Chapter 2
Regeneration, Cultivation, and Sustenance of Bamboo

Abstract This chapter examines the basic techniques available for regenerating seedlings to be used in plantations or on the farm. The three most important methods used in producing young seedlings for plantation are discussed in detail, as well as the processes for its cultivation. The chapter places emphasis on the regeneration of seedlings by seeds, culm cuttings, and rhizomes. The selection of land sites and the preparation for plantation of young seedlings is also looked at in this chapter, with a description of land selection, pre-planting operations, propagation methods, post-planting operations, harvesting, and handling. The effects of fungal infections and attacks by insects on the bamboo before and after harvesting are dealt with and also post-harvest treatment and preservation methods. The effects of these infections and attacks on the bamboo culms, when not treated or prevented in time, will result in the deterioration of the physical features of the culm. Various scientific forms of preservation and the types of preservatives used in its treatment are discussed. Sustainable techniques for bamboo plants are examined.

2.1 Introduction

Bamboo is a natural regenerative plant which naturally grows mostly in the forest as a bushy grass in tropical and subtropical ecology. It is also naturally found as an understory plant, which can also grow in moist regions and can be referred to as woody grass and classified into species ranging in number from 1439 to 1500 with 115 generas across the globe. The bamboo plant plays a significant role in the preservation of the forest as it releases about 35% more oxygen into the atmosphere than other plants, thus reducing atmospheric carbon dioxide as compared to hard and softwood. They are grown on farmlands in the plains and through the hills, as well as in the valleys. They also serve as a medium to check soil erosion because their remaining roots hold the surrounding soils after harvesting and provide nutrients to the topsoil. In recent years, the growth and uses of bamboo keep increasing rapidly across the globe due to its versatility, hence the need to encourage its commercial farming. The steady growth of its application over the

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past few years, in every aspect of humanity, has raised concern about how sustainable this plant will be over time since most industries are now competing for it as raw material for production and diverse applications globally.

Harvesting of bamboo from its native forests (naturally occurring), as well as those from commercial plantations, requires properly designed schemes for its harvesting, as this approach would enhance its sustainability. The farmers who go into commercial cultivation of bamboo need to be introduced to the appropriate techniques for propagation, as well as the harvesting techniques that promote the sustainability of bamboo plants. As new applications are being exploited industrially, scientific methods should be simply implemented to control its over-exploitation in farmlands, as well as the in natural forests. Over/exploitation is a global concern to industries and governments and needs discussion, despite bamboo's vigorous growth and somewhat invasive characteristics. There is a well-established and tested system of controlling this resource in countries such as China and India that can serve as a benchmark for its development. Many countries in Africa, such as Ghana and Ethiopia, have adopted the success story of these Asian countries by using the appropriate techniques for the development of bamboo and its products. Non-governmental organisations and the private sector are involved in its cultivation since it is in high demand for industrial purposes. Many farmers in Ghana have been encouraged to create commercial plantations of bamboo, as there is a high request for this resource for various industrial applications, especially in the design, manufacturing, and construction industries. Also, because bamboo can help to rehabilitate degraded lands, it is suggested that communities with degraded lands employ its propagation to restore the nourishment of the topsoils in communities of Ghana and other countries in Africa, as well as on a global scale.

Globally, commercial bamboo farmers are required to use an appropriate technology for the propagation of this resource in order to promote its sustainability. Bamboo does not depend strictly on inorganic chemicals such as insecticides, fertiliser and others for its growth in the natural forest. However, commercial farmers of bamboo do apply these chemicals for higher yields. Hence, appropriate methods of the application must be followed in order not to cause any negative effects on the land, as well as the entire ecosystem. Promoting bamboo conservation globally is recommended to make available (introduce) high-quality seedlings (breeds) or other planting stocks that can easily adapt to new environments (habitats) without much difficulty (Banik 1991).

2.2 Methods and Techniques of Bamboo Propagation

Bamboos can be propagated through the use of seeds (sexual) or by vegetative (asexual) methods, depending on the species available for plantations (Ramyarangsi 1988). However, not all bamboo species produce seeds, and even with those which do, the seeds are sporadic, as it takes about 30–120 years for some species to flower after which the parent plant dies off. Mostly in bamboo plants, the parents die off

just after flowering, and this is associated with those species which flower gregariously. There are only a few bamboo species that flower frequently to produce seeds and can be used to propagate seedlings when required. However, bamboo seeds have a relatively short lifespan that prevents its preservation for longer periods, and, if a longer storage period is required, then an intense and sophisticated drying technique is adapted to enhance drying, after which they need to be sealed in airtight polybags or other vessels. Bamboo species that do not flower to produce seeds for regeneration of seedlings have to be propagated through vegetative techniques, such as culm (stem) cuttings or rhizomes of non-clump species (Rao et al. 1989; Fu and Banik 1996).

2.2.1 Bamboo Propagation

Bamboo can be propagated using basic planting techniques such as seedlings, vegetative propagation through culm cuttings, and rhizome transplants (Rao et al. 1989; Fu and Banik 1996; Banik 2008). However, before using any of these methods for plantations or farms, the following factors needs to be critically examined, among many others:

- The type of bamboo species to plant.
- Determination of the size of culm after maturity.
- Determination of the growth habit of the selected species.
- Planting style to ease movement for maintenance in the plantation.
- The harvesting technique.

The propagation of bamboo seedlings in a new site can be done by using either sexual (seedlings) or asexual techniques from the bamboo plants from nursery-raised seedlings, directly planting cut offsets of the culm, or by rhizome transplanting. These parts are nurtured to grow to form new seedlings. The growth rate of bamboo depends on the species type and the method used in the plantation, as well as the environment in which the plant is cultivated. The cultivation methods are classified as sexual and asexual propagation (Banik 1995). A well-drained soil is critical for bamboo growth and habitat, hence, before planting the seedlings, the land needs to be surveyed to know the nutrient level of the soil, as well as the porosity of the soil and its propensity to flooding. Bamboo has been observed not to do well in alkaline, as well as waterlogged, soils. Hence, recommendations are that, preferably, bamboo plantations/cultivation should be situated on moderate slopes (Rao et al. 1989; Fu and Banik 1996).

Plantations of bamboos with a high yield of culms are those with a well-planned layout for distances between seedlings. This plantation allows for free movements of persons and equipment within the plantation and for sunlight to reach every single plant on the farm (Rao et al. 1989; Fu and Banik 1996). It is important to plant seedlings during the rainy season and, when necessary, apply manure in the

holes before planting seedlings to achieve high yields of bamboo culms. Bamboo seedlings need to be planted vertically in the holes, and the holes should be covered with the required amount of soil and then should be mulched. It has been observed that bamboo propagation highly depends on the species type, because some can only be propagated using culm cutting or rhizomes. In other words, some can also be propagated using seeds for high-quality yields of culms. Propagation of bamboo seedlings either by seed, culm, branch, or rhizomes cuttings requires a nursery, to enable regulation for a certain number of months or years, before being transplanted onto the farm.

2.2.2 Production of Bamboo Seedlings

The production of seedlings of bamboo is essential for regeneration of new propagules by using basic techniques, such as sexual (seeds) nursery, or asexual (culm cuttings and rhizome) transplants (Banik 1994). These production methods are discussed next.

