 1.92 for wood in different districts of Mizoram (Table 4.10).

Table 4.10: Turnover rate (*k*) and turnover time (year) of C and N in bamboo forests of Mizoram

Litter	Aizawl	Lunglei	Mamit	Serchhip	Kolasib	Total
Turnover rate (*k*)						
Leaves	0.92	0.90	0.80	0.94	0.95	4.51
Wood	0.59	0.54	0.62	0.52	0.62	2.89
Mean	0.75	0.72	0.71	0.73	0.79	0.79
Turnover time (year)						
Leaves	1.09	1.11	1.26	1.06	1.05	5.57
Wood	1.69	1.85	1.61	1.92	1.61	8.70
Mean	1.39	1.48	1.43	1.49	1.33	1.33

4.12 C and N stocks in the bamboo forests of Mizoram

4.12.1 C and N stock in the soils (up to 30 cm depth) of bamboo forests of Mizoram

The estimated total C stock in the soils (up to 30 cm depth) of the bamboo forests in Mizoram was 41.5 Tg. Maximum soil C stock was recorded from the Mamit district and minimum from Champhai district each having 10.5 Tg and 1.9 Tg respectively (Table 4.11).

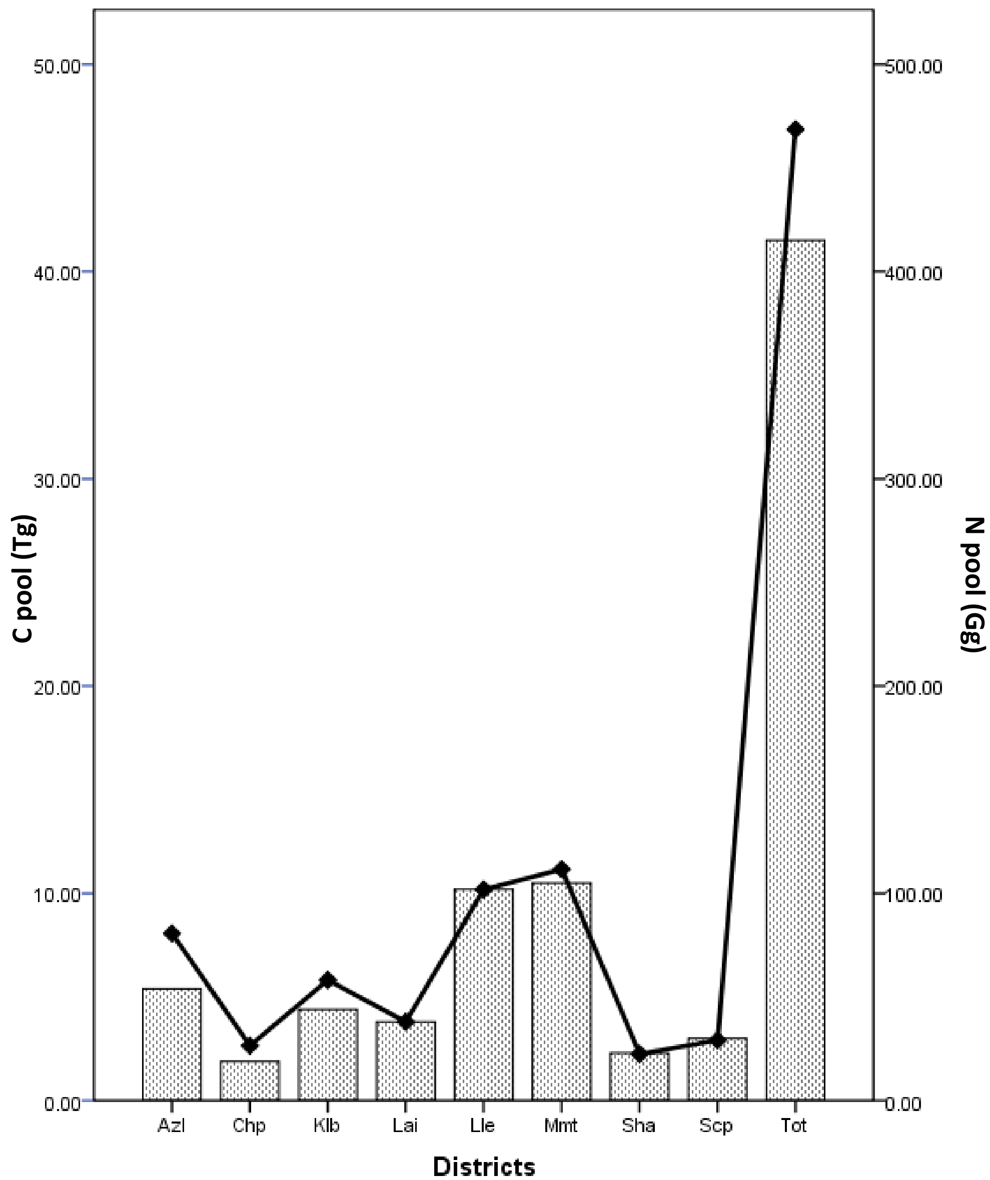
The total N pool in the soil of bamboo forests of the state was 468.6 Gg. Maximum was recorded from Mamit (111.9 Gg) and minimum from Saiha district (22.5 Gg).

