2.1. **Bamboo - ecology, distribution and growing stock**

Bamboo is an ancient woody grass widely distributed in tropical, sub-tropical and mild temperate zones. There are about 1,200 species in some 90 genera. Bamboo taxonomy poses certain difficulties for science, owing to its long flowering cycles, thus taxonomist still debate the total number of species and genera.

Bamboo occurs naturally in four of the five continents (except Europe) of the world and is found mainly in the wide belt between the Tropics of Cancer and Tropics of Capricorn, as well as the adjacent temperate and subtropical areas. The distribution of bamboo extends from 51° N latitude in Sakhalin island of Japan to 47° S in South Argentina. The altitudinal range is from just above the mean sea level to 4,000 m. The occurrence of herbaceous bamboos has never been reported from an altitude above 1,500 m. Seetalakshmi and Muktesh Kumar (1998) mentioned that bamboos are distributed in the country varying from sea level to altitude of 3600 m. Bamboo prefers region of high rainfall of about 1,200 mm to 6,350 mm. But the species like *Dendrocalamus strictus* is found even in drier area of Rajasthan. Bamboo prefers different optimum temperature, humidity, soil types, physiographic situations, etc., depending upon species for best performances. According to Tewari (1992) bamboos are found in moist deciduous, semi evergreen, tropical, sub tropical and temperate forests.

Bamboos, also popularly called ‘tree grasses’ attains height upto 46 m (e.g., *Dendrocalamus giganteus*) in China and upto 30 cm in diameter (e.g., *D. sinicus*). However, diversity is not lacking as in species like the American genus *Raddiella swallen* are quite delicate and only a few centimetre in height. In India *Sinarundinaria densiflora* from South India is hardly 1 m in height and only about a cm in diameter (Naithani, 2010).
2.1.1. Growing stock

While extent of area of bamboo forests is difficult to estimate because of the often sparsely distributed nature of bamboo clumps and co-dominance of some bamboos with forest species, productivity on a global basis is even harder to ascertain. Quantifying the harvest of bamboo shoots as a food commodity is also fraught with error, but recently the Food and Agriculture Organization of the United Nations (FAO, 2005) estimated that 3.5 million tonnes (Mt) of non-wood forest products are harvested annually in Asia for food, of which the majority are in China and most being for bamboo shoots. This value concurs with reports that China consumes 1.2–1.6 Mt of bamboo shoots annually (Vantomme et al., 2002; Collins and Keilar, 2005). But the utilization of bamboo is more than just about harvesting bamboo for shoots it is also about harvesting bamboo culms (or poles) as substitute materials for timber, either processed for fibre or in the natural form, and it is about provision of ecosystem services (Zhou et al., 2005) such as carbon sequestration, erosion containment, integrity of watershed hydrology and local climate regulation. On a global scale, the gross value of world trade in bamboo was estimated few years ago to be anything between US$2.5 billion and US$7.0 billion (Hunter, 2003), albeit from a relatively small number (c. 50) of the 1,500 known bamboo species. The export value of all bamboo products from China was estimated to be US$1.1 billion in 2007 (Global Wood, 2008). The ecosystem services afforded add considerably to the dollar value of bamboo, but are largely not quantified. A database detailing trade in bamboo (and rattan) is managed by the International Network for Bamboo and Rattan (INBAR). FAO and INBAR have launched a systematic assessment of global bamboo resources and their dynamics based on the analysis of the latest inventory data from bamboo growing countries and also remote sensing analyses (Lobovikov et al., 2007).

As per the report of Lobovikov et al., (2007); Asia remains the richest continent with about 65% of total world bamboo resources with 24 million ha out of about 36.8 million ha worldwide.
African countries reported 2.8 million ha (about 7%) and Latin America about 10.4 million ha (about 28% of global bamboo area). The global coverage which is 1% of total global forest area is considerably greater than 14 million ha estimated by Fu and Xiao (1996) and probably reflects improved sensing technology developments that allow for greater coverage of the earth’s surface and the greater vigilance in including bamboo, as well as a real increase in bamboo plantation.

Monopodial species normally prevail in the sub-tropics and mild temperate regions while sympodial bamboos are much more common in the tropics. At the global level sympodial bamboo dominates, although in Asia, the share of monopodial bamboos has increased from 28 to 30% in the last 15 years due to the extensive planting in China of *moso* ("Mao Zhu" in Chinese meaning “hairy bamboo”) bamboo (*Phyllostachys pubescens*). In Asia, the major bamboo producing countries are India (almost 11.4 million ha) and China (over 5.4 million ha) followed by Indonesia (2.0 million ha) and Lao People’s Republic (1.6 million ha). India accounts for roughly half the total area of bamboo reported from Asia. According to 2005 estimate (Lobovikov *et al.*, 2007), the other dominant Asian countries having bamboos are Myanmar, Vietnam, Malaysia, Thailand, Philippines and Japan covering about 0.86, 0.81, 0.68, 0.26, 0.17 and 0.15 million ha respectively.

In India and Sri Lanka the bamboo coverage accounts for 10% of total forest cover and in India out of 11.4 million ha the share of natural bamboo is 8.434 million ha and the rest is planted bamboo. As per 2001 estimate *Moso* bamboo alone covers about 3 million ha which is about 2% of the total Chinese forest area (Fu, 2001).

Within the 2.7 million ha of bamboo coverage in Africa, Nigeria with 1.59 million ha has 14% bamboo bearing forest followed by Ethiopia (0.85 million ha i.e., 6.5%), Tanzania (0.128 million ha i.e., 0.4%) and Kenya (0.124 million ha i.e., 3.5% of bamboo bearing forest).

Among the Latin American countries Brazil, Ecuador and Peru reported 9.3, 0.9 and 0.19 million ha of bamboo area respectively covering 3.2% of their total forest area. However, bamboo is known to exist in other countries in the region as well including Ecuador (0.009 million ha),
Argentina, Bolivia, Colombia, Costa Rica, Mexico, Paraguay, Panama, Guate Mala, Honduras, El Salvador, Nicaragua and the Caribbean islands (Fan et al., 2006; Takahashi, 2006; Lobovikov et al., 2007). The most reliable export estimate is of 11.0 million ha of bamboo area in the region (Londoño, 2001).

As per Indian State Forest Report, Forest Survey of India, MoEF (Anon., 2011), the total bamboo bearing area in India is estimated to be 13.96 million ha. Arunachal Pradesh heads the list with 1.60 million ha followed by Madhya Pradesh (1.3 million ha), Maharashtra (1.13 million ha) and Orissa (1.03 million ha).

Although most bamboo resources grow naturally, greater attention has been paid in recent years to the establishment of planted bamboo. Approximately 30% of the total area of bamboo in Asia is planted. Planted bamboo receives a great deal of attention in China. The share of planted bamboo from 1990 to 2000 increased from 27% to 35% and this figure is higher than in any other country. The area covered by moso bamboo (P. pubescens) is 3.71 million ha contributing 69.4% while other bamboos cover 1.67 million ha with a share of 30.6%. Total bamboo area in China increased from 3.04 million ha to 5.38 million ha from 1976 to 2008 with annual increase of 100 thousands ha/year since 1990 which is almost 2 times the annual increase during 1980s. (Yue, 2012). As per 2001 estimate moso bamboo coverage was about 3 million ha i.e., 2% of the total Chinese forest area (Fu, 2001).

India reported nearly 3 million ha of planted bamboo which is approximately 25% of total bamboo resources. China and India contributed over 80% of the total growing stock of the prominent eight Asian countries. The growing stock as per latest information ranges from 4.9 tonnes per ha in Indonesia to 35.2 tonnes per hectare in the Philippines with an average of 16.04 tonnes per ha. Though coverage of Chinese bamboo is far less than that of India, the former has much more growing stock (30 tonnes per ha) than India (11 tonnes per ha) (Lobovikov et al., 2007).
In India, the total bamboo growing stock is around 80.428 Mt within 8.96 million ha coverage (Rai and Chauhan, 1998; Naithani, 2008). Of this 67.3% is contributed by clump forming bamboos and the rest by non clump formers. The NE states have 66% of the total growing stock of the country. Assam is at the top of the states in terms of percent growing stock of 16% followed by Manipur (14%), Mizoram (14%), Arunachal Pradesh (12%), Madhya Pradesh (including Chhattisgarh 12%), Orissa (7%), Meghalaya (6%), Nagaland (5%) and Maharashtra (5%). Species wise contribution of growing stock is in the decreasing order as *Dendrocalamus strictus* (45%), *Bambusa bambos* (*B. arundinacea* 13%), *Dendrocalamus hamiltoni* (7%), *Bambusa tulda* (5%), *Bambusa pallida* (4%) and others 6%. According to the Indian State Forest Report, Forest Survey of India, MoEF, 2011 (Anon, 2011) total number of culms at the national level has been estimated to be about 23,297 million out of which percentage of green sound, dry sound and decayed has been estimated as 79%, 16% and 5%, respectively. In Jharkhand, where the present study undertaken, total forest area is 2.36 million ha (29.2% of total geographical area) and 14.51% of this is under prominent natural bamboo stands. The growing stock of Jharkhand has been estimated to be about 9.0 tons per ha and at least 3.0 tons per has could be harvested annually. The dominant species is the *D. strictus* with occasional *B. bambos* and very rarely *Gigantochloa albociliata* (Nath et al., 2012a, 2013). About 14.51 % of total forest in Jharkhand is covered with bamboo, mainly *Dendrocalamus strictus* (>99%) and *B. Bambos* (<1%) The other bamboo species are *Gigantochloa albociliata and Dendrocalamus sericius*. From homesteads of the state, 10 species have been reported covering 1.55 % of total geographical area. The dominant species being *Bambusa nutans* (84.58%) **followed by D. strictus** (11.92 %) *B. bambos* (2.26%) (Krishnamurty, 2010; Nath et al., 2012a, 2013).
2.1.2. Species distribution.

Bamboo is able to adapt to a wide variety of ecosystems and climatic conditions. Diversity of bamboo has been addressed in many studies and in various countries and regions (Lobovikov et al., 2007). According to Sharma (1980), Soderstrom (1985) and Upreti and Sundriyal (2002) bamboo is spread in over 1,250 species under 75 genera in the world whereas Ohrnberger and Goerrings (1985) mentioned approximately 110 genera and 1,010-1,400 species.

China has the highest bamboo biodiversity in Asia, with over 500 species, followed by Japan, India, Indonesia, Myanmar and Malaysia, each with more than a hundred species. Among other Asian countries, nearly 237 species are found in Japan, 90 species in Myanmar (Burma), 55 species in Philippines, 50 species in Thailand, 44 species in Malaysia, 31 species in Indonesia, 30 species in Nepal and 30 species in Sri Lanka (Sharma, 1980). Presently there are 62 species found in Philippines comprised of 21 endemic (13 climbers, 8 erect) and 41 introduced (Virtucio, 2009.). So far 9 genera and 33 species of bamboo have been recorded in Bangladesh (Banik, 2000).