2.2.3 Sexual Propagation

Sexual propagation is a reproduction method involved in producing new bamboo seedlings through the use of seeds (Rao et al. 1989; Fu and Banik 1996; Banik 2008). The seeds are necessary for propagation and reproduction of new seedlings. For large-scale plantations, bamboo seedlings are recommended as the suitable method of propagation because it has been scientifically proven that clumps produced from seeds tend to maintain their genetic originality (ancestral roots). Also, a high, maximum quality of culms is produced from a vegetation of clump bamboos which was originally propagated from seeds, and this can foster a longer life span for the clumps on the plantation. However, one characteristic of bamboos before seeds are produced is that the clumps die off after flowering. When seeds are produced, they have short-lived viability and hence, they should not be stored for long periods. To store them requires highly sophisticated drying, the correct temperature, and sealing techniques in a humidity environment. However, seeds stored under reduced humidity and temperature can only last for two years, after which they will not be viable for production of seedlings. Bamboo seeds have a high germination rate before deterioration if sown within s about three months. Bamboo seeds are first nursed in a nursery bed having a moist loamy soil. The seeds are sown by spreading them on the nursery bed after which the seeds are then covered with a required amount of moist soil to proper depth which can enhance its germination.

The nursery bed is required to be kept in shade, to protect the seedbed, as well as the newly germinating seedlings, from direct sunlight, and to provide a high rate of germination (Pattanaik et al. 2002). There should be constant watering to keep the seed beds, as well as the soil of the seedlings, moist. This activity should be performed in the early hours of the mornings or the evenings using fine rose-watering containers. To keep the soils moist on the nursery bed, but not have them in direct sun rays, the seeds in the nursery, as well as the seedlings, should be mulched in their initial months of nursing, thus protecting them. Mulching serves as a means of protecting the surface of the nursery bed from getting direct sun rays and from high impact by raindrops and rapid evaporation of soil moisture, as well as also to keep the soil under the seedlings moist. The primary materials usually used for mulching include; dry straws, grass, and leaves. The kind and the quantity of mulch depends on the time of sowing of the seeds in the nursery beds and the rate of growth of the seedlings. The nearly mature bamboo seedlings from the nursery can be transferred into Poly bags for full maturity before being transplanted at the farm or the plantation. See Fig. 2.1, a photo of a set of Poly bag pots ready to receive bamboo seedling for transfer from nursery beds in the process of sexually propagating bamboo.

The young bamboo seedlings are then uprooted from the nursery beds and transferred into polybags. The seedlings must be kept moist during this period of uprooting from the nursery as some amount of soil is attached to the seedlings. The process is done with much care so that the shoots of the seedling do not detach from the roots. A set of bamboo seedlings which are being transferred from the nursery bed to be planted into the row of polybags under the shade (Fig. 2.2).

Fig. 2.1 Rows of Poly bags ready to receive bamboo seedlings

Fig. 2.2 Bamboo seedlings being transferred from nursery into Poly bags

The stages of seedling growth labelled from A–D in Fig. 2.3 is explained here:

Stage A: Depicts the transplanting of the bamboo seedlings from the nursery into the row of Poly bags, which are kept under shade after one week

Stage B: Depicts the growth rate of the bamboo seedlings after one Month, under the shade in the row of Poly bags

Stage C: Depicts the growth rate of the bamboo seedlings after six weeks under the shade in the row of Poly bags

Stage D: Depicts the growth rate of the bamboo seedlings after eight weeks under the shade in the row of Poly bags.

Raising bamboo from seed is not as easy, as compared to rhizomes and stem cuttings. This is because most bamboos do not produce seeds, and those species that do flower and bear seeds take 30–100 years to bear flowers and subsequently seeds. The growing of bamboo from seed is, therefore, rare, and it is only through vegetative propagation methods that seedlings can be grown or propagated by growers (Banik 1994).

2.2.4 Asexual Propagation

This method of propagation makes use of the vegetative parts which includes rhizomes, offsets, and culm cuttings. These propagules are then carried to the nursery for regeneration of new shoots. The formation of new shoots from these propagules is allowed to mature and develop new rhizomes before being transferred

Fig. 2.3 Stages of growth of bamboo seedlings in Poly bags under shade

to their permanent place of cultivation. The types of vegetative propagation methods include offset planting, rhizome planting, culm cut planting, split culm cuttings, branch cuttings, layering, marcotting, and macro proliferation of seedlings (Banik 1994, 1995).

2.2.4.1 Bamboo Propagation by Offset Cuttings

The offset method of culm propagation requires the usage of a length of culm possessing between 3 and 5 nodes from the bottom (approx. 1–2.5 m) and having the rhizome axis and the roots attached. Offset propagation is said to be one of the appropriate methods of regeneration of bamboo seedlings. The culm employed in this technology should be between one to two years old (Rao et al. 1989).

Offset Cutting

The culm of bamboo is cut at a slant angle to a suitable length, after which it is uprooted from the ground with its roots and rhizomes intact, for the regeneration and development of new shoots (Rao et al. 1989). To ensure their survival in the field of the plantation, the following should be considered:

A healthy parent clump should be the source for collecting the offsets of bamboo and:

- One must be cautious not to damage the rhizomes and the attached roots during offset cutting.
- The rhizome is separated from the clump during offsetting, and usually the culm is taken from the outer ends of the clump.
- The buds on the rhizome are lightly pressed to see that they are not rotten.
- After uprooting the offset rhizome from the ground, it is important to cover the base portion of the offset culm in Poly bags or jute bags so as to have moist soil or wet sawdust filled in before being transported to the place of cultivation.

Treatments

The application of offsets culms of bamboo for cultivation on a plantation requires some basic treatments and technicalities before being transferred to the farm. It is advisable that, during the offsetting of culms from the parent clumps, care should be taken to make sure roots and rhizomes are not damaged in the process. Also, offsets materials need to be available at the planting site as early as possible before the rainy season starts. Planting of the offset should be done at the beginning of the rainy season to enhance the chances of survival. Before transplanting the offsets of the bamboo, it is important to collect them as early as two to three months before the planting season (Midmore 2009). The offsets can be collected and kept in a nursery bed close to the plantation temporally in a moist and loamy soil. The slant cut offset of culm is sealed with earth. When offsets are planted, it is mandatory to isolate the plants from other plants that may be competing for soil nutrients (Midmore 2009). Therefore, clearing of weeds and other plants from the plantations is necessary, using weedicides or using manual cutlasses and hoes to maintain the farm. The chance of survival of offsets plantation is 50% during an outbreak of drought, and, in such periods, watering is required for the plants' sustenance.

Limitations

- Offsets are bulky and weighty in a range of 6–30 kg.
- This method of planting is costly due to its labour intensity. Excavation and transportation to the site are expensive.
- One can only excavate a limited number of bamboo offsets from a clump. Harvesting of more than two to three offsets in some cases from a single clump may lead to regeneration of the parent clump and retarded growth until, at a certain time, it dies off completely.
- The method is unsuitable for developing large plantations.

- This method of propagation can only be employed in bamboo clumps forming species with thick walls (i.e. Melocanna baccifera).
- This method of propagation shows a 30–50% rate of success for Melo-canna baccifera and other bamboo species.