Table 4.11: Soil C and N stock of bamboo forests in different districts of Mizoram

District	Bamboo Area (ha)	C Stock (Mg ha^{-1})	C pool (Tg)	N stock (kg ha^{-1})	N pool (Gg)
Aizawl	92769	58.11	5.4	870.11	80.72
Champhai	34568	55.01	1.9	766.51	26.50
Kolasib	66180	65.83	4.4	879.5	58.21
Lawngtlai	73079	52.64	3.8	520.65	38.05
Lunglei	195659	52.64	10.2	520.65	101.87
Mamit	159800	69.22	10.5	698.88	111.68
Saiha	43204	52.64	2.3	520.65	22.49
Serchhip	43908	51.91	3.0	662.9	29.11
TOTAL	**709167**	**N/A**	**41.5**	**N/A**	**468.62**

(Where 1Gg = 10^9 g; 1Tg = 10^{12}g)

Fig 4.20: Soil C and N stock (Mg ha^{-1}) of bamboo forests in different districts of Mizoram. C stock was represented by bar and the N was represented by line diagram



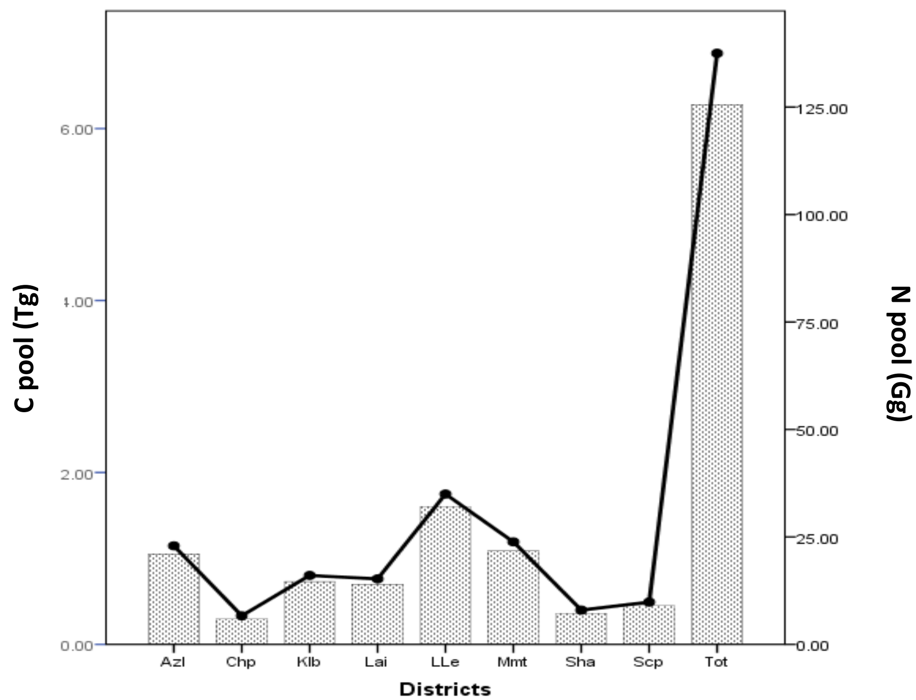
(Azl = Aizawl; Chp = Champhai; Klb = Kolasib; Lai = Lawngtlai; Lunglei = Lle;Mmt = Mamit; Sha = Saiha; Scp = Serchhip; Tot = Total)

4.12.2 C and N stock in bamboo forests of Mizoram

The estimated C stock in the bamboo vegetation (product of mean concentration of C and estimated dry weights) of the state was 6282464.8 Mg. Lunglei district has the highest amount of C stock; having 1598199.4Mg (8.17 Mg ha^{-1}); whereas minimum C stock of 304327.5 Mg (8.8 Mg ha^{-1}) was estimated from Champhai district (Table 4.12).

The estimated total N stock was 137.5 Gg for state of Mizoram. Lunglei district has the highest N stock in the bamboo amounting to 35 Gg. Minimum N stock was recorded from Champhai district (6.7 Gg).

Fig 4.21: Vegetation C and N stock of bamboo forests of different districts of Mizoram. C stock was represented by bar and the N was represented by line diagram



(Azl = Aizawl; Chp = Champhai; Klb = Kolasib; Lai = Lawngtlai; Lunglei = Lle; Mmt = Mamit; Sha = Saiha; Scp = Serchhip; Tot = Total)

Table 4.12: Estimated value of vegetation C- and N- pools of bamboo forests in different district of Mizoram

District	Bamboo Area ha	No. of culms (millions)	Growing Stock (Green Wt) Tg	Dry Weight Tg	C pool Tg	C stock Mg ha^{-1}	N pool Gg	N stock Kg ha^{-1}
Aizawl	92769	1020.94	4.0	2.4	1.0	11.3	22.9	247.1
Champhai	34568	296.64	1.2	0.7	0.3	8.8	6.7	192.7
Kolasib	66180	714.1	2.8	1.7	0.7	11.1	16.0	242.3
Lawngtlai	73079	678.49	2.7	1.6	0.7	9.5	15.2	208.5
Lunglei	195659	1557.85	6.1	3.7	1.6	8.2	35.0	178.8
Mamit	159800	1061.89	4.2	2.5	1.1	6.8	23.8	149.2
Saiha	43204	355.27	1.4	0.8	0.4	8.4	8.0	184.7
Serchhip	43908	438.66	1.7	1.0	0.5	10.3	9.9	224.4
MEAN	N/A	765.48	3.0	1.8	0.8	9.3	17.2	203.5
TOTAL	**709167**	**6123.84**	**24.0**	**14.5**	**6.3**	**N/A**	**137.5**	**N/A**

*N/A = Not applicable

(Primary Data: Bamboo Area, No. of culms, Growing Stock courtesy of MIRSAC, 2009)