According to Remualdo (2006), about 80% of the world bamboo resources are in Asia. China is the leading country with 39 genera of bamboos with around 500 species and a plantation area of 5.0 million ha. However, some discrepancies were noted in the data presented in the literature and the reports. Ohrnberger (1999) reported 626 species in China versus 500 in the country report, and 84 species in Japan versus139 in the country report. According to the latest information (Yue, 2012) there are about 39 genera and more than 590 species in China with 5.38 million ha of pure bamboo forest which accounts for 25% of the bamboo area in the world. According to him, 7 genera and 103 species represent monopodial bamboo, 15 genera and 192 species of sympodial, 9 genera and 107 species of amphipodial and 8 genera and 196 species of other group. Out of 5.38 million ha area covered by bamboo, contribution of moso bamboo is almost 69.4% (3.71 million ha) and the rest (1.67 million ha or 30.6%) is covered by other bamboos.
Latin America is the richest region with 20 genera and 429 species within American continent in terms of diversity and number of woody bamboo species distributed from 27° N in Mexico to 47° S in Chile. Among these only one species *Arundinaria gigantea* found in North America but not recorded from Latin America. In Latin America, Brazil has maximum bamboo biodiversity with 134 species followed by Venezuela with 68 species, Colombia with 56 species, Ecuador has 42 species and Peru with 48 species (Fan *et al.*, 2006, Takahashi, 2006). In Central America, Costa Rica is the most diverse country with 39 species followed by Mexico 35 species, Panama 21 species, Guatmala 17 species, Honduras and El Salvador with 11 species each and Nicaragua with 9 species. There are 36 species out of 4 genera found in the Caribbean and West Indies with richest diversity in Cuba.

African countries have the lowest diversity of bamboo species. Bamboo resources of Ethiopia are comparatively richer and 67% of African bamboo resources are found in this country (Tadesse, 2006). The United Republic of Tanzania reports four native species, followed by Uganda, Malawi and Zambia. The greater bamboo biodiversity has also been recorded from eastern Africa around Lake Victoria, and in Southern Africa, including Zambia and Zimbabwe. Kenya has about 1,50,000 ha of bamboo forests, partly pure and partly in mixture with trees and shrubs. Kenya has both indigenous (*Arundinaria alpina*) and introduced exotic species (Ongugo *et al.*, 2000, Kibwage, 2006). Rawanda has very limited natural bamboo resource with two indigenous species are *Arundinaria alpina* and *B. vulgaris*. In the recent past 11 species have been introduced successfully (Bonavventure, 2006, Sigu, 2006). Madagascar is a special case. It has 33 bamboo species, including 32 native and one introduced pan-tropical species, *Bambusa vulgaris*. This species is found mainly near villages and along rivers. Endemism of bamboo in Madagascar reflects its long isolation from continental Africa and its unique evolutionary path (INBAR, 2005).
Ohrnberger (1999) listed an additional 25 countries with at least one bamboo species. These are Angola, Benin, Burundi, Central African Republic, Comoros, Côte d’Ivoire, Eritrea, the Gambia, Ghana, Guinea, Guinea Bissau, Mozambique, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Bahamas, Dominica, French Guiana, Guadeloupe, Jamaica, Martinique and the United States Virgin Islands.

There are many reports regarding number of genera and species of India. According to Seetalakshmi and Muktesh Kumar (1998) there are 128 species under 18 genera known from India. According to the latest report from INBAR (Anon., 2005) India is having 205 species belonging to 23 genera. However, Sharma (1980) and Upreti and Sundriyal (2002) reported 136 species under 23 genera and notable among these are *B. bambos* and *D. strictus*. These occur all over the country as a component of tropical, dry and moist deciduous forests. According to Bahadur and Jain (1981), there are 113 species belonging to 22 genera.

India is reported to be the largest producer of bamboo in the world after China with area of about 8.96 million ha and out of these nearly 28% falls in the North Eastern states (Naithani, 2010). In the NE region of India, bamboo diversity is quite rich, with about 63 species belonging to 15 genera (Biswas, 1988). However according to Bhatt *et al.*, (2005a) the NE Himalayan region represents 58 species belonging to 16 genera.

Rai and Chauhan (1998) elaborated on the percentage of bamboo species in different states and on the growing stock. In Himachal Pradesh, Madhya Pradesh and Maharashtra *Bambusa* spp. and *D. strictus* are dominant. In Andhra Pradesh, Bihar (including Jharkhand) and Uttar Pradesh the main species are *B. bambos* and *D. strictus*. *Melocanna baccifera* is widely distributed in Assam (40%), Manipur (94%), Meghalaya (46%), Mizoram (93%) and Tripura (92%). *D. strictus* is a main species in Rajasthan, Gujarat (56%) and Karnataka (63%). *D. hamiltonii* is widely present in the states of Arunachal Pradesh (29%), Assam (60%) and Nagaland (54%); *B. tulda* in Arunachal
Pradesh (32%) and Nagaland (25%) while *B. pallida* is 37% in Arunachal Pradesh and 13% in Nagaland. *B. bambos* is present in Gujarat (44%), Karnataka (34%) and Orissa (24%).


2.2 Use of bamboo.

Earliest reference to use of bamboo reported by Kurz( 1876) According to him no plant is known in the tropical zone which could supply to man so many technical advantages as the bamboo. The report says regarding various use of bamboo during the period in Indian and Malay subcontinent. The strength of the halms, their straightness, smoothness, lightness combined with hardness and greater or less hollowness, the facility and regularity with which they can be split; the different size, various length and thickness of the joints makes them suitable for numerous purpose to serve which other material would require much labour and preparation. The uses outlined are (i) paper making (ii) house construction (iii) temporary shelter either by native or traveller (iv) bamboo bridges and railings (v) living hedges (vi) bamboo for construction of triumphal arches and posts (vii) furniture (viii) Chinese mason used for white washing brushes made of thin a bamboo slips (ix) fitted for yokes of cattle, axle and springs of the smaller carts. (x) bamboo loops for weeding (xi) walking sticks (xii) baskets (xiii) use as textile plants (xiv) rafts (xv) candle stick (xvi) obtaining fire(xvii) making knives (xviii) carrying poles (xix) ornaments (xx) medicinal virtues
(xxi) religious purposes (xxii) educational purposes (xxiii) ornamental purposes and landscape gardening. Sharma (1980) outlined uses of bamboos for sprayers, ropes, tholepins, masts, sails, net floats, basket fish traps, awnings, food baskets, beds, blinds, bottles, bridges, brooms, food, lanterns, umbrella handles, fans, brushes, chains, chopsticks, combs, drogues, dustpans, paper, pens, nails, pillows, tobacco and hookah pipes, anchors, fishing nets, fishing rods, flagpoles, hats, ladles, lamps, musical instruments, mats, tubs, caulking materials, scoops, shoes, stools, tables, tallies, traps, joss sticks, back scratchers, walls, buildings, walking sticks, lance staves, thatching and roofing, loading vessels, trays, bows and arrows, water and milk vessels (chungas), hedges, furniture, agricultural implements, fodder, fuel, floats for timber, trellises, flues, handicrafts, sledges, toys, pipes, cooking utensils, tool handles, polo mallets, stabilizers for haystacks, coffins, cart yokes, scaffolding, ladders, containers, stakes, tiles, seed drills, slats, ornamentals, cordage, wrappers, shuttles and afforestation. Nearly 80 paper mills of India depend wholly or partly on bamboos. In Japan, even the twigs and branches are converted into brooms and exported. In the Philippines nearly 80% of the bamboos are used for construction and for rural endeavours.

Tewari (1992) described the consumption pattern of bamboos in India : pulp (35%), housing (20%), non residential (5%), rural uses (20%), fuels (8.5%), packing including baskets (5%), transport(1.5%), furniture (1%), other wood working industries (1%), other including ladders, staff, mats etc. (3%).

Suri and Chauhan, (1984) described important bamboo species and their uses : Drepanostachyum falcatum (basketwork, fishing rods, hooks pipes), Thamnocalamus spathiflorus (Pipes, mats and basket making), Arundinaria racemosa (roof construction and making for house), Indocalamus wightianus (mating), Bambusa bambos (Rafters, house posts, ladders tent poles, shafts of tongas, mat and basket making, scaffoldings, chicks, etc. besides pulping. Seeds and shoots are used as food, B. balcooa (pulping), B. tulda (building material, scaffolding and roofing, mats and baskets, paper making, tender shoots as food), B. polymorpha (construction works and for thatching and
roofing), *B. vulgaris* (furniture, toys, cages and construction works, scaffolds and for roofing, paper making), *Cephalostachyum pergracile* (building, mat making, fishing rods, etc.), *Dendrocalamus giganteus* (building and for masts of boats, the culm when cut into sections can be used as water buckets and boxes), *D. hamiltonii* (Paper manufacture, construction works, basket making, mats, furniture, agriculture implements, tool handles, paper and rayon manufacture), *Gigantochloa macrostachya* (matting and basket work), *Melocanna baccifera* (building and basket work), *Ochlandra travancorica* (Agriculture implements & tool handles, paper pulp temporary huts and thatching), *O. scriptoria* (mats and basket making besides paper pulp), *Pseudoxytenanthera ritcheyi* (tent poles, walking stick, baskets and umbrella handles), *Gigantochloa rostrata* (building huts and basket work besides paper making) and *Schizostachyum polymorphum* (baskets, umbrella handles and walking sticks).

There is 1500 different documented traditional use of bamboo (Shrestha 1999). 300 companies engaged around the world in production of various bamboo based products. (Xuhe, 2003).

**New generation bamboo products:** The production of bamboo culms in China changed little from 1978 to 1990, but significantly speeded up during the next 20 years due to the industrial utilization of bamboo, especially from 2000. In China, bamboo industry has reached a annual production value of 13.8 billion US$ and provides employment opportunities for over 5.6 million people directly. The production of bamboo floorings and bamboo based panels in China reached 39.4 million m$^2$ and 3.59 tons respectively in China. The bamboo mat panels find its value-added applications fields, such as concrete forming templates and decking for trucks and containers (Yue, 2012.).