2.2.4.2 Bamboo Culm Cutting Propagation

Bamboo culm cuttings for propagation are segments of the culm (stem) usually consisting of one or up to between two–three nodes with buds or branches. This method of propagation applies to most clump-forming bamboo species and might not be suitable for species that are non-clumpy. Using this method of propagation is efficient when various pieces of bamboo culms are cut with a single or more nodes. The culm cuttings are then placed horizontally in the propagation beds in the nursery with the vascular culm tissue slanted into the wet soil at an angle (Rao et al. 1989; Zamora 1994). The nursery bed is covered with a shade cloth and is constantly watered until the cuttings sprout and the roots are well developed or mature up to a certain stage when they are then transferred into Poly bags. In this process, the nodes with more than one shoot and a well-established root system are carefully split into two or more divisions before being transferred into the Poly bags (Fig. 2.4). The bagged seedlings are then kept under the shade and are constantly watered until they are fully mature; they are then moved to the farm or another place of cultivation for transplanting. This form of propagation production can produce several shoots.

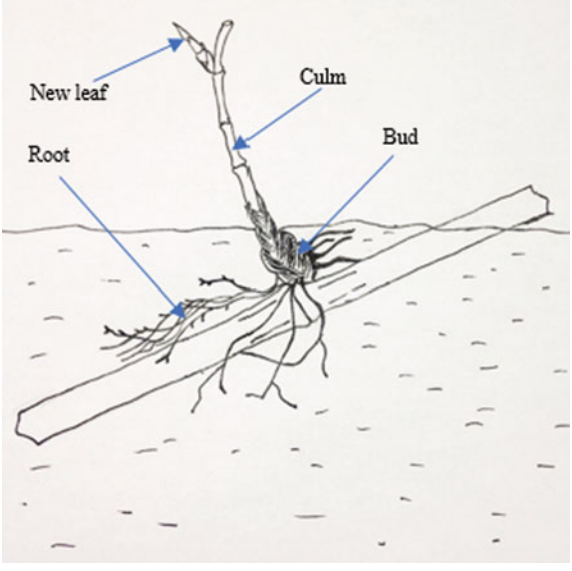

Fig. 2.4 Bamboo shoots propagation using culm cutting process

Bamboo Culm Cuttings

One of the methods used in germinating bamboo seedlings is from culm cuttings; the steps are as follows (Rao et al. 1989; Zamora 1994; Midmore 2009):

- A vigorous and healthy culm is selected for the cutting, preferably not more than two years of age.
- The parts employ for cutting are taken from between the base and the middle portion of the bamboo culm.
- The first cut of the culm should be about one–two inches below the node.
- The second cut should also be about one–two inches below the next node.
- The branches must be trimmed off, leaving only one or two at the node end.
- The part of the branches of the culm selected for propagation is cut to a length of 10–30 cm. Care must be taken not to damage the new bud with any sharp edge tool.
- The parts are cut with a sharp knife or saw. Care should be taken to prevent the culm from splitting during the cutting process, especially culms that have thin walls. There should be an allowance of 5–10 cm kept on both sides of the node on the culm cutting.
- The cut end of the culm is waxed immediately after cutting or segmentation and also covered with jute sackcloth which needs to be moistened or by being placed in loamy soil, thus reducing evaporation of water from the cut ends.
- The bamboo cuttings are then transported to the propagation or nursery bed
- The culm cuttings are then nursed in the bed or in Poly bags containing moist loamy soils.
- The bamboo culms are then inserted into the ground at an angle, covering the node and leaving the branches sticking out of the ground.
- A culm cut plants are watered constantly and regularly in the Poly bags or the nursery bed.
- The plants or the culm cuttings in the Poly bags or the nursery bed should be covered with a shade cloth.
- The culm cuttings need to be covered with soil occasionally when exposed to sustain the ground moisture through the process of mulching.
- When the bamboo sprouts and roots and the rhizomes are well developed in the nursery or the polybags, then they can be transferred to the farm or the site for cultivation.

Preparing the Propagation Bed

The size of beds for propagation of bamboo culm cuttings said to be one-meter wide by 5–15 m long, depending on land availability. Beds must be formed on a level ground and should be 20–30 cm deep. The ground or soil in the prepared bed should possess the following features. The bed should be covered with loamy soil and must contain 10–15 cm of sandy soil. The top layer of fine sand must range 10–15 cm over the base layer. It is suggested that the beds be three-layered to aid easy outflow of rainwater, whenever there is a continuous rainfall, to prevent water-logging (Banik 1994).

Placing Culm Cuttings in the Bed

The placement of bamboo culm cuttings in the prepared bed is required to be horizontal, and the space between culms must be in the range 15–30 cm. The process also requires that the culms be placed in the top soil layer, ranging from three–five cm above the sandy soil and then covered by three–six cm of the fine-sand soil finally. The bed is mulched to keep the soil moist, while the plants are kept under partial shade to have some degree of sunlight reaching them.

In the case where the internode is long (e.g. *Bambusa polymorpha* or *Schizostachyum lima*), the segment may have one–two nodes. Also, when the internode is short, segments with three nodes may be prepared for this propagation. For higher regeneration of seedlings, there must be more nodes on the culm for propagation. However, culm cuttings that are long create problems in handling and transportation.

2.2.4.3 Bamboo Propagation with Rhizomes

This process of propagation has been traditionally used to propagate non-clump forming bamboo species, where rhizomes are slightly leptomorph and long. These are rarely used to regenerate or propagate clump-forming species seedlings of bamboo with pachymorph rhizome types. The rhizome is an underground stem, which consists of two parts, namely the actual rhizome and the rhizome neck, which is the base of the original rhizome. The stem of the rhizome has nodes, but those of the neck always lack buds and usually roots (Zamora 1994). The original rhizome has roots or root primordia and buds at all of the nodes. There are two distinct types of rhizomes, which are called pachymorph and leptomorph.

Pachymorph Rhizomes: These rhizomes are characterised by a short, thick, curved and sub-fusiform and are rarely spherical in shape. The internodes of pachymorph rhizomes are broader and asymmetrical (i.e. larger on the side that bears buds). The shoots at each node are in a row, usually five each on the side of the rhizome. When pachymorph rhizomes are dormant, the bud is dome-shaped but asymmetrical (Rao 1989). The pachymorph rhizomes are distinguishable by having a top (upper side) and bottom (lower side), where more of its roots are produced. All tropical bamboos (e.g. the clump formers) have pachymorph rhizomes. Pachymorph rhizomes have short necks (e.g. *Bambusa, Dendrocalamus*, *Thyrsostachys*, *Gigantochloa*), but the species *Melocanna* sometimes has its elongated rhizomes (Fig. 2.5).

Leptomorph Rhizomes: Leptomorph rhizomes are cylindrical, slender, or sub-cylindrical in shape. They are usually narrower than the aerial culm. The internodes are long rather than broad, relatively uniform in length and symmetrical, hollow (rarely solid) with the narrow central lumen partitioned by a diaphragm, and nodes may or may not be raised or swollen (Rao et al. 1989; Zamora 1994). The node bears a single bud and a single row of roots, as typified by Phyllostachys. However, others buds are not available on their nodes, and roots may be sparse or absent.