Chapter - V

DISCUSSIONS

5.1 Physico-Chemical Properties of Soil

Variations in the amount of C and N in soils of different bamboo forests in Mizoram were influenced by the concentrations of these elements in the soil. Increases in the organic matter (Johnston, 1986) and nutrient availability in the soil has been found to be affected by number of factors like cation exchange capacity (Schnitzer and Khan, 1978), climate, natural vegetation, texture and cropping and crop sequence (Brady, 1984), amount of precipitation and temperature (Jenny, 1941). Soil in the cooler climate generally has more soil organic matter than in warmer climate (Brady, 1984; Bot and Benites, 2005) because of retarded decomposition in the cool region due to less activity of soil microorganisms. Tropical soils have low accumulations of soil organic matter because of higher rates of decomposition, weathering, leaching and often nutrient impoverished (Jordan, 1985; Singh, 1989; Tripathi and Singh, 1994). Bamboos growing in essentially oligotrophic systems in Vindhyan region have been reported to efficiently use the available nutrients and builds up relatively fertile soil around the clump bases because high turnover rates of large quantities of fine roots produced near the clump bases (Tripathi *et al.*, 1999).

Low bulk densities of soil were observed in the forest of the Mamit and Kolasib districts, which corresponds to the high C and N pool. Higher organic matter content in the soil decreases the soil bulk density by increasing the soil porosity and fertility. The increase in the amount of C and N stock in the present study was due to increase in the levels of soil C and N rather than the bulk density. The differences in soil C and N pool in the study sites were also mainly due to the differences in vegetation it harbours; the study sites with the higher C and N concentrations were dominated *Dendrocalamus longispathus* and *Bambusa tulda* respectively; whereas forests dominated by *Melocanna baccifera* generally has lower C concentration (Table 4.1)

5.2 Standing Crop Biomass

Determination of biomass is an important aspect that gives an idea of plant growth performance at the site. Among various factors like diameter at breast height (DBH), height and DBH against height of bamboo were the major parameters contributing to the amount of biomass in bamboo individuals. Even though the height of the plant also shows positive almost same or a weak correlation, hence, DBH measurement and prediction was suggested because it is much easier to record with accuracy in comparison to height, which is inaccurate and less precise to record in the field. Density of culm is another major factor influencing the biomass per unit area. Among the three major species of the state, *Bambusa tulda* possessed the highest biomass per unit area. Bamboo attains its maturity in size in one growing season, in terms of height and girth. Biomass accumulation and production depends upon the production and rates of maturity of new shoots.

Different components of the bamboo contributed to the biomass, each with a different capacity. In the present study, 57.6% of the mean aboveground biomass was contributed by the culms, 23.9% by the leaves, and 23.15% by the branches and 23.9% by the new shoots (current year shoots); whereas 56.2% of the belowground biomass was produced by the fine roots and the remaining 43.8% by the coarse roots (Table 4.4). The allocation of biomass in the different components of the bamboo, in the present study, is comparable to that of Tripathi and Singh (1991), which were 55%, 24% and 24% by the culms, branches and leaves respectively.

5.3 Pools and fluxes of C

Vegetation plays an important role for C sink by using of the atmospheric CO_2 as the source of C (Negi *et al.*, 2003). C fixation varied widely in different species depending on the capacity of the species to sequester C from the atmosphere and the fertility of soil along with climatic conditions (Korner, 1993; Bot and Benites, 2005). After the implementation of the Kyoto Protocol accumulation of C in vegetation and soil of terrestrial ecosystems has become an important aspect of the study to mitigate the increasing level of CO_2 in the atmosphere. Amongst the world's forests, tropical forests have the largest potential to mitigate climate change through conservation of existing C pools (e.g. reduced impact logging), expansion of C sinks (e.g. reforestation, agroforestry), and substitution of wood products for fossil fuels (Brown *et al.*,2000). The potential of bamboo to sequester high amount of C per unit area per unit time can make the bamboo based agroforestry system a possible prototype for Clean Development Mechanism (CDM) type projects in tropical regions particularly northeast where the bamboo is abundantly available (Nath and Das, 2012).

C sequestration potential of bamboo is directly proportional to the regeneration of new shoots, annually. Annual production of new shoots and maturity of new shoots are the two important factors affecting the C sequestration potential and C stock of bamboo. Congestion in the clumps, over exploitation of culm and new shoots deteriorate the C sequestration and stock; whereas, value addition of bamboo products enhances the sequestration capability and prolonged the C storage.

5.4 Pools and fluxes of N

Savanna dominated by bamboo represents a derived ecosystem characterized by lower levels of nutrient storage in soil and vegetation (Singh *et al.*, 1989). However, the bamboo ecosystems of the northeast India showed a higher nutrient storage as compared to the savanna (Rao and Ramakrishnan, 1989). In fact, the N pool in the vegetation of the present study (169.5 – 404 kg ha^{-1}) is comparable to the uptake by bamboo ecosystem of the north-east India (439 kg ha^{-1}) as reported by Rao and Ramakrishnan (1989); whereas the N uptake (114 – 206 kg ha^{-1} yr^{-1}) by the vegetation of the bamboo savanna (Tripathi and Singh, 1991) is comparable to the present study (273.5 kg ha^{-1} yr^{-1}). In the present study, gross uptake and pools of N were higher in the *B. tulda* dominated forests and lower in the *D. longispathus* dominated forests.