From the processing waste, bamboo powder polymer composites, bamboo pellet for energy, vinegar and charcoal are produced. In 2010 bamboo charcoals production in China reached 0.14 million tons/yr. The value of bamboo charcoal is further added in secondary processing units for bamboo charcoal fibre and cloth, charcoal for adsorption and purification materials, in
handicrafts and even for improving sleeping materials. Similarly from vinegar in the secondary processing units, vinegar for bathing, for horticulture and agriculture purposes are produced. Attempts are being made to manufacture bamboo carbon based lithium battery and conductive polymers. High value-added bamboo products viz., bamboo decorative veneers are also produced. Advanced bamboo engineered materials are significantly different from the existing various bamboo composites to replace glass fibre re-inforced particles for application in wind blade and yacht. Bamboo scrimbers, a novel structural composite, has been developed for producing strand, panel, floorings, structural components in houses, top-grade furniture and for outdoor applications. Bamboo structural lumbers are produced for using as the loading component for construction purposes like roofs, poles, etc. (Yue, 2012).

2.3 Bamboo shoot.

In addition to above uses edible bamboo shoots has its importance both as traditional food and modern day food items in different forms. Bamboo shoots are young bamboo stems, eaten as vegetable for thousands of years in many Asian countries. Bamboo shoots form a part of traditional cuisine, fresh, dried, shredded or pickled. There is, however, also a growing market for processed (fermented, roasted and boiled) and packaged shoot representing an opportunity for establishing commercial processing units.

Bamboo shoots may be harvested at many stages – before they break the surface of the soil, shortly afterwards or once they have reached a meter or more in height. The stage of harvest determines their fibre content and tenderness, with younger shoots being more palatable. The fibre content also determines the way they are handled or processed. The essential requirements for successful shoot production are availability of bamboo forests and plantations of the right species for producing bamboo shoots and availability of basic management strategies of the bamboo clumps among others. In India, the short shoot production period may be one of the major hurdles
for large scale processing and consumption. By careful management of bamboo plantations a maximum number of shoots can be encouraged to grow each year.

### 2.3.1 Bamboo shoot species.

Most bamboo species produce edible shoots. According to Fu and Banik (1995), over 500 species can produce edible shoots. The main monopodial species used commercially in China is *Phyllostachys pubescens*, known colloquially as ‘Moso’. Other widely used species are: *P. praecox, P. propinqua, P. dulcis, P. irridenscens, P. vivax, P. prominens, P. flexuosa* and *P. bambusoides*. Some of the best sympodial bamboo shoot-species of China are *Bambusa beecheyana, Dendrocalamus asper, D. latiflorus* and *Dendrocalamopsis oldhamii* (Lin Quingyi, 1995).

While reviewing the nutritional properties of bamboo shoots, Chongtham *et al.* (2011) listed a total of 8 commercially important edible species consumed from Australia, 4 from Bhutan, 12 from China, 7 from Japan, 3 from Korea, 4 from Nepal, 7 from Puerto Rico, 9 from Taiwan, 8 from Thailand, 6 from USA and as many as 26 from India. Within the total of 47 species of that list, 13 species are under genus *Bambusa*, 10 of *Dendrocalamus*, 11 of *Phyllostachys*, 3 of *Gigantochloa*, 2 each of *Schizostachyum* and *Thrysostachys* and 1 each of *Chinobambusa, Sinocalamus, Guadua, Melocanna* and *Teinostachyum*.

Singh (2006) listed 50 native bamboo species used for edible purpose from North East (NE) India and according to him *Bambusa bambos, B. tulda, D. giganteus, D. hamiltonii, D. membranaceus* and *Melocanna baccifera* are the dominant species from delicacy, taste and consumption point of view. In regards to diversity of commercial edible species of North Eastern Himalayan region as studied by Bhatt *et al.* (2004) a maximum of 8 species have been recorded from Manipur followed by Tripura (6 spp.), Arunachal Pradesh and Nagaland (5 spp. each) (Bhatt *et al.*, 2004). In Sikkim the edible species are *B. tulda, Chimonobambusa hookeriana, D. giganteus, D. hamiltonii, D. hookerii, D. sikkemensis, D. strictus* and *Phyllostachys manii* and among these *C. hookeriana* and *D. hamiltonii* are the two commercial species (Bhatt *et al.*, 2003b). Jha (2010) reported five species, viz., *B. tulda, D. giganteus, D. hamiltonii, D. Longispathus* and *M. baccifera* as the shoot producing species in Mizoram.

In Central and Eastern India, tribal collect bamboo shoots from natural bamboo forests having mostly pure patches of *D. strictus*. The other common edible bamboo species are *Bambusa bambos, B. balcooa, B. nutans, B. pallida, B. polymorpha, B. tulda, D. brandisii, D. giaganteus, D. hamiltonii* and *D. longispathus* from Central India (Pandey *et al.*, 2012). The common edible species found in Southern India are *Arundinarai aristata, A. hirsuta, B. bambos, B. glaucescens, B. longispiculata, B. vulgaris, Cephalostachyum capitatum, C. fuchsiaum, D. hookeri* and *Oxytenanthera albociliata* (Shanmughavel, 2004).

### 2.3.2 Shoot consumption.

Bamboo shoots have intercontinental delicacies and are extensively used in Thailand, China, Denmark, Philippines, Taiwan, Tanzania, Puerto Rico, Malaysia, Singapore and Japan as vegetables, pickles, salad and various other purposes. For example, Japan has cultural preferences for *Phyllostachys pubescens* (Moso) somewhat larger than *C. hookeriana* and *P. bambusoides* of India. These two species could be exported to Japan. Among other species *D. longispathus, D. sikkimensis, D. Membranaceus* and *Gigantochloa rostrata* are ideal for canning and could be
exported to Japan and Singapore. In Bangkok area of Thailand consumes more than 10,000 ton of fresh shoots every year. In Japan it is estimated to be between 30,000 to 50,000t/year. Japan has plantation of 70,000 ha of moso bamboo plantation. Based on shape, size and weight different bamboo shoots are preferred in international market. Japanese prefers smaller bullet shaped and sweet shoots (0.2-1.0 kg) whereas Thais prefer larger shoots (2-4 kg). Their major consumption is D. asper with smaller amount of bitter Thyrostachys siamensis.

Bamboo shoot is being consumed as traditional cuisine throughout the bamboo growing and tribal dominated regions – the entire NE hills region, Jharkhand, Orissa and North and South West Bengal, the Central India – Chhattisgarh, M.P. and along the bamboo growing areas of Western Ghats covering areas of Konkan, Coorg and even in Kashmir (ERG, 2004). Though average Indian is not an avid consumer.

Hotels and especially restaurants prepare large quantities of oriental and continental cuisine that lends them to consumption of shoot. Processed food manufacturers use bamboo shoot for downstream products. Cuisine of different origins such as Chinese, Thai, Japanese, Korean, Tibetan, Malaysian, Mexican, etc. served in star hotels require bamboo shoots and these are being supplied from NE states or imported from Thailand. Canned products are reportedly convenient to use since they retain freshness despite losing its aroma and crunchiness.

The total consumption of edible shoots by each household in different villages of NE states ranges from 7 to 20 kg per annum (Singh, 2006). In a locality of 168 families annual total consumption has been found to be 2,688 kg per annum. Manipur has the potential bamboo shoot output of 1,42,350 tons/year and it has been estimated that the average consumption rate of bamboo shoot is about 60 kg/person/year. Bhatt et al., (2004); On an average 1,979 tons, 2,188 tons, 442 tons, 433 tons, 442 tons and 201 tons of shoots were harvested for consumption annually in Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. In Japan annual per capita shoot consumption is 3.0 kg compared to 1.2 kg during 1950 (Choudhury et al., 2012).
2.3.3 **Nutritional values of bamboo shoot.**

Young succulent bamboo shoots had been held in high esteem for centuries as an edible delicacy. They are used in numerous Asian dishes and broths and sold in various processed shapes and available in fresh, dried and canned versions. A shoot is generally 20-30 cm long (Choudhury, 2012) taper to one end or conical in shape and weighs about 400 – 500g. However, shape, size and weight differ considerably due to species, climatic and soil condition. Shoots having dimensions of more than 70 cm long and 40 cm basal circumference are also very common in NE Indian states and other countries (Bhatt *et al*., 2005b; Singh, 2006). Bamboo shoots look like coiled springs and have an acerbic flavour. Fresh shoots have a crisp, crunchy taste, and sweet flavour, imparting a unique taste.

Moisture content in fresh shoot is about 90% (ERG, 2004) and 78 to 94.7% moisture are very common in shoots of our country (Chongtham *et al*., 2011; Bhatt *et al*., 2005b; Singh, 2006). The edible content of a newly harvested shoot is usually 25 to 30%, small shoot yielding species have lower edible part. Studies from NE India (Singh, 2006) with a large number of species have indicated higher proportion of edible part (45 to 74%).

Bamboo shoots are not only delicious but are also rich in nutrients. In Japan, the bamboo shoot is called the ‘King of Forest Vegetables’. Presently, though the shoots are consumed more as a vegetable by local people, they are made available to others as a delicacy in up-scale markets and specialty restaurants. Hence, bamboos are no longer considered as ‘poor man’s timber’ but they form a ‘rich man’s delicacy’.

The nutritional value of edible shoots of different bamboo species has been worked out by several workers (Giri and Janmejoy, 1992; Shi and Yang, 1992; Tripathi, 1998; Chen *et al*., 1999; Sharma *et al*., 2004; Xu *et al*., 2005; Bhatt *et al*., 2005b; Singh, 2006; Kumbhare and Bhargava, 2007; Chongtham *et al*., 2007, 2008). Bamboo shoots are low in calories, high in dietary fibre, and rich in various nutrients. The main nutrients in bamboo shoots are protein, carbohydrates, amino acids,
minerals, fat, sugar, fibre, and inorganic salts. The shoots have a good profile of minerals, consisting mainly of potassium (K), calcium (Ca), manganese, zinc, chromium, copper, iron (Fe), plus lower amounts of phosphorus (P), and selenium (Shi and Yang 1992; Chongtham et al., 2007). Fresh shoots are a good source of thiamine, niacin, vitamin A, vitamin B6, and vitamin E (Visuphaka, 1985; Xia 1989; Shi and Yang, 1992). They are rich in protein, containing between 1.49 and 4.04 (average 2.65 g) per 100 g of fresh bamboo shoots. They contain 17 amino acids, 8 of which are essential for the human body (Qiu, 1992; Ferreira et al., 1995). Tyrosine amounts to 57% to 67% of the total amino acid content (Kozukue et al., 1999). Fat content is comparatively low (0.26% to 0.94%) and the shoots contain important essential fatty acids. The total sugar content, 2.5% on average, is lower than that of other vegetables. The water content is 90% or more. Major advances have been made in fresh shoot production and processing and in the analysis of nutrient components of edible shoots. Based on nutritional analyses, it has been determined that bamboo shoots are a good source of food energy and are being projected as a new health food. This is because bamboo shoots are endowed with these health-enhancing properties. The high cellulosic content of bamboo shoots stimulates appetite.