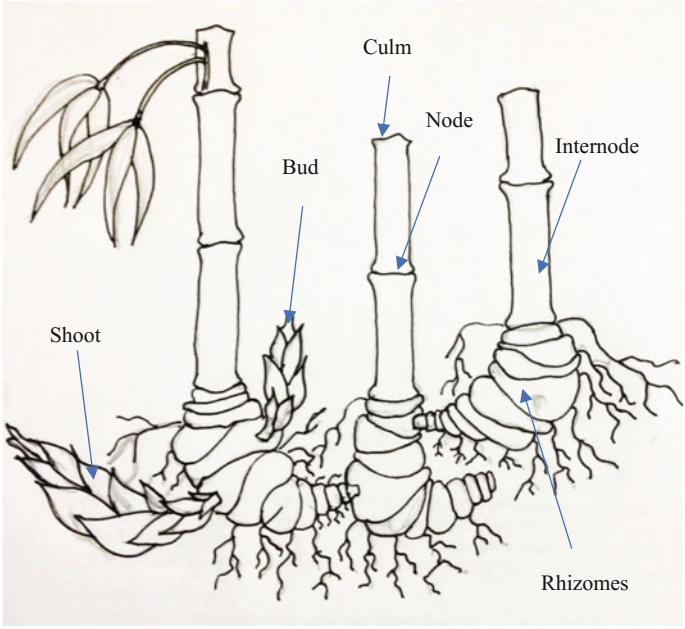

Fig. 2.5 Pachymorph (Clumpy) rhizome bamboo

These rhizomes are not distinguishable either by their bottom or top as most of the buds produce culms while some produce rhizomes. These types of rhizomes always have short necks. Some priority bamboos with leptomorph rhizomes are the non-clump forming species of Phyllostachys.

This method of propagation is applied whereby an offset or a rhizome of a culm from a clump is removed by digging around its rhizome and offsetting the rhizome from the main clumps. There are several ways to use leptomorph rhizomes with roots, and these include rhizomes with culm and roots and rhizome with culm-stock and roots. The rhizome with culm-stock and roots is similar to offset propagation, but there are a few differences (Fu and Banik 1996). This method of rhizome propagation involves separating culms from clumps and shortening them to the nodes above the culm, which is the most efficient method of reproducing young rhizomes into culms (Fig. 2.6).

Healthy rhizomes for propagation

- The rhizomes should be healthy and fresh in colour before being planted.
- They should not be more than two–three years old as those older than three years cannot produce high yield of buds, as well as shoots. When old rhizomes are used in the planting, the shoots cannot grow tall, leading to low-quality culms. The older the rhizomes, the less vigorous the production of shoots.

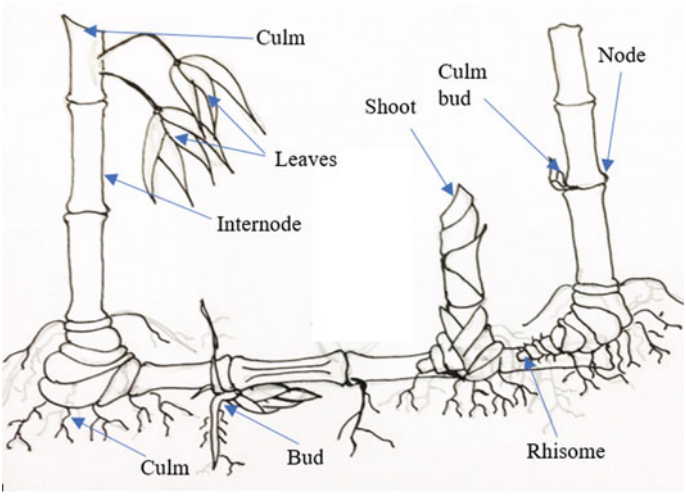

Fig. 2.6 Leptomorph (Running) rhizome bamboo

- When using rhizomes for this propagation, care must be taken with the rhizomes so that they are not damaged, as well as having enough roots around them.
- Rhizomes without culms are cut in a range of 50–60 cm long with about 10–15 nodes and with roots. In the process of transferring the rhizomes to distant places, care must take by wrapping them in moist peat moss or straw, after which they can then be covered with polyethene after the soil has been washed away.
- In this process of planting, some rhizomes need to be attached to the bearer's buds, while the rest are cut off.
- The young culms along with associated rhizomes and roots are used in this process. When the culm is young, its rhizome is maintained intact as compared to when it is large, since its top part can then be removed or the branches trimmed.
- This process is essentially for a rhizome with roots between 30 and 60 cm of the basal portion and connected to the culm only.

Post-Collecting Treatments of Rhizomes

The post-collecting treatment is when only rhizomes are used in the planting process. The rhizomes are collected and then laid horizontally to root for a period in a nursery. Another variation of this method is transplanting the rhizomes directly into the field or the farm after excavating them from a clump of bamboos. When laying them in the nursery bed to root out, the standard arrangement employs a ratio of 3:l soil with sand with the rhizomes planted 10–15-cm deep, the plants are separated by 25 cm (Banik (1997). Watering of the rhizomes is necessary, as well as a straw mulch to enhance growth. They should be kept under shade when young shoots emerge.

When large plants are to be produced from one piece of rhizome, they are separated in a range of one-to-two sprouts per piece. The piece should consist of three–four nodes each, with an intact bud at least 15–20-cm long. The rhizome may affect the survival of the shoots when its length is longer since a large amount of nutrients are required to enhance the growth of new buds. The species of culms with thick diameters require rhizomes with a length about five times the basal girth of the culm. The normal rhizome length for *Phyllostachys* is 2 cm. Planting of the bamboo rhizome is mainly for smaller plantations since it is labour intensive for larger farmlands as compared to using seeds (sexual propagation). It must be noted that planting of rhizomes is appropriate and efficient during the rainy season (Zamora 1994). The procedures for the planting of rhizome cuttings of bamboo directly on the farm is the same as that of planting stock from nursery raised seedlings, except that the cuttings are going to be planted directly in the field holes without putting them in Poly bags. To attain an efficient rhizome planting process in the plantation or farm, the following factors should be carefully observed:

- One must haul the offset cuttings to the planting site.
- One must loosen the soil in previously prepared planting holes.
- The cut rhizome is to be planted in a vertical position, with the lowest node of the culm offset above the ground.
- One must place the cutting at the centre of the planting hole and fill up the hole with soil, ensuring that the culms stand firmly in the holes.
- There should be regular watering of the plant, and mulching around the hole keeps the soil moist.

There is a limitation regarding its propagation as it is labour and time intensive removing the rhizomes. Hence the number of propagules to be extracted for larger farms or plantations will be limited. It is only appropriate for smaller farms.

2.2.4.4 Bamboo Propagation by Branch Cuttings

Planting of bamboo using branching patterns varies among several types of bamboos. The planting of the bud or culm node can potentially produce a branch, however, in many species, the original branch remains dominant and stout (Rao et al. 1989). In some others, buds are widely branched, while the original bamboo branch is uncertain from the other branches around. Each branch is a stem material. Primary stout branches have swollen bases, and this looks like the underground rhizome (usually referred to as a rhizomatous swelling).

Use of Branches instead of Culms

The process of planting bamboo through the use of branch cuttings is an effective method as the material can be handled very easily compared to bamboo culms. In this process, the thick-walled bamboo species with buds are ideal for planting (i.e. *Dendrocalamus* spp., *Bambusa* spp.). In this method, the likelihood of survival

of the branch is only 50% assured, as in *D. hamiltonii* species. However, this method of planting bamboo or growing seedlings of bamboo is associated more with *D. asper* species. In most cases, it takes about 6–12 months nursing a branch plant to root and between 12–20 months for its rhizomes to develop the process of producing culms. Bamboo species that yield small branches at the top of the culm (e.g. *Thyrsostachys* oliveri and *T. siamensis)* cannot be adopted using this technique (Zamora 1994; Banik 1995).