5.5 Litterfalls and accumulation

Site productivity is the primary factor influencing the production of litter, but other properties of environment also affects the litter production in the forests (Bray and Gorham, 1964; O'Neill and De Angelis, 1980). In tropical rain forest, highest amount of litterfall occurred in the dry periods (Edward, 1977; Tanner, 1980; Bruijnzeel, 1984; Proctor *et al.,* 1989) or in the wettest periods (Steinhardt, 1979; Weaver *et al.,*, 1986). In bamboo savanna of the Uttar Pradesh, India, litterfall was highly seasonal and about three-fourth of the leaf litterfall occurred during the cool-dry period of the year (Tripathi and Singh, 1991).

The higher tendency of leaf fall in bamboo during winter is possibly related to a combination of decreased temperature and lowered soil moisture during the period (Tripathi and Singh, 1995). Investigating the role of plant water stress on the leaf fall, Wright and Carnejo (1990) have concluded that soil moisture availability and plant water status could not be the proximal cue for litterfall in majority of tropical species; however, it may rarely be the proximal cue for few species and hence the response varies from species to species.

5.6 Litter turnover rate and turnover time

Using exponential models of litter breakdown, Jenny *et al.,* (1949) and Olson (1963) and many others have calculated coefficient based on litterfall input and the standing crop of litter that reflect the turnover of organic matter on the floor. However, a few authors also suggested that k estimates must be considered as imperfect indices of the turnover of standing crops of litter (Spain, 1984).

In the present study, the turnover rate ranges from 0.71 to 0.95. The litter turnover time (*k/*t) was in the range of 1.05 to 1.92. The mean residence time of nutrients in detritus can be used as an index of the rate of nutrient cycling in an ecosystem (Rodin and Bazilevich, 1967).

5.7 Comparison with other ecosystems

The outputs of the present study were compared with other related research work adapted through literatures.

5.7.1 Soil C and N

Bamboo ecosystem is relatively poorer than the natural forest soil. In the present study, the C accumulation was computed to a range of 51.9 – 69.2 Mg ha^{-1} which is comparable to the a report by Singh *et al.,* (1982) from the Tropical Moist Deciduous forest of Dun Valley, Uttar Pradesh (51.6 – 65.1 Mg ha^{-1}). The N accumulation in the present study (521 – 880 gm^{-2}) is considerably higher than that reported by Tripathi and Singh (398–438 gm^{-2}) this may attributed due to suitable climatic conditions of the region such as high rainfall and temperature that favour the organic matter production and its accumulation in soil organic matter.

5.7.2 Mean annual biomass and biomass production

A comparison and compilation of bamboo biomass in several bamboo ecosystems are summarized in Table 5.1. The aboveground biomass in the present study was comparable to the bamboo biomass reports from Assam (21.7 – 76.6 Mg ha^{-1}), however with a narrower range, with a slightly higher values. Rao and Ramakrishnan (1989) reported a much lower *Dendrocalamus hamiltonii* biomass (0.8–6.2 Mg ha^{-1}) from Meghalaya.

The annual production of biomass (20.2–49.5 Mg ha^{-1} yr^{-1}) by *Bambusa tulda*, *Dendrocalamus longispathus* and *Melocanna baccifera* in the present study is comparable with that of the bamboo stand of Philippines (20 – 45 Mg ha^{-1} yr^{-1}) as reported by Uchimura (198); whereas a much lower net production of biomass was reported the Indian dry tropical region by Tripathi and Singh (1991).

Table 5.1: Comparative account of aboveground biomass (Mg ha^{-1}) and net production (Mg ha^{-1} yr^{-1}) of various bamboo ecosystems.

Species	**Locality**	**Biomass (Mg ha^{-1})**	**Production (Mg ha^{-1} yr^{-1})**	**Authors**
Bamboo stand	Phillipines	-	20 – 45	Uchimura (1978)
Phyllostachys edulis	Central Taiwan	79.3*	16.1*	Kao and Wang (1988)
Dendrocalamus hamiltonii	Meghalaya, India	0.8 – 6.2	-	Rao and Ramakrishnan (1989)
Arundinaria falcata	Nainital, India	22.4 – 29.2*	7.3 –14.7*	Pandey (1990)
D. strictus	Mirzapur, India	3.2 –26.0 11.2*–36.0	1.8 – 8.0 7.8*– 15.7	Tripathi and Singh (1991)
P. edulis	Japan	165.1	-	Isagi (1994)
Bambusa balcooa	Thirssur, Kerala, India	54 –499	12.1	Kumar *et al.* (2005)
B. cacharensis, *B. vulgaris*, *B. balcooa*	Cachar, Assam, India	21.69–76.55	-	Nath and Das (2012)
B. tulda,*M. baccifera*, *D. longispathus*	Mizoram, India	43 – 84.1	20.2 –49.5	Present study

**including above and below ground*

5.7.3 C sequestration by vegetation

Increase in annual productivity corresponds to an increase in forest biomass and hence higher carbon sequestration potential (Lal and Singh, 2004). The rate of C sequestration in the present study (8.9 – 22.7 Mg ha^{-1} yr^{-1}) is comparable to that reported by Nath and Das (2012) from the bamboo based home gardens of Cachar, India (18.93 – 23.55 Mg ha^{-1} yr^{-1}). The broader range in the case of Mizoram may be attributed to the inclusion of more diverse species of bamboo; to be precise, single species each from three different genera were accounted.

The rates of C sequestration by several multipurpose trees of agroforestry systems of Banswara, Uttarakhand were relatively low (1.8 – 3.1 Mg $ha^{-1}yr^{-1}$) as compared to the present study. A report from bamboo based home gardens of Barak Valley, Assam indicated lower rates of C sequestration (1.2 – 1.5 Mg ha^{-1} yr^{-1}). Management systems relating to harvesting, density of the clumps and land use system is another factor determining the rates of sequestration. Harvesting of bamboo resulted in greater annual allocation of dry matter to the belowground parts (Tripathi and Singh, 1991).