Fresh shoots of 14 species have been analyzed for their nutritive value (Chongtham et al., 2011). The fresh shoots have a high content of carbohydrates, proteins, and fibre but are low in fat. Protein content is highest in *Dendrocalamus hamiltonii* (3.72 g/100 g fresh weight). Carbohydrate content ranged from 4.32 to 6.92 g/100 g fresh weight with *Bambusa tulda* having the highest fibre content. In Indonesia, shoots (*rebung*) are sliced thinly, boiled with coconut milk and spices to make a dish named *gulai rebung*. Other recipes are *sayur lodeh*, mixed vegetables in coconut milk and *lun pia* or *lumpia* i.e., fried wrapped *rebung* with vegetables. Shoots of *B. bambos* and *B. tulda* have sweet flavour, are tender, and tasty and are the most popular, being liked by all consumers. Of the 14, 5 species, *B. tulda*, *B. bambos*, *D. asper*, *D. giganteus* and *D. hamiltonii* are nutritionally better than the rest and have high potential for the necessary massive commercial
production of shoots. Studies indicate that there is an overall decrease in all the nutrient components in 10-day-old shoots compared to the freshly emerging juvenile shoots (Chongtham et al., 2007). Freshly emerged shoots are nutritionally richer than the fermented and canned shoots. A comparison of the nutrient components of juvenile bamboo shoots with some of the commonly consumed vegetables revealed that free amino acid, protein, and dietary fibre contents in bamboo shoots was higher than all other vegetables listed in. Except for D. brandisii, all the presently studied bamboos have higher protein and fibre contents than the common vegetables. Bamboo shoots, though having lower vitamin E content, have a higher amount of vitamin C in comparison to the other green vegetables except Brassica.

Regarding minerals, bamboo shoots have a comparatively higher K content than most of the vegetables except spinach, Spinacea oleracea (558 mg/100 g) and potatoes, Solanum tuberosum (421 mg/100 g). The sodium (Na) contents in cucumber (Cucumis sativa), brinjal (S. tuberosum, and S. melongena) and ladies finger (Abelmoschus esculantus) are lower than that of bamboo shoots. Magnesium (Mg) is a life-supporting element and has an indispensable role in body metabolism. Its content was highest in the shoots of D. giganteus (10.09 mg/100 g) that is close to that of S. Melongena [melogenan] (10.0 mg/100 g fresh weight). Children and women before menopause, during pregnancy or while nursing, require high amounts of Fe (Tapiero et al., 2001). This can be obtained by consumption of bamboo shoots that contain a comparatively higher amount of Fe than other commonly consumed vegetables. A higher amount of selenium, commonly known as “Miracle life element,” is present in the bamboo shoots of some species compared to other vegetables.

2.4 Shoot season/Duration

No concerted effort has so far been made for documentation of duration of shoot season, the shape and dimension of the harvested shoot and the productivity from the mainland India. Shoot related information is available only from NE states of our country. Shoot season in different countries
varies depending largely on climatic condition, geographical locations and genetic variability. Grown under southern sub-tropical region of China, the shoot period of sympodial *D. oldhamii* in Fujian province of China lasts for 5 months starting from mid-May reaching the peak from early July to late August and the shooting activity decreases from early September and ends around late October (Lin Quingyi, 1995). Under almost similar geographical situation, shoot season extends from February to December for four shoot species of Philippines though individually maximum duration is met with *B. vulgaris* (February to November) and the minimum for unidentified *Bamusa* sp. April to late August. In Malaysia, the shooting duration is from May to September while that in Thailand it is May to October (Azmi and Azmy, 2002).

In Central and Eastern India, shoots emerge during rainy season. In NE states, the season begins at the onset of monsoon i.e., May to June and continues till early September. The temperate bamboos are runners which shoot twice a year – once in the spring from Mid-March to Mid-June and the other during winter that lasts from November to March (Qiou and Fu, 1985).

According to Midmore (2009) the shoot season is a characteristic unique to each species for reasons that remain a mystery. However, appropriate agronomy and crop management may play a key role in extending the shoot season. If irrigated timely and adequately, the duration of shoot emergence can be increased. From trials with *B. blumeana* plantation in Philippines, it is clear that maximum shoot production coincides with rainfall one month or so in advance and the clumps that received irrigation generally produced more shoots (Malab *et al.*, 2009). In China, rice chaff has been found to be the best among all the mulches applied which advanced the shooting time by 41 days and increased shoot yield by 29.4% (Cao *et al.*, 1985). The relation between shoot emergence and shoot mortality as a function of monthly rainfall is very important as this could serves as a guide in gauzing when to harvest bamboo shoots for food before mortality occurs. This type of information is also important for managing irrigation schedule both for culm and shoot production and to attain yield sustainability.
2.5. **Bamboo productivity**

Bamboo comes into production in 3 to 4 year after plantation and reaches maximum productivity in 7 to 8 year. Well managed stands of *B. bambos* and *D. hamiltonii*, may produce 33 and 53 shoots weighing 30 – 50 kg and 20 – 40 kg per clump respectively in 4 years. Like total and above ground biomass, shoot biomass may also vary substantially within individual species, even when cultivated at the same site. Due to high genetic variability, shoot production may vary enormously. Kiang *et al.* (1976) measured yields of edible shoots ranging from 7.4 to 20.3 kg/clump/yr i.e., 0.74 to 2.03 t/ha/yr with 100 clumps/ha in different strains of *D. latiflorus* growing in one site. Although *D. latiflorus* may have a yield potential up to 41 t/ha of edible shoots per year. For a well managed reasonable stands (2,225 culms/ha for larger and 9,000-1, 2000 culms/ha for small to medium sized 3-4 yr old), the ranges of production are 10-20 t/ha and 10-30 t/ha in monopodial and sympodial bamboos respectively (Kishwan and Nautiyal, 2008). The culm age structure of a bamboo stand can modify shoot production capabilities enormously.

2.6 **Bamboo and bamboo shoot market**

It is estimated that the bamboo markets excluding markets for bamboos in paper/pulp production and unprocessed bamboo supplied to construction industries and other uses, have a combined value of 6.8 billion US $ per annum and traditional bamboo products like handicrafts, blinds, chopsticks, bamboo edible shoots account for almost 95% of this value (Smith *et al.*, 2006 ). The emerging markets with newer industries, particularly wood substitutes have been pioneered by Asian producers and include flooring, panels and non-traditional furniture. According to the Smith *et al.*, (2006), these represent the largest growth opportunities for bamboo. Strong world demand and China’s productive capacity and exports have produced a structural change in the wood industries. Newer industries offer interesting growth potential and their market demand may reach 16.8 billion US$ per annum under mid-level world market growth within the present decade. New
markets for bamboo including modern/laminated furniture, flooring and panels emerge to account for approximately 45% of the world market from the present level of only 5%. China is the largest exporter of a range of bamboo products – shoots, chopstick and toothpicks to handicraft, furniture and industrial products such as bamboo flooring, sheet products (plywood, MDF), textiles, charcoal, activated carbon, vinegar etc. The present bamboo handicrafts, shoot, blinds, chopstick, furniture, flooring, panels, charcoal and activated carbon account for 3000, 1500, 500, 300, 1100, 100, 200, 100 and 20 million US$. Demands remains strong for bamboo shoot along with handicrafts and blinds, but the growth rate for bamboo products are highest in the emerging wood substitute based markets. Additional niche market opportunities exist with processed bamboo charcoal and bamboo activated carbon.

About 2.5 billion people in the world depend economically on bamboo (INBAR, 1999), and international trade in bamboo amounts to about US$2.5 million (INBAR, 2005). The latest data from China indicate that the Chinese bamboo industry created a value of US$ 5.5 billion in 2004. The bamboo-based GDP grew by 120 percent from 2000 to 2004.

According to INBAR’s trade database, the annual export of bamboo in 2000 was valued at about US$ 2.5 billion. China, Indonesia and Viet Nam were the major bamboo producers and exporters in Asia. The total value of exports of raw bamboo is about US$ 89 million. China exported some US$ 25 million worth of raw bamboo, roughly a third of the world total. It was followed by Indonesia (US$ 10.6 million, 12 %) and Viet Nam (US$7.7 million, 8.6 %). Singapore and Hong Kong were important bamboo and rattan processing centre and exporters. There was a US$ 18.6 million trade of bamboo raw materials in Singapore, which accounted for over 20.9 % of world trade. Hong Kong’s annual trade value was US$ 4.69 million, which accounted for 5.3 % of the world total. Dutt (2004) reports the combined value of internal and commercial consumption of bamboo is worth US $ 10 billion (approx. Rs. 50,000 crore) which is expected to increase about US $ 20 billion by 2015.
The main importers (USA, UK, Netherlands, Germany, France, Japan and Hong Kong) together make up some 80% of the world bamboo import trade. The European Union, Hong Kong, Japan and the United States were the major markets for bamboo products, collectively accounting for 71% of the total market share.

According to Chinese customs statistics, the total trade value of nine bamboo commodities (identified by country-specific, eight-digit codes) was over US$ 517 million in 2002. This is 9.4% more than the average for the previous four years, 1998–2001. The shoot trade is accounted for US$ 23.66 million during that year.

From Myanmar on an average 170 tonnes of bamboo shoots are exported annually, with a market price of US$ 210–600/tonne. The value of annual exports of chopsticks, bamboo wares, etc. varied from US$ 880 000 to US$ 1120 000 during 2001–2003. (Lobovikov et al., 2012)

In Latin America, Chile’s trade was 4.5 million culms in 2000 and over 10 million culms in 2005 (corresponding to approximately 6,000 tonnes in 2,000 and 13,000 in 2005), with a market value of US$ 3 million in 2005. Ecuador harvested 36,000 tonnes in 2000 (US$ 1.2 million) and 53,000 tonnes in 2005 (US$3.0 million). During 1991-92 Bangladesh exported bamboo hukka, a traditional smoking device, and earned 1.41 million Taka (69 Taka = 1.0 US$) (Akhtar, 2006). Export Promotion Bureau of Bangladesh has recorded 17 exportable bamboo products earned 38.4 million Taka by exporting bamboo poles during July 2002 to June 2003. During 2003-04 it earned 4.20 million US$ by exporting handicraft items. India’s annual bamboo harvest was slightly over US$23 million (Pabuayon and Espanto, 1997.) Bamboo shoots are most valued in fresh and dried forms. The prices of canned bamboo shoots are lower than the fresh ones. Shoots are canned and exported predominantly from Taiwan, China and Thailand and the later two countries being the largest supplier to the world markets.
During 1991-2000, bamboo furniture and handicraft industries of Philippines generated export revenues of 1.9 million and 436.94 million US$ per year respectively. In 2000, total export of bamboo furniture alone valued at 3.18 million US$.