Reduced Regeneration Time

It is necessary to reduce the regeneration time of branch cuttings in the field, since some branches may show natural aerial rooting with rhizome formation. The reduced regeneration is seen especially on injured culms and in congested clumps. When cuttings are taken from there, they are known as *pre-rooted and pre-rhizome branch cuttings.* Additionally, this method is can be used to stimulate growth of aerial roots and rhizomes near the base of branches. Regeneration time is significantly reduced when such materials are used.

2.2.4.5 Pre-rooting Propagation in Bamboos

Pre-rooting propagation of bamboo is a planting practice whereby the top part of the culm is chopped off or removed to allow for new culms to emerging from the clump. The latter, if done continuously for two years, is more efficient.

2.2.4.6 Pre-rooted, Rhizome, and Branched Propagation

In this process, the cuttings are prepared as follows:

- Roots should appear healthy.
- Branches should be selected from between 1 and 2 year-old culms.
- Branches should be cut from the culm using a saw. Using a cutlass or knives leads to the splitting of the culm.
- Branches that bear aerial roots, buds, and sometimes rhizomes, though not always, are selected.
- Well-drained and loamy soils kept under moist conditions are used to nurture the branches of bamboo.
- The branch cuttings are prepared by trimming leaves, small branches, and the branch tip with secateurs.
- The branch is trimmed between two–six nodes with fresh buds.
- The cuttings are planted into the nursery bed at two–three cm apart and the base at a depth of seven–ten cm. The sand formed around the base of the culm is then pressed firmly. Organic manure from animals and plants are used to cover up the exposed cut-off ends of the culm.

- The sprouting of the bamboo shoots occurs within a week or more. The roots of the new cutting will take between two–three weeks to start growing and as long as five–twelve weeks to fully develop.
- The culms start to develop immediately from 30 to the 60 days from the cuttings.

The cuttings should be taken from the bed before the new culms are produced and transplanted in Poly bags (15 × 23 cm) containing sandy 1oam and animal manure in a ratio of 3:l. The culm branches that are transplanted cuttings get hardened under shade for three–five days, but care is taken to make sure that the Polybags are well drained to prevent rotting of the culm cuttings.

2.2.4.7 Layering Bamboo

The layering of bamboo is a method of bringing a culm or branch in contact with soil so that propagation occurs. There are four methods of layering, namely: ground or simple layering; stump layering; air layering or marcotting; and seedling layering.

2.2.4.8 Ground Layering

The process of ground layering is whereby the whole bamboo culm or part of a branch of the culm is buried in a trench in the ground and enclosed with soil. In this case, young bamboo culms are used for layering. The top section of the culm is cut off to allow stimulation and growth of shoots. Branches and leaves on the upper part of the nodes of the culm, except for lower branches, must be kept at four–five nodes on each culm (Banik 2008). Bamboo species such as *Melocanna baccifera* with no main branches are trimmed into smaller branches. Species which can be used for this method include *Bambusa glaucescent, B. polymorpha, B. textiles, B. vulgaris*, *Guaduaangustfolia*, *Dendrocalamus giganteus*, and *D. long spathous*.

The main limitation associated with this approach is when the clumps are cultivated close to each other, making trench layers in between them difficult. This restriction of planting the culms too close to each other is so because the size and depth depend on the size of the culm being laid. The culm rooting medium used in ground layering involves the application of dry corn husks, dry leaves, dry coconut husks, and other dry weeds to cover the bamboo culm layering 5–9-cm deep in the ground. Regular watering is needed, but waterlogging must be avoided. The process of mulching around the culm will enhance the moisture of the soil.

2.2.4.9 Stump Layering

This process involves cutting the bamboo culm from the base of the node allowing for two–three basal nodes. Rooting materials such as dry corn husks, dry coconut husks, dry leaves, and other dry weeds are used to cover the stump on the ground. This approach is uncommon, and it was only reported to have been successful with the *Bambusa longispiculata* species. In this method, the stamps should only be covered by one–two cm of material. The application of 200 ppm IBA concentration is employed to treat the stump before covering it in the ground to produce shoots. However, sprouts usually emerge between 150 and 180 days after cutting the culms.

2.2.4.10 Seedling Layering

In this process of layering, the seedlings from the nursery bed must be 6–12 months old. The seedlings should be laid by placing them horizontally on the sand footing medium, and the culms are buried between 1.5 and 2.0-cm deep, but branches on the nodes are allowed to project above the ground (Banik 1995). Most seedlings at this age have three–four culms each with six–eight nodes. This technique is particularly effective for *Bambusa polymorpha* species, but shows low success with some other species, particularly B. *bambos,* B. *tulda,* and *Dendrocalamus strictus.* Usually, roots develop at the nodes in 60–90 days. The new shoots of plants are separated by cutting with secateurs and transplanting into Poly bags containing fertile soil.

2.2.5 Macro-Proliferation Methods

Macro-proliferation is the method of using cut bamboo rhizomes to produce multiple seedlings based on their ability to proliferate (Zamora 1994). The rhizomes to be nursed, when cut into pieces for planting or nursing, need to have roots and shoots, whereas single seedlings can produce multiples of shoots and seedlings ranging three–seven times depending on the species of bamboo. The method has been successful with seed producing bamboo species. Seeds are nursed in polybags as well as in nurseries immediately when they are collected from the field to produce the seedlings.

2.2.5.1 Raising Seedlings by Proliferation

Normally 15 × 23-cm polybags, containing soil, natural compost from decaying plants, or manure, as well as inorganic fertilisers, in the ratio of 3:1, can be applied.

The species that forms clumps produce about 48 culms over 150–270 days when they are ready for an increase.

2.2.5.2 Proliferating Seedlings

When the soil is washed from the root and rhizome system of the bamboo plant, then the old roots may be trimmed. Firstly, the rhizome is cut into pieces, each is replanted, and then hardened under shade for three–five days, while kept well-watered. After that, the transplanted pieces are brought to the nursery bed under the sun. The bamboo seedling can be multiplied in this technique during any month of the year, and its survival rate is 90–100%. As the young seedlings develop, they, in turn, can also be used as first seedlings from which new proliferating pieces can be produced once again (Zamora 1994; Rao et al. 1989).

This method is advantageous because, once seedlings are available, the process can be continued throughout the years of its survival. Proliferated seedlings are small in size, hence they yield a significant number of plants. The only disadvantage associated with this method is that, if the propagation continues for many years, then the multiplied plants might approach physiological maturity or flowering in later years. It is more advisable not to keep relying solely on this method of seed stocks, as there is a possible narrowing of the genetic base. Thus, different provenances or genotypes of the plant should be used, and, for each original seedling, the last multiplication should not exceed ten years (Fu and Banik 1996).

2.2.6 Post-care of Bamboo Cuttings

2.2.6.1 Poly Bags

The use of Polybags for potting of bamboo cuttings is, nowadays, considered standard practice. They are readily available and reasonably inexpensive for handling a large number of bamboo propagules. The polybags used for potting depending on the nature of the cutting and the species vary in size. Some common sizes and their uses are:

- Culm cutting: must have width 40 cm, height 50 cm, thickness 0.1 mm
- Branch cutting: must have width 15 cm, height 23 cm, thickness 0.1 mm
- Layered seedling: initially 10 × 15 cm, and 0.06 mm thick and finally 15 × 23 cm, and 0.06 mm thick

Bags usually used for potting are black. However, transparent Poly bags can also be utilised for the potting of culms. When bamboo culm cuttings are raised, it is not advisable to transplant them immediately in the same rainy season into the field. They can be prepared at least two-three months before the rainy season for

well-developed rhizome systems to be produced. The cut culm seedlings in the Poly bags need to be in the nursery for about nine–ten months before they are planted and must be planted in a rainy season.