Table 5.2: Comparative account of Rates of C sequestration (Mg $ha^{-1}yr^{-1}$) and net production (Mg ha^{-1} yr^{-1}) of various bamboo ecosystems.

Species	**Locality**	**C Sequestration (Mg $ha^{-1}yr^{-1}$)**	**Authors**
D. strictus	Mirzapur, India	6.3 – 8.7	Tripathi and Singh (1991)
Multipurpose trees (MPT)	Banswara, Uttarakhand, India	1.8 – 3.1	Maikhuri*et al.* (2000)
Medicinal plantation	Haryana, India	3.1 – 11	Gera and Chauhan (2010)
B. cacharensis, B. vulgaris,B. balcooa	Barak Valley, Assam, India	1.2 – 1.5	Nath and Das (2011)
B. cacharensis, B. vulgaris,B. balcooa	Cachar, Assam, India	18.9 – 23.6	Nath and Das (2012)
B. tulda, *M. baccifera*, *D. longispathus*	Mizoram, India	8.9 – 22.7	Present study

Chapter VI

BAMBOO ECOSYSTEM: SYNTHESIS AND IMPLICATION

Biomass and productivity measurements in bamboo ecosystem were carried out in the past to more biomass production for various uses. However, in recent years, many ecological services of bamboos to the humanity has been acknowledged, which has led to refine quantification methodologies and to set bamboo-specific examples in climate change mitigation where the information is limited due to untapped potential of bamboo for climate mitigation measures.

Productivity data of bamboo will be resourceful in assessing the potential of the bamboo forest of Mizoram in rendering ecological services to the humanity that can be profitably en-cashed as carbon credit through carbon trading to the developed nations. Improvement in the bamboo biomass production through proper management plans by considering the ecosystem level strategies for dry matter production and nutrient allocations would be important criterions in selecting species suitable for afforestation and reforestation programmes in particular locations (Tripathi, 1991).

This chapter provides a general synthesis of information collected regarding the dry matter productivity and edaphic conditions of bamboo ecosystems in different districts of Mizoram. The notable functional traits and ecological strategies involved in bamboo forests, including the management protocols are discussed.

6.1 Role of bamboo in C offsetting

After the implementation of Kyoto Protocol for C offsetting or controlling greenhouse gas emissions through Clean Development Mechanism (CDM) that allows industrialized nations to earn C credit through implementing afforestation/ reforestation programmes in developing nations and trading between countries and companies for establishing C credit exchange in the business world (Mondal and Sachdev, 2012). Therefore, the potential for sequestering C in agriculture and forestry sinks to generate C-credits has received increased attention by legislative bodies, government and non-government organizations, private firms, farm managers, and universities over the last few years (Williams *et al.*, 2009). Plantations typically combine higher productivity and biomass with greater annual transpiration and rainfall interception thereby making it prominent tools for C sequestration (Jackson *et al.,* 2005)

The focus of forest-based ecosystems for sequestering C has largely been on creating permanent stores of C on defined areas of land with a single payment to the forest owner for the C (Bisby, 2009). With their ratification of the Kyoto Protocol, many countries have established forests on previously non-forested land with the view of offsetting greenhouse gas emissions (Whitehead 2011). C sequestration through *Paraserianthes falcataria* based agroforestry systems in Philippines was found to be more cost effective than pure tree-based systems (Shively *et al.,* 2004). Bamboo has an important role to play in reducing pressure on forestry resources. For instance, in China, since nationwide logging bans of certain forests came into effect in 1998, bamboo has increasingly been seen as a possible substitute to timber and has entered many markets traditionally dominated by timber. The high amount of C sequestration potential per unit time can make the bamboo based agroforestry system a feasible prototype for Clean Development Mechanism (CDM) type projects. Besides that, such agroforestry system can provide other environmental services like improved land and water quality and hence improved microclimate (Nath and Das 2009). The successful use of bamboo in different product lines, ranging from furniture and flooring to paper and packaging demonstrates the high potential for bamboo as a more sustainable alternative material in production of many products (Yiping *et al.,* 2010).

So far, C accounting methodology for afforestation with bamboo has been developed and adapted in China. In order to meet the objective of implementing bamboo C sequestration projects in all 38 International Network for Bamboo and Rattans (INBAR) member countries, INBAR and partners (CGCF, ZAFU and RISF-CAF) are in the process of developing a global version of the existing and accredited "C Accounting Methodology for Afforestation with Bamboo in China" (Kuehl and Yiping, 2012). C accounting methodology will ensure that C accounting methodologies comply with national forest definitions and other national laws and regulations in the respective countries.

C offsets are quantified and sold in Mega gram (Mg) of C dioxide equivalent (CO_2e). The present study revealed that an average of 14.7 Mg ha^{-1} of C has been sequestered annually by the bamboo alone. In terms of C credit, it can be expressed as 14.7 C credit in a unit area (ha) per year. The estimated C stock, in bamboo, for the whole state is 6.3 Tg C at the rate of 98 Mg C ha^{-1}.

6.2 Clump management in bamboo ecosystems

Climate change mitigation and adaptation services cannot be fulfilled by establishing new plantations through afforestation or reforestation programmes alone rather it also requires broader approach to optimize management of existing bamboo resources that can help ensure bamboo groves (Kuehl and Yiping, 2012). Further, clump management is an important factor to enhance the productivity of a bamboo as well to maintain the health of the clumps. Moreover, bamboo congestion, one of the most serious problems in clumps management, along with damage by human agency should be taken care to optimize bamboo production. Clumps congestion in bamboos may occur as result of soil compaction, insufficient soil depth for too many Coarse rootss in a season (Kondas, 1982), cumulative effect of careless felling. As per recent report, in bamboo forests as many as 90% of the bamboo clumps are badly congested (Anon 2010a).