2.6.1 Bamboo shoot market: world.

Bamboo shoots are exported as canned, packed in plastic or dried. There is interest from restaurants in America and Europe. To further stimulate interest INBAR collaborated in the production of a ‘fusion’ cook book containing western cuisine with the use of bamboo shoots. INBAR has also sponsored research into the use of bamboo flour in new products (Hunter, 2003).

International trade of bamboo is generated from a narrow range of utilized 50 species out of about 1,500 species. Many underutilized species are threatened by loss of forest habitat. Bamboo could more widely be used in constructions as reinforced cement, inexpensive houses and buildings that resist earthquakes and land slips. Also bamboo can substitute wood in many wood’s traditional uses – paper, fibre board, glue-laminated furniture, panels and flooring. Edible bamboo shoots have developed rapidly in the world markets. New uses of charcoal and medicine are developing (Hunter, 2003).

The current global shoot market, as stated earlier, is 1.5 billion US$ out of 6.8 billion US$ of total bamboo market excluding markets for bamboo in paper/pulp production and unprocessed bamboo supply to domestic construction industries and other uses (Smith et al., 2006).

As per 2000 estimate (ERG, 2004), the total world trade for bamboo shoot has been estimated at Rs. 3,200 to Rs. 3,400 crores and in volume term was 3,00,000 tons. The quantum of Chinese shoot export was 1,50,000 ton valued at Rs. 12,000 crores. In volume terms China’s shares of total export was pegged at almost 50 %. Japan and USA are two major importers of Chinese bamboo shoots and accounting for about 74 and 11.5 %, respectively. Exports from Thailand and Taiwan were 68,000 and 40,000 tons respectively contributing 23 and 13 % of world exports and their export to Japan, USA and Australia account for about 60 %. Canned shoots occupy an
important place in Thailand global trade providing export earnings of about 30 million US$ annually. India imports a very small quantity from Thailand.

Japan’s import of fresh and canned shoots was about 1,34,000 tons per annum contributing about 45% of total world import of which 4,000 ton and 1,30,000 ton were fresh and canned shoots, respectively. Imports of USA and Australia during 2000 were 44,000 and 12,000 ton/annum, respectively accounting for 14.5% and 4.0% of world imports. Domestic consumption in Australia is increasing at 20% per annum. The net retail price of canned shoot there ranges from US $ 4 to US $ 8 per kg. USA imports more from Thailand than from China. In Japan, shoots fetch at higher price at about US $ 5 per kg while average price of US imports is around US $ 1 per kg. India has a substantial price advantage in edible bamboo exports. The local market price of fresh shoot during peak season is generally US$ 0.23 to 0.27 per kg. Korea’s import is about 12,000 ton per annum and trading ahead of Australia in volume (ERG, 2004). Taiwan is said to have imported 5,000 canned shoot in 2000 AD from Thailand, China and Philippines. Hong Kong imported fresh and canned shoot from China and re-exported to Singapore, Taiwan and USA.

2.6.2 Bamboo shoot market: India

In India, the demand for Bamboo Shoot appears to be low, in spite of the abundant availability of some good species. Household consumption is just restricted to selected ethnic groups. As far as processed food items are concerned, its growth is again a function of demand from these ethnic groups. In India very little efforts have been made so far to evaluate the consumption pattern, its production potential, gross output, harvest rate and monetary benefits.

Bhatt et al., (2003b) surveyed three tribal states –Meghalaya, Mizoram and Sikkim and revenue earned through sale in order to understand the export possibilities of potential edible species to generate revenue by creating employment opportunities and to frame a comprehensive policy for uses afforestation of commercially available edible bamboo species for the NE states. Singh et al.,
(2004) reported Manipur, one of the eight states of north eastern India, harbors a high diversity of bamboo. Bamboo shoots, both in raw and fermented forms, are largely consumed by the people and can earn a large share of household economy to an amount of Rs. 2,130 million (US$ 45 million) annually for the nation as a whole. Revenue of Rs.0.43 million (9000 US$) is generated from bamboo and its products annually by the State Forest Department of Manipur.

The selling price for bamboo shoots varied from place to place and in Meghalaya, shoots of *D. hamiltonii* fetched maximum mean price of about Rs. 5.16/kg during 2001-2002 followed by *M. baccifera* (Rs. 4.95) and *B. balcooa* (Rs. 4.82/kg). In Mizoram on average price of *M. baccifera* shoots was highest (Rs. 7.50) while in Sikkim, the market rate were reasonably high – Rs. 15 to Rs. 20/kg for *D. hamiltonii* and Rs. 20 to 30 for *Chimonobambusa hookeriana* shoots. In the 3 states, Meghalaya carried an average of 31.33 kg shoots/vendor for sale followed by Mizoram (27.64 kg/vendor) and Sikkim (7.78 kg/vendor). In all the states primary vendors or collectors are more numerous than the secondary vendors and females put more physical efforts to harvesting and selling bamboo shoots.

Bamboo is harvested almost every day either for marketing (in any form) or household consumption. The major share goes to immediately consumed food and rest for making pickle and other fermented products. From sale of bamboo shoots may provide employment to 131, 88 and 55 persons/year in Meghalaya, Mizoram and Sikkim respectively. Likewise pickle processing may provide employment for 67 persons on per year basis. Cost-benefit analysis has shown the total gross income of Rs. 19.659 lac, Rs. 13.22 lac and Rs. 8.20 lac per year in Meghalaya, Mizoram and Sikkim, respectively. The net revenue earned by the tribals to the tune of Rs. 11.38 lacs (24,250 US$), 7.74 lacs (16,485.6 US$) and 7.01 lac (14,930.8 US$) per year for the respective states. As per the estimate of Singh et al., (2003), the annual income from edible bamboo shoot in Manipur state is Rs. $213 \times 10^7$ (45 million US$).
In another study from NE hill states, Bhatt et al., (2003b) have demonstrated the net income of 23,888 US$, 14,200 US$ and 14,700 US$ per year for Meghalaya, Mizoram and Sikkim while the consumption in the respective states were 448t/year, 505t/year and only 27t/year, respectively. The marketable quantity of 980 ton excluding household level consumption is valued at 1,11,000 US$ per annum. In addition to the above quantity, utilization of fermented, roasted and boiled shoots was estimated to be 680 ton yearly. The current market for bamboo shoot in India is 5 crore (Choudhury et al., 2012).

Six states of NE Himalayan region have been surveyed to explore the possibilities of potential edible species to generate revenue covering 51 districts, 141 market places and 2081 vendor during 2002-2003 by Bhatt et al., (2004). The net revenue earned by tribal through sale of shoots was Rs.8.86 million. (1 US$=Rs. 45.73) (US$ 19, 3740), Rs. 5.69 million (US$ 12, 4410), Rs.1.78 million (US$38,950), Rs.1.14 million (US$24,900), Rs. 0.58 million (US$12,730) and Rs. 0.75 million (US$ 16,940) in Arunachal Pradesh, Manipur, Nagaland, Meghalaya, Tripura and Mizoram, respectively. On an average, D. hamiltonii, D. hookerii, D. sikkimensis, D. giganteus, M. baccifera, P. bambusoides and B. balcooa contributed 33%, 18%, 16%,14%,8.5% and 3% of total earned revenue.

Market days varied from state to state and between 1st week of June to 3rd week of September, the average market days available for sale were 84, 84, 53, 81, 76 and 42 days per year in AP, Manipur, Meghalaya, Mizoram, Nagaland and Tripura respectively. The average sale per day has been noted as 6.9, 12.7, 441 and 0.12 tons in Arunachal Pradesh, Manipur, Nagaland and Tripura respectively. A vendor on an average, sold 2.7 to 39.4 kg, 13.6 to 44.1 kg, 6.1 to 13.5 kg and 5.3 to 6.1 kg shoot after collection in markets in Arunachal Pradesh, Manipur, Nagaland and Tripura, respectively. The average distance travelled by the villagers to collect shoots were ≥ 2.0 km, 1.6 to 4.0 km, 1.5 to 4.0 km and 3.7 to 6.3 km in the respective states. In spite of consumption of fresh bamboo shoots in the entire NE region, a considerable quantity being consumed by all ethnic
groups throughout the year in the form of fermented products, roasted and pickles after processing through conventional methods. Total quantity of processed shoots consumed during 2003-2004 in the five states viz. Arunachal Pradesh, Manipur, Meghalaya, Nagaland and Sikkim amount to 680 tons. Arunachal Pradesh has contributed highest (481 t/year) followed by Manipur (114 t/year), Meghalaya (39 t/year), Sikkim (27 t/year) and Nagaland (19 t/year) respectively, Bhatt et al., (2005). The net income from the sale of the processed product was Rs. 23 million/year (US$ 502950) and in that respect Arunachal Pradesh headed the list with Rs. 17.5 million (US$ 38,270) and Sikkim the least (0.47 million-US$ 10,280). Employment opportunities have also been worked out and 1,260 persons/year could earn their subsistence through sale of bamboo shoot products. The gross income from shoot sale in Sikkim amounts to 45,530 and 18,000 US$ in going and considering the physical efforts (Bhatt et al., 2003), and by selling edible shoot the tribal communities could earn 14,931 US$ (Bhatt et al., 2003a), [1 US$= Rs. 46.95].

Jha (2010) highlighted consumption pattern, percent contribution of different species, number of families involved in collection from forests and trades frequency of collection, distance covered by villagers for collection etc. from Mizoram having total geographical area of 21,081 km² and population of 10,91,014. Total shoot sale has been estimated to be 29, 14,360 pieces or 14, 57,180 number of bamboo shoots. About 1,500 vendors’ sale bamboo shoots in the market and out of these 400 vendors came to Aizawl market alone 97% of vendors sold bamboo in market collected by themselves in 2000 which has reduced to 88% in 2002. Out of these vendors, 34, 44, 16 and 6 % are collecting shoots on weekly, thrice weekly, twice weekly and daily basis respectively. Total consumption in Aizawl alone was 4, 19,535 shoots per year during 2000. M. baccifera contributed maximum shoot in the market (50 – 54%) followed by D. longispathus (32-33%), D. hamiltonii (12-15%) and least by B. tulda (2%).
In Philippines, primary and secondary data were gathered about market potentiality of bamboo shoot, response of bamboo shoot vendors and on volume demanded source of shoots and opportunities and constraints in shoot commercialization (Rivera, 2009). Average volume of shoot sold during lean months (September to November) was 535 kg/month and during peak season (April to August) 1032 kg/month at each region out of 4 region surveyed in that country during 2000 and 2002. Average buying price from growers and harvesters was PH£ 9.73 to 14.33 per kg and average selling price was PH£ 15.38 to 19.88 per kg. People, generally requesting dishes incorporating shoots at higher class hotels and restaurants, are of middle to high income group and mainly Filipino, Chinese and Japanese nationals. Most restaurants use imported canned shoots and occasionally fresh shoots.