2.2.6.2 Selection of Land Site for Nurseries

In choosing a place for cultivation of bamboo and its product, one should take into consideration that its siting must be near where the seedlings are nursed in the seedbed for the seedlings to mature. The next sections treat further considerations.

2.2.6.3 Poly-bag Usage in Nursing Seedlings

Nursing of the seedlings of culm cutting in Poly bags should first be kept under shade for a number of days or weeks under partial sunlight in the 50–60% range. They can then be exposed gradually to full sunlight after a week. The polybag sizes employed in nursing seedlings of bamboo include large, medium, and small. The polybag usually are arranged in blocks of rows side by side with the bigger sizes in blocks four-bags wide; the medium and small sized ones are arranged in 10–12 and 15–17-bag wide blocks. However, a block with a width of 1.0–1.2 m is found to be ideal. Routine weeding and regular watering, as well as applying fertilisers, becomes difficult when blocks of seedlings in Poly bags are wider than the recommended 1.2 m dimension (Rao et al. 1989; Pattanaik et al. 2002). However, the block length can be adjusted to take into account the available space of land for the nursery. The adjustment of polybag arrangement can be 4–6-m blocks to minimise overcrowding and over shading. There should be 0.7–0.8-m wide footpaths of polybag arranged in blocks for accessibility by workers and for transport (Banik 1997; Midmore 2009).

2.2.6.4 Choice of Nursery Site and Nursery

The choice of nursery site for a bamboo seedling nursery is essential when propagation. As polybag are left for extended periods of time (i.e. six–eight months), cuttings produce strong rhizome systems and roots that can penetrate neighbouring polybags creating an intermingled rhizome and root mass of cuttings. The choice of site for a nursery is always a challenge when it comes to selection for propagation. It also creates a problem for the transportation of cuttings of culms from the nursery to the farm or site. Care must be taken during the separation process of the polybags not to disturb the roots, and the rhizomes in the Poly bags when shifted from one bed to another at three-month intervals and to minimise challenges. If any culm

cutting starts producing flowers, it is to be marked. It must be noted that the flowering cuttings will die and therefore, should not be planted in the field (Rao et al. 1989).

2.2.6.5 Routine Activities Carried Out on Nursed Plants

The nursed bamboo plants require regular weeding, watering, and addition of soil to the bags, as and when needed, to help prevent washing of soil from the nursed plants as long as the cuttings are kept in the nursery beds. The few problems associated with bamboos such as pests, insects and animals attacks are treated with care in the nursery beds. Insects and pests which attack the nursed plants are sprayed with insecticides or pesticides,while the nursed areas are fenced to prevent wild and domestic animals from feeding on the plants' leaves and the shoots emerging from the ground (Banik 1994).

2.2.6.6 Field Performance of Various Planting Methods

The percentage of culm branch cuttings and macro-proliferation seedlings are superior to those of offsets and rhizomes. The size (height and diameter) of the fully-grown culms produced by offsets, rhizome, and culm cuttings are comparatively greater in the first year of plantation than those generated by branch cuttings. However, due to juvenility and the dynamic nature of the rhizome system of branch cuttings and proliferated seedlings, within three–four years, culms attain more or less similar sizes as those of offsets and rhizomes. Once the clump is well-developed (i.e. in five years), the seasons of planting, the originated branch cutting, or the offset becomes impossible to distinguish between (Banik 1995).

2.3 Pre-planting Operations

Several factors need to be considered before transporting bamboo seedlings propagated from seeds or vegetative stems or rhizome methods to the farm for transplanting include (Banik 1994, 1995; Fu and Banik 1996).

- Selection of land or planting site for the cultivation (type of soil, type of species to plant, climatic conditions).
- Preparation of land or planting site (clearing or weeding, burning of weeds, uprooting of stumps, levelling of land, etc.). The land site can be prepared using manual labour or mechanised methods.
- Propagation techniques or methods (seeds or vegetative propagation).

2.3.1 Selection of Land Site for the Cultivation of Bamboo

- Though bamboo species grow well in a wide range of soils under the right climatic conditions in an area having an altitude ranging from sea level to 1500 above sea level, it is important to critically look at the land or site selected for the cultivation. The land for a plantation must be fertile, because the quality of the soil enhances the growth speed of the bamboo. Hence, the site or land for the plantation is required to have fertile soil, which is moderately acidic, loamy soil, with a high-moisture content and preferably a pH of 5.5 to enhance the growing off well-developed quality culms (Banik 1994, 1995; Fu and Banik 1996).
- The loamy soil contains a good balance of clay, sand, and silt particles. Whenever the land is known to include soils that are too sandy or clayey, they can easily be modified using mulch and composts. Sandy soils drain too quickly and retain only a few nutrients, while clayey soils become waterlogged and trap nutrients in the ground, making them unavailable to the bamboo. Thus, soils can be improved by adding manure when sandy, thus providing drainage in the plantation for easy flow of water and also by adjusting the pH level.
- Tropical to moderately temperate climates are best suited for raising high-density plantations of bamboo seedlings.
- Selecting the type of species to plant at the land site is also necessary since some grow well in particular soils and geographical areas.

2.3.2 Preparation of Land or Planting Site

- After selecting the site or land to be used for the plantation of the bamboo, it is necessary to first weed or clear the land of all weeds and other plants on the site, either by manually or by mechanised means. If there are stumps on the land, they must be uprooted and removed as they may regenerate to compete with the growth of the bamboo seedlings (Banik 1994, 1995; Fu and Banik 1996; Pattanaik et al. 2002).
- The weeds and the other plants that have been cleared from the land are then burned on the ground once dry, especially in the dry season or allowed to decompose into the soil.
- The site is then levelled to prevent collection of rain or irrigation water on the plantation, particularly when stumps of trees and other plants have been removed. The land preparation can be done using manually or by mechanically.

2.4 Planting of Bamboo Seedlings

Planting of bamboo in the farm can be done using seedlings, culm cuttings, or offsets of rhizomes. When using seedlings nursed from seeds or culm cuttings that are grown in a nursery in the polybags, then it is necessary during planting to cut off the polybag to remove the mature seedlings before placing them into the dug pit. However, critical care needs to be taken in order not to disturb the rhizomes and the roots of the plant. After placing the plant in the pit, soil should be mound around the plants by pressing it with the feet.The surface of the pit after filling needs to be slightly sloped to one side to help maintain moisture around plants. In the case where a rhizome is being used as a seedling for a plantation, it must be noted that the technique is not different from the former. However, the depth of planting rhizome seedlings would be greater than that of the seeds and the culm cutting seedlings. Depending on the parent clump size, plant spacing of bamboo can range from 4×4 m to 10×10 m. Higher densities of spacing are appropriate for smaller sized bamboos, while lower densities require more space, which is suitable for larger bamboos (Zamora 1994; Banik 1994, 1995; Fu and Banik 1996; Pattanaik et al. 2002).