Possible remedies to overcome with the problems of congestions includes; (i) closing the area for grazing in case of soil compaction, (ii) mounding of heaping earth around the clump in order to influence the development of future Coarse rootss outwards that can effectively control requirement of soil depth, (iii) removing or harvesting of excess new shoots can effectively to control congestion, (iv) hacking and looping of top ends for fodder by grazers should be prohibited, (v) harvesting of culms should be cut as low as possible preferably just above the first node.

6.2.1 Felling of culms

Imposing and monitoring of proper felling rules to contractor or stakeholders. Felling rules and conditions are hardly followed rather they are normally averted, especially by the contractors to reduce the cost of harvesting (Anon 2010a). Harvesting of the culms from the periphery of the clumps is easier but deteriorates the outward development of Coarse rootss resulting in to congestion of clumps.

Harvesting is recommended in the dry season where almost all culms over 3 years or older can be removed from a clump by cutting them just above a node (about 20cm above the ground). Some of the younger ones should remain for further nourishment of the Coarse roots. In the growing season, selective removal of shoots that are going to create overcrowding would be beneficial. Healthy shoots with good diameter should be promoted which have potential to produce straight strong poles for timber use.

The proper maintenance of the clump not only improves productivity but also eases the job of the plantation worker. Clump management is partly a maintenance task and partly a result of harvesting. As a maintenance activity it involves removing unwanted culms to prevent clump congestion. This is particularly necessary with densely tufted species. It is sometimes necessary to sacrifice a few culms in order to allow for better shoot production in the clump.

Following clump management rules have been suggested by Salam and Deka (2007): Harvesting of mature culms may begin in the fourth year after planting. For sympodial bamboos, all culms of four years and older should be removed from the clump at the time of harvesting. In the case of *Melocanna baccifera*, culms mature after two years, and therefore all culms two years and older should be removed from the clump. Controlling the clump from rotting is necessary to promote the healthy growth of shoots and new culms. Attention should be placed on rotting in the stubs of culms that have been harvested. If rotting is apparent it is advisable to dig around the stub and completely remove it. Likewise rotting culms should be removed.

6.2.2 Harvesting of shoots

Growth of new shoots in a bamboo forest occurs as a result of transfer of the energy accumulated in culms through photosynthesis in the previous year (Magel *et al.*, 2005). The emergence of new shoots begins during the rainy season of the year after planting, however, seasonal variation is observed in the development of new shoots that varies from species to species. The number of shoots produced per clump also varies from species to species. It is best not to harvest new shoots developed from clumps below 3 years (Salam and Deka, 2007). A small amount of edible young shoots may be harvested in the third year of the plantation, i.e. two rainy seasons after planting.

Apart from the physical factor, development of new shoots is greatly influenced by the age of the clumps, harvesting procedure and intensity, density of culms and other management systems. Even though there is no clear cut system for age determination of bamboo, especially in natural forest, it was observed that shoots development is lower in aged clumps, as well as in highly congested clumps. It seems that clumps which were never subjected to harvesting of shoots tend to lose their productivity. Like all other grasses, thinning of culms is required to enhance the productivity. Removing of aged culms is required to give more space for the newly developed shoots and to sanitize the clumps from pest and diseases.

In India, domestic market for bamboo shoots is valued at ₹ 4.8 crores (Anon 2003). In Northeast India, consumption of bamboo shoots is largely restricted to tribal families. On the contrary, net C sequestration potential is expressed in terms of production of new shoots; therefore, harvesting regulations of bamboo shoots is the need of the hour. Proper management system of clumps should be developed for each species to enhance the productivity and to guarantee its availability to the locals.

6.3 Value addition

C sequestration refers to the prolonged storage of C in the biomass, without releasing it to the atmosphere. Bamboo culms of most species attain maturity after approximately 7 – 10 years, after which they deteriorate rapidly, releasing C from the above-ground biomass back into the atmosphere (Liese, 2009). Therefore, in a natural state, bamboo reaches a stable level of above ground C relatively quickly, where C accumulation through sequestration is offset by C release through deterioration of old culms. In order for the bamboo system to continue to be a net sink, C has to be stored in other forms, so that the total accumulation of C in a solid state exceeds the C released to the atmosphere (Yiping *et al.,* 2010). Prolonged sequestration of C is provided through a great variety of bamboo products that range from construction materials to pulp (Liese, 2009).

Comparisons between bamboo species and wood species is assume that there is an equal rate of conversion from living C to biomass (Yiping *et al.,* 2010). A number of factors may affect this assumption, amongst which the durability of products is of key concern. The longevity and durability of bamboo products may determine the C storage performance to a great degree. It is important to reduce by-products and waste and to produce durable bamboo products during bamboo processing, which in-turn is a way of maintaining the C in the bamboo itself. Processing technologies and innovations have greatly increased the proportion of durable bamboo products. Development and promotion of durable products sustain the longevity of C storage. Processing of bamboo into products with long life cycles, such as construction materials, panel products and furniture prolonged the C storage.

In Mizoram, value addition centre for bamboo and its products is another aspect of C sequestration. The State's Bamboo Development Agency (BDA), a Semi-Government enterprise take up the initiatives in promoting and assisting the bamboo based industries of the state. Under BDA, 25 units of industries were registered, majority of the industries are producing bamboo chips (12 Units) and eight units of bamboo composite board manufacturing Industries are doing in large scale. Other small scale industries are concentrating on production of incense stick, bamboo charcoal, bamboo vinegar and other handicrafts items (5 units).