2.7 Silvicultural/Agronomic practices.

It is important to have a systematic management of bamboo resources to ensure adequate and continuous supply of raw materials and other products over a long period of time. The productivity of bamboo can be influenced by irrigation, seasonality of harvest, age of bamboo shoot harvest, standing culm density, bamboo shoot harvest, improving soil physical properties and nutrient uptake. However, the prevailing environmental condition at each site influences the management option that may give greater financial gain (Rivera, 2009). Optimum management regimes differ depending on what product is sought – culm/timber, timber and shoot, shoot or paper/pulp (Marquez, 2009; Fu and Banik, 1995).

The bamboo shoot absorbs soil and nutrients using root and rhizome. Generally root system of bamboo do not elongates to a great depth. It develops a root mat at the uppermost layer. Only few roots are extending below 40 cm depth. Qiu et al., (1992) reported that approximately 90% of the belowground biomass of P. pubescens was within 60 cm of the surface. Kleinhenz and Midmore (2001) speculated that those roots might only extend to a maximum of 1m when soil A horizon is very deep. Due to this type of root structure, they are able to take water and nutrients rapidly and
exhibit faster growth habit. The exceptionally rapid flush of growth of below ground shoots and above ground culms require net import of energy and nutrients. Further, the greater part of the carbohydrate required by new shoots and culm growth originates from the current photosynthesis by leaves of the existing culms and the greater part of the nutrient ions originates via absorption from soil during shoot season. This has clear implication for managing environment in relation to providing sufficient resources i.e., nutrients and water during rapid growth phase of bamboos (Kleinhenz and Midmore, 2001).

Farrely (1984) reports that bamboo species having shallow root system are more affected by deficient and fluctuating water condition. They are also affected in over wet condition. The bamboo root remains in 0-30 cm soil depth zone. Due to shallow root system leaching of nutrients is low. Age of the culm has also influence on shoot production. Older culms are deep into the soil having older tissues. Due to older tissues they are less effective in producing shoot and even viability of shoot is less. Age of bamboo culm has also affect on photosynthesis rate and so growth and yield. Huang (1986) and Huang et al. (1989) noted 3 times high photosynthesis rate in less than 1 year old leaves than more than 1 year old leaves. It also depends on the age of the culm on which leaves are present. Diurnal change in air temperature, photon flux density and seasonal variation in temperature also influences growth and yield of bamboo. The required nutrient for production of shoot is taken from the soil. Rhizome also contains nitrogen, but its ability to translocation to other parts has not been substantiated. Li et al. (1999) reported that during shooting season there is no decrease in nitrogen content of rhizome. So even if for shoot production taken from rhizome it is immediately replenished.

The optimum standing-culm density and age structure for maximum productivity of mature bamboo plantations is of foremost interest. The seasonality of bamboo timber harvest is also important. During shooting season it causes damage to new shoots. In addition in this season bamboo contains starch. Harvesting will make them vulnerable to insect attack due to higher
accumulation of starch. Bamboo growth can be managed by manipulating culm growth by harvesting culms of different age. Harvesting depends on age of the harvesting culm, standing culm density and age structure of standing culm. Fu and Banik (1995) reported that improper management has affected bamboo resource worldwide. They prescribed different harvesting practice depending on end use: stand for shoot only, stand for shoot and timber, stand for timber only and stand for paper pulp. In India most of the bamboo culms are harvested from periphery of the clump for the convenience leading to congestion. Prasad (1987) reported that clear felling and control of density of subsequent culm regrowth can be the basis of strategy for rehabilitating over harvested or congested clumps. Sharma (1980) and Lakshamana (1994) recommend that even simple management practice such as removal of dead, dying culms can increase productivity of congested clumps. Age structure also influences productivity.

A few studies have related shoot and culm productivity of bamboo to the age structure of their stands. Lakshmana’s (1990) work with *B. bambos* showed that 1-year-old standing culms contributed 77% to annual production of new culms, 2-year-old standing culms, 20%, and standing culms >2 years old, only 3%. A similar contribution across age structure can be calculated with data from other studies, e.g., Huang (1984) with *P. pubescens*, Shanmughavel et al. (1997) with *B. bambos*, Kao and Chang (1989) with *D. asper*, and Prasad (1987) with *D. strictus*. It is apparent that younger culms contribute disproportionally in favour of production. In ancient China overharvesting of 1-year-old culms for papermaking harmed bamboo populations (Fu and Banik, 1995), while harvesting of 2-year-old culms resulted in depleted bamboo stands in Indonesia (Sutiyono, 1988). It appears that 1-2-year-old culms are required to maintain productivity of bamboo stands; culms younger than 2 years must be left to reach productive age, while older culms could be harvested since they contribute little to stand productivity. For shoot productivity less than 2 year culm should be left for maturity while more than 3 years culm may be removed depending on end use. Bamboo shoot harvest also increases bamboo shoot production.
potential of bamboo shoot. The mortality becomes lesser. More vigorous bamboo culms are available after selective bamboo shoot harvest.

Nutrient management plays important role in increasing the productivity. Nutrient can be both organic manure and inorganic fertilizer. Hong (1987), Ahmad and Haron (1994), Widija (1991), Lakshamana (1994a) and various other researchers found positive impact on fertilizer on growth and yield of bamboo species. Like other crop NPK and their ratio plays vital role in increasing the productivity. Element like Ca and Mg also have influence on bamboo and shoot productivity and growth and yield of bamboo. Excessive application of inorganic fertilizer has some long term negative effect, so inorganic fertilizer with organic manure is recommended. The use of strategic application of fertilizers in the management of bamboo for shoot production should provide an economic advantage in the market (Traynor and Midmore, 2009).

2.7.1. Soil work and mulching.

Soil physical properties also plays important role in increasing yield. Physical properties can be manipulated by tillage, use of covers and mulching. Reports indicate that various silvicultural operations have marked effect on the shoots, culm diameter and height of bamboo (Hoanh, 1992; Virtucio et al., 1990). Ling (1984) and Lin (1995) recommended tillage during non shooting season. Most villagers of Sijiang County, China did not timely loosen the soil, hoe up weeds and plough soil, so the bamboo shoots grow unsatisfactorily. This provides better soil environment for bamboo shoot growth. Mulching improves the soil physical properties. Mulching protects rhizome, root and new emerging shoot from extremes of temperature and solar radiation. It also helps in evaporation loss leading to moisture conservation. In temperate climate it helps base of bamboo stand from heat loss. Thanarak (1996) mentions that mulching also enhances other soil physical properties like reduction in bulk density, improves water holding capacity, cation exchange capacity, weed control and maintains soil organic matter.
Lin (1995) recommended tillage during the non-shoot season to improve soil physical properties for better growth of shoots, rhizomes and roots through the soil. Tillage should cover a maximum soil depth of 6 – 25 cm for both monopodial and sympodial bamboo species. Possible schedules for tillage are: before the shoot season (Fu and Banik, 1995; Lin, 1995), after the shoot season/before rhizome growth and before maximum root growth (Kleinhenz and Midmore, 2001). Soil loosening and weeding could be combined in established stands. Raking of top soil in D. oldhamii clumps during February every year in China facilitated exposure of buds to higher temperature and sunlight and thus stimulated shoot sprouting, prevented roots from getting crossed and entangled, ensured proper growth with increased nutrient supply for shoot production (Lin, 1995).

Soil loosening in bamboo plantations is important, as maintaining a good soil structure in the stand helps the growth of shoots and the root system, as well as, water conservation. Soil loosening is done in China once or twice a year from November to February and involves surface tilling to a depth of 15-20 cm (Xiao and Yang, 2012).

The edible parts of newly germinated bamboo shoots are very tender and delicate with light yellowish sheaths which turn tough with green with time. This may be delayed by earthing up the base of the clump to a depth of 20-30 cm at the beginning of shooting. In order to stimulate development of shoot buds, the soil cover should be removed to expose the bud to high temperature and light in the following pre-shoot season (March or early April).

In China, scientists of Lin’an County developed a series of new technologies including covering clump base with chaff and straw that has forwarded the shooting period by 5 months from March to November. Decipulo et al. (2009) while studying the productivity of D. asper plantation located in Dukidnon, the Philippines, applied corn leaves, stalks and cobs as locally available in combination with fertilizer and culm thinning schemes and edible shoot production increased by fertilizer and mulch treatment. The benefits of mulch were much less than fertilizer application
probably because of the fact that the major role of mulch is to conserve soil water against evaporation loss and under that prevailing situation mulch might have prevented light, rainfall from entering the soil. The minor beneficial role of mulch in that condition may be associated with the cycling of nutrients in the corn mulch. Mulch with rice hull, bamboo foliage, weeds and grasses in combination with fertilizer and irrigation as studied in Iloilo and Capiz of Philippines (Marquez, 2009) also favoured shoot count and yield in addition to significantly longer duration of shoot emergence. Positive effect of mulch combined with fertilizer, irrigation and various culm density resumes on shoot yield has also been recorded by Malab et al., (2009) in a previously unmanaged stands of *B. blumeana* in Ilocos, Philippines.

To avoid loss in quality or freshness of edible shoots, Lin (1995) and Thanarak (1996) recommended covering of growing area with soil, mulch and/or plastic materials. Under tropical conditions, mulches can protect against excessive temperature, intent solar radiation (Oshima, 1982) and evaporation loss of soil moisture. In contrast mulches are maintained in temperate bamboo forests especially to insulate the soil against heat loss, thereby boosting physiological activities of bamboo plants, stimulating early and prolonged shoot development and improving total yield. Mulching has been adopted as an essential part of intensive management of the species for shoot cultivation. Cao et al., (1995a,b) while studying the effect of mulching on shoot production of *P. praecox* stands in Zhejiang Province, China have recorded higher soil temperature; earlier shoot emergence, prolonged shooting period and also higher yield and value of shoots. The results of comprehensive evaluation have shown that rice chaff was the best among the eight mulches tested. It has raised soil temperature by 3.83 °C, advanced shooting time by 41 days, prolonged the shooting period by 40 days and increased shoot yield by 29.4% and shoot production value by 270.3% and the stand’s economic benefits by 310.2%.
2.7.2. Clump management

Unregulated exploitation of stand is a major reason for degradation of bamboo resources worldwide (Fu and Banik, 1995). Harvesting of very young culms for fibre or timber has jeopardized bamboo growth since ancient times, e.g., in China, but more recently inappropriate harvest has led to extremely low and extremely high standing culm densities. If bamboo shoots are left undisturbed, biomass production increases until aboveground and belowground competition results decreasing annual rate of biomass gain. Control of standing culm density is the most important measure to combat such a decline in productivity.