2.5 Post-planting Operations

Even though bamboo does not need much maintenance, to ensure its sustainability and healthy plantation, several post-planting activities must be carried out. Some of the post-planting processes require urgent attention during the early stages of the bamboo plantation while others are the subsequent steps. This maintenance process includes: replacement of dead seedlings; maintenance of culms and clumps; maintenance of soil; mounding; mulching; weeding; pest and insect control; pruning;, and so forth.

2.5.1 Replacement of Dead Plants

The newly transplanted offset cuttings and nursery seedlings will not all survive in their new environment. Hence, close monitoring is a critical requirement to ensure the survival of the plants. The dead seedlings (culm cuttings, rhizomes, and seedlings) that do not survive should immediately be replaced, and constant watering is essential for their survival.

2.5.2 Culm Maintenance

The maintenance culture of a plantation should be taken into serious consideration. Maintenance on the plantation is mostly done during the first two years after planting to protect the young plants from competing with other vegetation, pests, and rodents. After the first two years, maintenance activities are mainly confined to clump maintenance.

2.5.3 Maintenance of the Soil

The need to improve soil aeration around the plants to have healthy rhizome growth and shoot production is paramount, especially during the dry/summer season, and this is accomplished by keeping the soil moist. This practice also enhances the water retention capacity and the fertility of the soil. It is important to loosen the soil during the first year of a seedling plantation because this helps to correct the soil's air permeability, and temperature, and to decrease the number of weeds growing in the plantation that may compete with bamboo seedlings for nutrients and water, as well to improve the soil's chemical and physical profiles. Hence, this practice can be done about twice or thrice a year for each plant to enhance their growth. In the process of loosening the soil around the bamboo plant, care must be taken not to disturb or damage the rhizome system underneath (Fu and Banik 1996).

2.5.4 Weeding

The growth of bamboo plant is hampered by weeds which also compete for food and water with bamboo plants. These weeds compete with bamboo plants for nutrients, sunlight, and water. Constant weeding of the plantation is necessary to enhance the establishment of rhizomes and roots of the bamboo, as well as clumps. Weeds and stumps have rhizomes which sprout again if not removed (Fu and Banik 1996). It is critical to control and arrest the growth of weeds and other plants around each bamboo clump. When this is not done, then invariably it will result in poor root and stem development in the young bamboos plant. Weeds should be removed thoroughly, systematically, and regularly. It is critical to keep each bamboo plant clear of weeds and vegetation in a 0.6-m radius. Weeds should be removed when the soil is moist and also properly disposed of and burnt when dry. However, when the clumps of bamboos become well developed, they start to shed their leaves which prevent the growth of competing weeds and other plants within the plantation (Fu and Banik 1996).

2.5.5 Pests, Insects, and Animal Protection

The presence of parasites, insects, and grazing animals within the environment of the bamboo should be systematically controlled during the early stages of bamboo growth. In areas or communities where there is a likelihood of animals invading the plantation to graze on the plants, protection for the seedlings must be taken seriously to prevent the animals access to the farm and, by so doing, to maintain the quality growth of the seedlings to be produced. Fencing of the plantation is mostly associated with smaller plantations, while, for commercial farming, appropriate supervision is suggested to prevent grazing because fencing a large area is more expensive, considering the longer duration it might take for the bamboo seedlings to mature fully as culms. To monitor and control any defects or outbreak by insects and animals on the plantation, it is necessary to patrol the length and breadth of the farm to check each plant for damage, to assess the cause of damage, and then to find remedies to solve the problem. Bamboo is not easily attacked by pests and insects while on the plantation. However, those insects and pest that do attack it can easily be controlled by using appropriate pesticides and insecticides should there be an outbreak. Such untreated occurrences tend to hinder the growth and quality of the culms.

2.5.6 Mulching

This farming process has proved to be an effective means of improving the growth of bamboo plants in the plantation. Mulching is vital in plant cultivation, more so during the dry season, and bamboo needs a rainfall not less than 1000 mm. Growth is also enhanced by reducing evaporation of water from the soil when the plant is protected from direct sunlight and when the growth of weeds around the clumps of bamboo is checked. Branches and tips of harvested culms, sheaths, and leaves, which accumulate at the bottom of the bamboo clump and over time, serve as a manure to the plant. The process of uniformly spreading layers of leaves, branches from parent bamboo, and other organic material on the soil surface results in decomposition at the base of the culm that serves as mulching materials, as well as manure. When the natural decay of the mulch releases nutrients, it also does improves the soil moisture through organic carbon increment. This process is described as an efficient method to prevent rapid growth of weeds on the farm, as well as serve as a medium to check evaporation of excessive water from the soil under the plant. This process is a requirement that needs to be followed if high-quality bamboo seedlings are to be produced. Juvenile shoots require mulching because it provides protection from direct sunlight and ensures soil moisture, which ultimately results in the optimal growth of the bamboo without hardening and losing their good quality.

2.5.7 Soil Mounding

This method of maintenance on bamboo rhizomes and roots in clumps is usually done to prevent retardation in the growth of rhizomes when they are exposed in the soil to sunlight. Maintenance of clumps occurs when the clump is getting older, and the soil around the clump has been eroded, as the soil moisture tends to also be reduced, as well as the soil nutrients. Mostly these challenges occur when roots, emerging from the rhizomes and needing soil to grow sufficiently into culms, tend instead to be left to the mercy of the direct sunlight. The rhizomes and roots systems are critical parts of bamboo as they are the main networks that hold the tall and cumbersome culms in the ground. When the rhizomes are from sympodial bamboo, they grow horizontally from beneath the soil, while the new shoots grow upward from the soil. However, if these rhizomes and roots are not covered with soil, the culms may fall over to the ground if any strong wind or rainstorms should occur, since they lack enough soil to hold them. Soil mounding is usually done on older plantations of clump bamboos with the rhizomes being exposed from the soil. To prevent the tall and cumbersome culms from falling over at the occurrence of rain and storms, first old soil around the clump must be loosened, and then new soil should be mounded around the clumping bamboo to a height of about 20 to 60 cm, covering the base of the clumping bamboo.

2.5.8 Pruning Clump of Bamboo

This process involves removing large branches of culms and branches at the bottom of the clump to prevent congestion. If this is not done, it will affect the development of the new shoots. Pruning of bamboo branches can be done after the clump is three- years old and repeated every year. The thick and excess branches and culms of dried and dead branches, as well as other culms, are removed from the clump to allow for quality culm forming. Also, to permit access for new shoots to germinate, pruning and thinning facilitate growth.

2.5.9 Clump Management

The practice of proper management of bamboo clumps on a plantation or farm and attention to the sustenance of the plants foster high-quality yields of culms. Bamboo clump management provides not only high production yield of culms but also provides easy maintenance on the plantations of clumps on the farm. This system of management is necessary when culms grow close to each other in a clumpy area, making quality development of juvenal shoots difficult in some species. The clump management system is sometimes described as a partial a harvesting process,

whereby unwanted culms areremoved from the class of clumps to prevent congestion in the plantation.

The maintenance of a bamboo clump is necessary for regeneration of new shoots of culms. Firstly, all unwanted branches need to to be thinned or pruned off from the interior sections of the clump, allowing it to form a "C shape" to facilitate and create an opening in the bamboo clumps (Fig. 2.7). Mostly, this can be accomplished only when a systematic management scheme is put in place to monitor the bamboo on the plantations. However, proper maintenance of clumps enables a 90% possibility of germination of new shoots, mostly at the outer boundaries of the clump, while the clump broadens in extent and the mature culms are dominant in the inner section. When cultivators of this resource plan for systematic management of clumps, sustainable development of bamboo and maximisation of productivity for a maximisation are fostered.