Even though bamboo shoots harvesting is done in large scale, and the need for management protocol is discussed in the previous section (section 6.2.2), the state lacks food processing industry fully dedicated to processing of bamboo shoots. However, each household are well aware of processing the bamboo shoots for consumption; the drawback is, the lack of techniques in storing and preservation of the pre-processed shoots.

6.4 Bamboo plantation

Under National Bamboo Mission, the Mizoram Environment & Forest Department set up 27,853 ha bamboo plantations during 2007 – 2013. Major drawback of these plantations, however, is introduction of exotic species, which are neither superior to the native species. Under the state's flagship programme, New Land Use Policy, 5, 220 ha of bamboo plantations are being established. Apart from these Government co-ordinate plantations; several private owned bamboo plantations are available in the state. Inventorisation and evaluation of these plantations is required, so as to justify the C credit owned by the state.

To promote the importance of the state's richest natural resources, bamboo day is observed each year since 2012. The date however is declared each year. Awards for bamboo entrepreneurs were distributed, exhibition for bamboo based industries was organized, and in which entrepreneurs from in and outside the states participated. Seminars were also organized.

Chapter VII

SUMMARY AND CONCLUSIONS

1. The study was carried out in five administrative districts – Aizawl, Lunglei, Mamit, Serchhip and Kolasib, Mizoram. These districts cover a geographical area of ~ 12944 Km^2, having a bamboo area of ~ 5583 Km^2 and a growing stock of 18.8 Tg. The studied area represents >75% of the bamboo area of the state and 73 % of the growing stock of the state. The study sites had a mild winter, warm summer and heavy down pour during rainy season.
2. Sampling was done for analysis of soil C and N concentrations of bamboo forests from five districts of Mizoram. Soil samples were collected from three horizons up to 30 cm at 10 cm interval. Litter trap was laid in each site, and was collected after every two months interval. Density of the culms in each clumps were recorded for sympodial bamboos, while 10 m × 10 m plots were marked for the monopodial bamboo (*Melocanna baccifera*). Numbers of new shoots developed were also recorded for each clump within the permanent plots.
3. Biomass of bamboo was estimated by developing allometric equation for the diameter at breast height of the culm. The aboveground plant components categorized into three – culm, branches and leaves. Fresh weight was recorded for each component, sub samples were collected from each component and

were analysed for their physical and chemical properties. Belowground biomass was estimated from the coarse roots and the fine roots.

4. Bulk density of the soils ranged from 1.01 g cm^{-3} to 1.3 g cm^{-3}. Minimum was recorded from Mamit district, having a density of 1.01 g cm^{-3} whereas maximum (1.3 g cm^{-3}) was recorded from Aizawl and Lunglei District

5. The soil C pool ranges from 51.9 Mg ha^{-1} to 69.2 Mg ha^{-1}. Maximum soil C pool, 69.22 Mg ha^{-1} was recorded in Mamit district and minimum in Serchhip district (51.914 Mg ha^{-1}).The major differences in soil C pool in the study sites were mainly due to the differences in soil C content, bamboo species and other local climatic conditions. The C pool and the C concentration decreases with the increase in depth ($p<0.05 – 0.01$).

6. The soil N pool ranged from 52.1 kg ha^{-1} to 87.9 kg ha^{-1} witha mean of 72.6 kg ha^{-1}. Maximum soil N pool was recorded in Kolasib district and minimum in Lunglei district. The total N concentration was found to be the highest (0.3%) in Kolasib District and lowest (0.13%) in Lunglei District. The N pool and the N concentration decreases with the increase in depth ($p<0.05 – 0.01$).

7. The total above- and below-ground biomass of the study sites ranges from 43 – 84.1 Mg ha^{-1}. The difference in diameter at breast height (dbh) is the major factor contributing to the amount of biomass in each individual. Density of culm is one of the factors influencing the biomass per unit area.

8. Of the total aboveground biomass of the plant of the five districts, 57.6% was formed by the culms. The leaves, the branches and the new shoots contributed 23.9%, 23.15% and 23.9% respectively, to the biomass. 56.2% of the

belowground biomass was contributed by fine roots and the remaining 43.8% by coarse roots.

9. The C concentration in the plant parts (leaves, branches, culms, shoots and roots) ranges from 40% – 45%, whereas the N concentration ranges from 0.5% – 1.5%. Maximum concentration of C and N were observed in the culms and the leaves, respectively.

10. The C sequestration rates of the study sites ranged from 8.98 Mg $ha^{-1}yr^{-1}$ – 22.07 Mg $ha^{-1}yr^{-1}$ with a mean of 14.67 Mg $ha^{-1}yr^{-1}$. The bamboo forest of the Lunglei district has the highest C sequestration potential (22.07 Mg $ha^{-1}yr^{-1}$), whereas Kolasib district has the lowest potential (8.982 Mg ha^{-1} yr^{-1}). The mean difference between each district per plant component wise is significant at 5% ($p < 0.05$).

11. The N sequestration potentials of the bamboo forests of the studied sites were in the range of 169.5 – 406.4 kg $ha^{-1}yr^{-1}$at a mean of 273.5 kg $ha^{-1}yr^{-1}$. Bamboo forests of the Lunglei district have the highest N sequestration potential (406.38 kg ha^{-1} yr^{-1}), whereas Kolasib district has the lowest potential (169.473 kg ha^{-1} yr^{-1}) to sequester C.