There are some important considerations in the selection of shoots to grow into culms. Shoots selected early in the season will have the full benefit of favourable wet-season conditions to become established culms, while shoots selected late in the season may have their development restricted by the onset of the dry season. Selected shoots should be of good size and evenly spaced around the clump. Some form of yearly identification marking of new culms may assist at thinning time.

Appropriate densities vary depending on the products for which bamboo is cultivated. These average 7,400, 9,100 and 13,000 standing culms per ha for shoot only, shoot and timber and timber stands only respectively. Variations from these averages are due to species difference (higher densities for thinner culms), yield (higher densities for greater total yield), shoot and culm quality (lower density for thicker shoots and culms) and production sites (higher densities to maximize yield in ‘poorer’ sites and lower density to maximize quality in ‘richer’ sites).

It is worthwhile to mention that leaving all shoot grow into culms cause congestion in clumps and constrained production of shoots in later years. Some minimum annual thinning of culms or shoots is necessary if clumps are to continue produce shoots (or culms) on sustainable basis (Midmore, 2009). In order to manage natural bamboo forest, Chaturvedi (1988) suggested that all
bamboo culms of more than 3 years are to be harvested each year, congested culms must be removed, twisted culms should be cut at the top and mounding or heaping earth around the bamboo culms should be carried out each year before the rainy season. Bamboo clumps in no case should be clear felled as these are degenerated into a bushy form and no felling operation should be carried out from April to October. Zhengi and Zong (1983) investigated on the bamboo shoot output and stand density and found that the average number of bamboo shoot per mother culm negatively correlates with the density. Liao (1984) also observed relative decrease in shooting number with the increasing number of standing culms.

Sulthoni (1995) has assessed the starch content of some sympodial bamboos in the rural areas of Yogyakarta, Indonesia and found that accumulation of starch in the mother culm signifies energy saving to regulate new shoots. It was seen that culm starch content fluctuates during the year reaching highest peak in the month of November (within the young season i.e., from July to December) and lowest level in the month of May (within the old season, from January to June). On Yogyakarta, during November-December shoot production takes place. The bamboo harvest in the old season is associated with the low culm starch content and thus making it least susceptible to attacks by powder post beetle. He has also recommended for annual selective harvest of older culms in relation to the annual average number of shoots produced.

An experiment was conducted to study the felling effect of mature *Gigantochloa scortechinii* culms in Malaysia at intensities of 0, 40, 60 and 80% (Azmy, 1995). It was observed that 40% felling intensity may be applied for culm production while for shoot it should be 80%. Fu and Banik (1995) emphasized on the culm density regimes based on intended end use. In their report on bamboo production system and their management reviewed of monopodial and sympodial bamboo stands in the tropical and subtropical parts of the world. For the planned end product of large sized monopodial species such as *P. pubescens* is 7/8 year old culms, the recommended age structure is in the ratio of 3:3:3:1 for 1 - 2, 3 - 4, 5 - 6 and more than 7 years old culms. For 4 year
old culms as end product for mid-sized monopodial species like *P. glauca, P. bambusoides* etc. should be at 3:3:3:1 and density of 10,000 to 15,000 culms per ha. For the end product of sympodial bamboo timber such as *D. strictus, B. bambos* and *B. textilis*, culms are to be harvested at the rate of 30% in winter or dry season retaining density at 700 clumps per ha with 10 to 20 culms/clump of 1 to 3 years old. Some species can be grown both for timber and shoots like monopodial *P. pubescens* and sympodial *B. prevariabilis, Cephalostachyum latiflorus*, and *B. textilis*, only nine culms of 1 to 3 year old are retained in each clump. For shoot stand, the reasonable density should be 2,225 culms per ha for large sized monopodial species and 9,000 to 12,000 culms (1 to 3 year old) for medium and small sized ones. In case of sympodial species each clump can have 6 to 8 culms of 1 to 2 years of age. A few 3 year old culms may be retained. (Fu and Banik, 1995). For young bamboo stands, early thinning within the first 2 years of establishment may negatively affect the bamboo growth. However, greater number of older culms reduces the size of the new culms (Midmore *et al.*, 1998).

In general, in Australia, treatments on culm density regimes at all sites (Queensland and Northern Territory) that had high number of young culms i.e., of 1 and 2 year old at the time of shoot emergence, led to higher shoot numbers. Under high rainfall area as in Northern Territory, shoots selected for culm production at the beginning of the shoot season themselves produced edible shoots near the end of the same shoot season (Midmore, 2009).

In the Northern Territory of Australia, by thinning of 3.5 to 4.5 year old *D. asper* and *D. latiflorus* clumps and retaining higher percentage of 1 year and 2 year old standing culm density (SCD), marketable shoot yield have been increased (Traynor and Midmore, 2009). Higher SCD may result in the development of more rhizome axes and a greater shoot yield potential from the growing points of these axes. It was found that 1 and 2 year old culms can produce 90% of new shoots. A productive thinning strategy for shoot production would maintain only 1 and 2 year old culms or their higher percentage and apply a SCD that encourages strong rhizome development.
Possible thinning scheme focusing on shoot production might be 4-4-2 or 4-4. If both shoots and mature 3-year-old timber culms are to be harvested, then 4-4-4 would be a better schedule. Before the first thinning operation of young bamboo plants, it is important to encourage a well-developed and branching rhizome.

In studies on shoot production as influenced by combined effect cleaning, irrigation, application of inorganic fertilizer, mulch, organic matter and varying SCD regimes in Philippines have shown that for previously unmanaged *B. blumaena* in Ilocos Norte, retention of 16 or 12 culms per clump of 4-4-4-4 (4 each of 1, 2, 3, 4 year old culm) or 4-4-4 schemes favoured more shoot number and yield than 3-3-3 scheme. Thus retention of specific number of different aged culms may provide a strategy by which it is possible to predict shoot productivity of *B. blumaena* on sustainable basis (Malab *et al.*, 2009). However, results from rain fed site of Bukidnon on *D. asper* (Decipulo *et al.*, 2009) have shown that standing culm density of 10-10 (10 each of 1 and 2 year old culm) gave more shoots than 6-6 treatment. On the contrary, Merquez (2009) has shown that *B. blumaena* in Iloilo and Capiz, Philippines have resulted in highest growth rate in terms of shoot and culm production with SCD of 6-6-6. According to Hua and Ping (2012) the marketable shoot yield increased with higher standing culm density (SCD) and with a higher percentage of 1- and 2-year-old culms across treatments. Higher SCD may result in the development of more rhizome axes and a greater shoot yield potential from the growing points of these axes. They recommended thinning schedules focusing on shoot production of 4-4-2 or 4-4. If both shoots and mature 3-year-old timber culms are to be harvested, then 4-4-4 is the better schedule.

**2.7.3 Shoot harvest.**

In the drier environment of Queensland, shoot production was greater when all early shoots were removed for sale, leaving only late-season shoots for culm production (Midmore, 2009). Studies relating to clump management and effect of different culm density regimes on shoot and culm productivity are mainly confined to China, Australia and some SE Asian countries. Recently some
initiatives have been undertaken in India with growing interest in bamboo shoot consumption. In Mizoram, trials on different edible species (*M. baccifera*, *D. hamiltonii*, *D. longispathus* and *B. tulda*) have been conducted in natural habitat to study the effect of earlier shoot harvest at different intensity on new shoot emergence within the same season (Jha, 2010) and also on the growth of the shoot species under different agroforestry system in degraded *jhum* land. In *D. longispathus*, 50% harvesting of young shoot favoured 49.7% and 38.1% increase in edible shoot production during 1st and 3rd year respectively while 75% removal favoured maximum yield during 2nd year of the study. In respect to increment height and diameter of shoots, 25% shoot harvest favoured maximum shoot length increase followed by 50 and 75% shoot harvest during 1st and 2nd year of study while in 3rd year 50% harvest greater shoot length. In respect to shoot diameter 50% shoot harvest supported maximum increase 15.7%, 17.4% and 15.0% in 1st, 2nd and 3rd year respectively followed by 75% and 25% shoot removal.

For *D. hamiltonii* also, harvesting of 50% young shoot for vegetables is recommended due to its greater influence on further shoot number (18.1 to 25.9%), shoot length (11.5 to 15.8%) and shoot diameter (8.2 to 26.%) in consecutive three years of study. For maintaining sustainability in shoot production by *B. tulda* 50 and 75% young shoot removal has been recommended. Moreover, a maximum increase of 64.6%, 20.05% and 27.4% in new edible shoot number has been found with 50% harvesting intensity in *M. baccifera* in 1st 2nd and 3rd year. During 1st year, increase (53.3%) in shoot number was more at 25% than at 75% harvest intensity. The shoot length and diameter also found to be more in all the three year with 50% harvest intensity in *M. baccifera* and thus this dose shoot harvesting is recommended for sustainable growth and shoot yield from *M. baccifera* (Jha, 2010).

While studying the effect of spacing and fertilization on growth of *D. longispathus*, *D. hamiltonii* and *B. tulda*, for agro forestry significant increase in new culm emergence has been found to be significant with 2.5m x 2.5m spacing in the 3rd year. Effect of fertilization on growth of three
species was significant in the three year of study. The number of new culms was more in *B. tulda* followed by *D. longispathus* and *D. hamiltonii*. However, height growth was more with *D. longispathus* followed by *D. hamiltonii*.

According to Jha, (2010) clumps of *D. hamiltonii* could best be managed by introducing 4 year felling cycle with 50% shoot harvest intensity at 45 cm height. *D. longispathus* require 50 to 75% harvest intensity.

### 2.7.4 Fertilization, manuring and irrigation.

Early nutrient management studies with bamboo were limited mainly to bamboo growth and culm/timber production. As for many other agricultural and horticultural crops, nutrient application rates, ratios between nutrients, schedules of nutrient application, form of fertilizer, and nutrient placement are equally important considerations in bamboo production. Since bamboo is a perennial crop, however, nutrient management schemes that have been developed for annual crops may not apply to it. Moreover, bamboo is grown for several products, and it is understandable that optimal fertilization will vary with purpose of cultivation. Nutrient management must not only satisfy requirements for yield but also for quality of harvested parts. Very little research has been conducted on the effects of fertilizer application on production and quality parameters of fresh edible shoots. For edible shoots, higher N decreases but higher P increases sugar content in *P. pubescens* (Hong, 1994). For the same species, Zhu *et al.* (1991) quantified the effects of N, P, and K on shoot quality. Silicon has a special role in the nutrition of bamboo, because it is associated with cell wall constituents and is present in xylem cell walls and fibres of plants. There is a general agreement that Si should only be applied to bamboo stands for timber production. For production of edible shoots, Si may prevent shoot development and reduce quality by increasing fibre content (Hamada, 1982; Hong, 1994; Fu and Banik, 1995).

Among the early workers on nutritional management for bamboo shoot cultivation, Ling (1984) emphasized timely fertilization for better management of *L. wenchouensis* for shoot growth which
produces both timber and shoots of high quality. While Farrely (1984) prescribed 110 kg per ha per year NPK at a ratio of 1:1:1 for production of both shoot and timber.

### 2.7.4.1 Schedule and mode of fertilization.

As for many other crops, bamboo responds more favourably to split application of nutrients throughout the year than to a single annual dressing (Raina et al., 1988). Whether nutrients are applied as single or multiple dressings, the optimum time of application during the year is of particular interest. Several studies have systematically tested the benefits of nutrient or fertilizer application during different phase of bamboo growth. Nutrient application earlier in the season, i.e., shortly before and during shoot season may be the most appropriate time of fertilizer application.

During shooting period or vegetative growth phases, the plant consumes more N than P and K. But during the period of shoot growth rhizome running, it needs more P or K than N and thus Huang (1995) recommended fertilizer application rich in N one month before the shooting season around the leaf changing period from mid April to end of May for *P. pubescens* in Zhejiang Province, China. In June and July coinciding with rhizome running period, he professed for application of fertilizer rich in P and K and organic matter during July to August and from December to January the next. According to Qiou and Fu (1985), the period of shoot bud differentiation and that of leaf renewal are suitable for fertilization. Lin Quingyi (1995) recommended fertilization twice in a year for a sympodial shoot species of Southern Sub-tropical China, *D. oldhamii*. The first application to be applied during June, about 6 weeks after raking the soil with 10 – 25 kg composted organic manure or 150 – 200 kg pond silt. The second fertilizing, as top dressing, in between June and August when bamboo shooting is most active with 10 to 15 kg human waste or 0.5 kg chemical fertilizer or 10 – 12.5 kg fermented barnyard manure. Since nutrient ions originates through absorption from the soil during shoot season, most
recommendations for nutrient application in bamboo suggest applying one month before shoots appear above ground and a second application during rhizome growth is also recommended. The first dressing may be N based whereas application later in the growing season i.e., during rhizome growth, may be P and K based.

2.7.4.2 Doses of fertilizer application.

Recent chemical analysis revealed that production 1,000 kg of bamboo culms need 1.5, 0.5 and 3.8 kg N, P and K respectively while each 1,000 kg fresh bamboo shoot need 7.0 kg N, 1.5 kg P and 2.5 kg K. Accordingly nutrient requirements of plantations yielding 15,000 kg fresh shoot per ha per annum can be met through 75 – 150 kg N, 15 – 22.5 kg P and 30 – 37.5 kg K per ha each year (Qiou and Fu, 1985; Hua and Ping, 2012).

The average rate of nutrient application, in general, is practiced at 318, 149, and 126 kg/ha/year of N, P, and K (N: P: K ratio: 2.5:1.2:1.0). In some instance, nutrients are added in larger quantities in stands primarily used for edible shoots (523, 226, and 228 kg/ha N, P, and K) than in stands for shoot and timber production (315, 97, and 142 kg/ha N, P, and K) and timber-only stands (225, 135, and 89 kg/ha N, P and K). Compared with the average nutrient content of total plant biomass, which is 288, 44, and 324 kg/ha of N, P, and K with an N: P: K ratio of 7:1:7, application rates appear excessive since only a proportion of that total biomass is harvested annually. At its maximum, about 85, 16, and 112 kg N, P and K/ha/year are removed when bamboo is grown for shoot and timber which is approximately 30, 37, and 35% of the total content of N, P, and K of a bamboo stand. In perennial crops such as bamboo, however, calculation of fertilizer rates cannot be based upon balancing nutrient removal through harvest with nutrient application, as is done in annual crop production. A great part of nutrients added promotes stand biomass that is not harvested, i.e., roots, rhizomes, and standing culms, indirectly improving yield (Kleinhenz and Midmore, 2001).
Shi et al. (1985) studied and reported regarding application of chemical fertilizer to the timber and paper-pulp stands of *Phyllostachys pubescens* in Anji County, China. Absorption rate of NPK is co-related with the amount of dry matter produced. As per study for each 1,000 kg of dry matter including roots, branches, leaves and culms, it needs to expend nutrition by as much as 2.7, 3.6 and 0.36 kg N, P and K respectively in soil. In Anji County, China soil does not lack P. Plenty of K is required which is supplied from decomposed leaves. *P. Pubescens* sheds its leaves once in two years. Applying urea at 150-225 kg per ha in Anji to timber stands and low yield paper pulp stands increased the yield substantially. In Fuyang County, the stands applied with 225, 230 and 64 Kg of N, P and K could increase the yield by 74%. So it is a better utilization of compound fertilizer i.e. NPK at 3:1:1 for such paper pulp stand. It has also been seen that only with 10% growth increase, bamboo yield could be improved by 800 to 1500 tons per ha per year.

Experimenting on *Thrysostachys siamensis*, *D. asper*, *Bambusa* spp. and *D. strictus* in three year old plantation in Donglarn in Khon Kaen, Thailand Suwannapinunt and Thaiutsa (1988) applied treatments at the rate of 0, 100, 200, 300 kg per ha rates with 15-15-15 NPK fertilizer. The fertilization was at the beginning of growing season. NPK at 100 kg per ha was found to be sufficient to increase the yield of *T. siamensis*, *D. asper* and *Bambusa* spp. For *D. strictus* 200 kg/ha was found to be appropriate. Patil et al. (1994) recommended for *D. strictus* for timber stand 200kg, 100kg, 100kg per ha per year N, P and K respectively in the ratio 2:1:1in India while Thanarak (1996) recommended NPK at the rate of 370 - 440kg/ha/year in the ratio 1:1:1 in case of *D. asper* for shoots and timber in Thailand.

Fertilizer application rate should always be based on the analysis of nutrient levels in plant tissues and that of the soil. The approach of diagnosis recommendation integrated system (DRIS) is based on establishing diagnostic norms for nutrients in specific plant parts and how they can be modified by fertilization. Zhou and Wu (1997) found that nutrient concentrations in one year old leaves of *Bambusa distegia* were better correlated with timber yield than those in less than one
year old leaves because the former were more responsive to soil nutrient concentration. Thus one year old leaves are suitable test tissues. Kleinhenz and Midmore (2002) have obtained a relationship between N application rate and leaf N concentrations for different bamboo species and suggested that fertilizer N should be added to ensure per cent leaf N at close to 3% for significantly higher growth and yield.

### 2.7.4.3 Mode of fertilizer application.

Distribution of minerals takes place through the rhizome system of monopodial bamboo species (Qiu et al., 1986). Translocation to young, growing plant parts, however, decreases with distance from nutrient sources. Therefore, fertilizers should be placed close to younger plant parts, i.e., broadcast around young (≤1-year old) rhizomes (without aboveground culms), rather than applied as a spot dressing to older (>1-year-old) rhizomes (with aboveground culms). Similarly, Oshima (1982b) recommended applying fertilizers to younger rhizome parts before the shoot season when a quick response is required and to older rhizome parts when a slow but sustained effect is sought.

For *P. pubescens* in Zhejiang, China two methods of fertilizer application have been proposed by Qiou and Fu (1985) – the stump fertilization and the furrow one around the culm base. It is easy to apply and the efficiency of fertilizer application is high. The organic fertilizer should be put into furrow or spread and the buried in soil. Fu (1998) prescribed NPK and Si compound fertilizer at 375 kg/ha for furrow and at 750 kg/ha in stump application during spring. The corresponding increment in yields he obtained were 46.9% and 54.3% respectively. Hua and Ping (2012) have supported the application of chemical fertilizer as per desired dose in two to four times during the shooting stage at intervals of one or two months and that should be applied in 10 – 15 cm deep drills that are prepared about 50 – 60 cm around the clumps.

For sympodial bamboo, Lin (1995) recommended applying fertilizers as spot dressings around clumps for immediate effects before the shoot season and broadcasting fertilizers away from
clumps for longer-term effects after the shoot season. Lakshamana (1988) obtained higher response with 0.5 kg NPK of 15:15:15 per clump through application during rainy season within a circumference of 1.0 m radius around the clump base of *B. bambos* after soil working upto 35 cm deep.

### 2.7.5 Conclusion- Agronomic/silvicultural practices.

In order to address the vacuum in the availability of scientific basis for technical recommendations in bamboo cultivation for timber and shoot production a series of trials have been conducted in Australia and Philippines (Midmore, 2009). The outcomes provide the basis for further development of bamboo resources throughout the globe. The approach was to highlight and evaluate the effects of the natural and imposed environments like thinning, irrigation, fertilizer application and mulching to enhance shoot and timber productivity and to investigate the effects of these on physical and chemical properties of culms, allow simple technology for expansion of use of bamboos and to explore the profitability of bamboos in Philippines. The outcomes of the trials are summarized as follows.

- Higher number of young (1 – 2 yr old) culms led to higher number of shoot emergence.

- Shoots emerged during initial shoot season may give rise to new shoots at the later phase of same season under high rainfall condition (in Northern Territories)

- Shoot production was greater when all early shoots were removed for sale leaving only late season shoots for culm production.

- Weight of harvested shoot was not affected by thinning regimes in the NT or by spatial arrangement of standing culms in Queensland.

- Treatments with more young culms (10-10 SCD than 6-6) raised the productivity index i.e., the number of shoots emerged over total existing culms.
• Some minimal annual thinning of culms or shoots is necessary if clumps are to continue to produce shoots on sustainable basis.

• Irrigation just before and during the shoot season has enhancing effect for onset and continued production of shoots for both monopodial and sympodial species.

• Irrigation increased the number of emerged shoots with the effect being greatest if combined with fertilizer application (Philippines).

• Number and size of shoots reduced significantly (Queensland) due to combined effect of withholding irrigation confounded by a complete absence of clump management.

• Water use efficiency increased by 28% even avoiding winter irrigation (Queensland). Year round irrigation is not important for shoot production provided irrigated only just before the anticipated shoot season (Northern Territory and other places).

• Under rain fed condition (100 mm per month) in one site of Bukidnon, Philippines the time of normal shoot emergence (June) after 2 months of dried period, have not been changed even under situations of less (<100 mm) rainfall and without irrigation.

• The rate of N required to maintain per cent leaf N close 3.0% level (Kleinhenz and Midmore, 2002) is uneconomical for shoot production.

• Fertilization at this level or even higher consistently hastened not only onset of shoot production but also rate of emergence and number of shoots.

• Even organic fertilizers showed consistently positive effect but to a lesser extent.

• Withholding N application led to significantly lower leaf N level and also smaller unmarketable shoots in Queensland and lesser number and yield of shoot without affecting size in Northern Territory and reduction in shoot production, number and size of shoots in Philippines.