12. Maximum amount of C sequestration is recorded from the culms (59.31%), whereas the leaves accounted for 1.96% of the sequestration which is lower than that by the branches (6.51%). Current year shoots sequestered 30.7%. The belowground components (fine roots and coarse roots) were accounted for 1.5% of the sequestration.

13. Maximum amount of N is being sequestered by the culms (59.6%), followed branch (8.58%) and leaves (3.83%). The new shoots or the current year shoots sequestered 31.8%. The belowground components were accounted for 1.53% of the sequestration. There is a statistically significant difference ($P < 0.05$) between the mean values among the different components of each sample.

14. *Bambusa tulda* has the highest potential for sequestering C and N, 19.46 Mg ha^{-1} and 360.2 kg ha^{-1}, respectively, which accounted for ~ 45% of the total sequestration. Among the sequestering potential of C and N, *Melocanna baccifera* was the next in order sequestering 12.68 Mg ha^{-1} yr^{-1} of C and 242.03 Kg ha^{-1} yr^{-1} of N, which accounted for ~30 % of the total C and N sequestration by the three species. *Dendrocalamus longispathus* was third in terms of C and N sequestration potential sequestering 19.94 Mg ha^{-1} and 205.25 kg ha^{-1}, respectively, which accounted for ~ 25 of the total sequestration potential of C and N by three bamboo species.

15. The total belowground biomass of the study sites was 24.4 Mg ha^{-1}. They were collected bi monthly from the study sites, up to a depth of 30cm. The net production of the fine roots in the studied area is 23.1 gm^{-2} yr^{-1}, whereas the net production of the coarse root is 19.1 gm^{-2} yr^{-1}. The production ranges from 39.4 gm^{-2} yr^{-1} to 58.0 gm^{-2} yr^{-1} throughout the year, in the case of fine roots. Mean annual coarse roots production were in the range 29.9 gm^{-2} yr^{-1} to 45.2 gm^{-2} yr^{-1}. Wide seasonal variation was observed in the production of roots ($p < 0.05$). The decline of production in the dry period was mainly due to the decrease in live roots fraction.

16. Out of the five districts, the bamboo forests of the Lunglei district contributed maximum i.e., 21.59% of the litterfalls, followed by the Kolasib district accounting to 21.24%. Aizawl, Mamit and Serchhip contributed 20.68%, 18.69% and 17.79% respectively.
17. The total leaf fall at each site peaked at the dry season (i.e. March to May); maximum litterfalls were observed in these two months. The difference in the litterfall in each district may be attributed to the physical factors like temperature, humidity and precipitation. Apart from the physical factors, age of the clumps (in the case of sympodial bamboos) and of the culms also play a vital role in terms of leaf litterfall. The mean difference of leaffall at each season in each district is significant at 0.05 levels ($p < 0.05$).
18. The turnover rate (*k*) of the litter mass was 0.90 and 0.58 for the leaves and the woods respectively, with a total turnover (*k*) of 0.75 in Aizawl district, 0.72 in Lunglei, 0.71 in Mamit, 0.73 in Serchhip, 0.79 in Kolasib. The turnover time (year) was 1.05 – 1.26 for the leaves and 1.61 – 1.92 for the wood.

Conclusions

The overall results indicated that the soil bulk density decreases with the increase in soil C and N content. Soil depth was inversely correlated with the concentrations of C and N in the soil. Soil characteristics have been found to be greatly affected by the species of bamboo growing in the site. For example, *D. longispathus* has been found to grow under high fertility soils, whereas *M. baccifera* has been recorded to grow under low fertility soils. It appears that the former species has more ameliorative effects on soil fertility than the later because bamboo a successional species found to grow on the degraded lands.

Bamboo biomass was more strongly predicted by the girth of the culms than its height and thus girth increment has stronger role to play in the biomass than the height which bamboo attained within a short interval of time. C and N pools and fluxes in the bamboo ecosystems are affected by species, its age, soil, climate and the density of culm. *B. tulda* has highest pools and fluxes of C and N whereas, the *D. longispathus* was lowest with respect to the pools and fluxes of C and N in the ecosystem.

In terms of C and N sequestration potential, bamboo is found to be the highest compared to other forest area nearby. This is because of the high seasonality of fine roots in bamboo ecosystem that adds C and nutrients to the ecosystems to speed up the process of sequestration. In addition, bamboo makes efficient use of nutrients through internal cycling, and conserved them by storing in the belowground parts, particularly, coarse roots.

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PHOTO PLATE 1

Pic 1: Bamboo forest. Some patches were cleared for Jhumming

Pic 2: Coarse roots of bamboo (*M. baccifera*)

PHOTO PLATE 2

Pic 3: Monopodial bamboo (*M. baccifera*)

Pic 4: Congestion in bamboo clumps (a) *D. longispathus* (b) *B. tulda*

PHOTO PLATE 3

Pic 5: Sympodial bamboo - Aged and congested clump of *D. longispathus*

Pic 6: Sympodial bamboo - *B. tulda*

PHOTO PLATE 4

Pic 7: Regeneration in bamboo (a) *D. longispathus* (b) *M. baccifera*

Pic 8: Bamboo shoots: (a) *D. longispathus [Inset - harvested shoots]*
(b) *B. tulda [Inset - harvested shoots]*

PHOTO PLATE 5

Pic 9: Carbon sequestration by bamboo through value addition
(a) Bamboo furnitute (b) Bamboo earrings (c) Bamboo bangles/bracelets [inset - rings]
(d) Household items (e) Miniature model of traditional Mizo baskets and household items
(f) Bamboo hair clips (g) Bamboo composite - flooring