When no systems are created to manage the clumps on the plantations, the clumps tends to get overly congested, resulting in the deterioration of the bamboo quality, as well as quantity. It is critical to know that when clumps are congested, it is not easy to harvest culms because many young culms from the clump may end up being destroyed. When proper management of clumps is always practised in bamboo cultivation, harvesting of culms can be done without any difficulty, and both high quality and quantity of bamboo culms are produced. A management

Fig. 2.7 A class of clumpy bamboo to be managed through prunning

technique known as thinning, which is employed on a bamboo plantation, helps to provide space in a clump for the emergence of new buds. Practically, thinning involves sacrificing some culms in a clump to make possible better shoot production. It is also necessary to remove older culms, as well as dead and rotten culms, from the clump of bamboo to enable healthy growth of the younger shoots. Much attention needs to be placed on the already harvested culms that become rotten in the stubs and need to be removed from the clump by digging the rhizomes completely from the ground using axe or pickaxe. Also, it is important to make every attempt to extract any identified infected culm which is rotting from the group of clumps. Any further infectious disease should be reported to a pathologist who should suggest the required remedies and control measures to eliminate the disease.

2.5.10 Protection Bamboo from Fire

Bamboo seedlings, when planted on the farm, need to be protected from fires, which may occur from nearby bush or from within the farm. In the case where seedlings are well grown on the farm or the plantation with mature roots and rhizomes beneath the soil, it may not be too serious if a fire occurs. The mature culm may have its upper section destroyed without affecting the bottom of the plant that comprises the roots and rhizomes of the culms. However, young seedlings with immature roots and rhizomes may be highly affected by any outbreak of fire. The young bamboo plants' upper and lower sections, comprising the roots and the rhizomes, may all be destroyed during the fire. However, if the upper parts of the mature culms are destroyed, with the start of rains or with the provision of irrigation to the site to enhance the soil's moisture, the bamboo culms would easily sprout again. However, in the case where the roots and rhizomes systems are totally destroyed, there must be a replanting to replace the dead seedlings. It must be noted that the affected plant's growth and the quality of the regenerated bamboo will be affected.

2.6 Harvesting and Handling

Efficient management of bamboo clumps involves the systematic harvesting of mature culms from a group of clumps without affecting the environment of other culms, and this enhances continuous sustenance of production of culms. When this procedure is followed carefully on the plantations, it tends to increase the annual yield (Farrelly 1984). However, harvesting of bamboo culms on the plantation depends on the type of species that have been cultivated, since some species can be harvested after four years and others not until after six years. Harvesting from a clump of bamboo that has been scientifically managed through proper pruning, thinning, and fertilising does enhance annual harvesting of culms through proper

management programs. A well-thinned clump from the early stages of planting gives a quality yield of culms, since spacing in a clump enhances efficiency in the harvesting of selected culms. The implementation of proper supervision of harvesting culms promotes regeneration of young shoots of culms based on which a constant supply of raw bamboo culms for industrial purposes is sustained.

The cutting off of the mature culms also helps in maintaining the vitality of the plant and also ensures germination and regeneration of new shoots. When harvesting mature culms, it is advisable to harvest culms which are older than three years, and only about 70–80% should be harvested, leaving about 20–30% of the mature culms to protect the young seedlings in the group of clumps. The reason for this practice is to ensure the young culms do not fall over as a result of high winds or storms, and this does help the growth. Culms that are in the age range of one–two years should be cared for during the harvesting of matured culms, along with a few of the three-year-old culms that are vigorous. This process would help the culms left in the clump to mature and also to regenerate young culms along with the already developed ones, after which, they may also be harvested. It must be noted that, as bamboo culms age, they deteriorate and eventually, die off and rot.

However, sustenance of bamboo clumps for regeneration mainly depends on healthy rhizomes systems from the class of clumps, which annually regenerates new shoots that develop into culms.

There are no records about the age of bamboos growing in natural forests, and due to this, it is impractical to use the difference during harvesting. However, bamboos that grow in their natural habitats regenerate and remain sustainable throughout their life cycle, whether harvested or not. Since harvesting of bamboo on a commercial farm or plantation depends on factors of species and age for its harvesting and handling, it is suggested that proper records need to be strictly maintained. It is recommended that a new plantation of bamboos should have its first harvesting six years after the time of cultivation. However, annual harvesting of culms can take effect after the first six years, or it can be determined within the ensuing years.

Sustenance of the culms in a clump is required for continuous harvesting, so therefore the implementation of an appropriate cutting of culms needs to be strategically implemented for quality bamboo plants. Bamboo sustainability integration is regarded as a mean of enhancing culm production and the life cycle of clumps, which largely depends on how efficiently the culms are selected during harvesting and how the extracted culm are processed into diverse products

Harvesting of bamboo culms from their natural habitats (forest) or a plantation is very laborious, and, because of this, it is suggested that efficient harvesting equipment need to be employed in this process to induce stress on those involved in the harvesting.

Suggested harvesting procedures to apply for bamboo culms include:

i. Bamboo culms selected in the harvesting process must be older than six years, if that is the first harvest since its cultivation, while for subsequent years it could be annually.

ii. Harvesting of selective culms from the clump require leaving an allowance on each culm ranging 0.15–1.3 m above the ground, or immediately after the first node above the from base. Cutting the culm to the given dimension and at the required point helps prevent stagnant water from accumulating in the internode as this could lead to insects breeding in them, as well as culms rotting.
iii. Harvesting of mature culms from a class of clumps is more appropriate done in the dry season of the year as compared to rainy season. It has been observed that starch content of culms reduces in the dry seasons, and, by this period, the culm is resistant to attacks by wood borers.
iv. Harvesting of culms from clumps needs to be carefully observed during the exercise in order not to cut the juvenal culms, as they might be fragile and the slightest touch of a sharp tool edge may easily destroy them.
v. Matured and healthy culms (three–five years) must be selected for harvesting.
vi. Culm harvesting should start from the central portion of the clumps since most of the matured culms are located in the inner sections.
vii. Harvesting of the culms must be performed with very sharp tools, and the harvesting tools should be disinfected using bleach as this can prevent any bacterial-risk infection to both the harvested and unharvested culms.
viii. Harvesting of quality and matured culms should not be above the juvenal culms in the group of clumps, as they need protection from the matured culms to shield them from a storm or the wind, so they do not collapse.
ix. Harvesting from a group of clumps requires leaving a sizeable number of culms in the groups of clumps for their sustenance. However, in an outbreak of disease in a clump, total cutting of culms is suggested to limit spreading to other clumps.
x. Harvesting of matured culms is recommended during the dry season of the year unless control of congestion from the clumps is necessary.
xi. Harvesting of culms from the class of clumps with the aim of preventing congestion and also maintaining high accessibility to culms in clumps should be executed with the technique of forming a C-shaped opening. This technique must make room at the periphery for the emergence of new shoots, resulting in the growth of multiples of culms.
xii. Harvested culms should be immersed in reservoirs filled with water or in rivers to aid leaching of starches and sugar from the culms. The leaching process provides resistance to insects and fungal attack on the culms, as these pests primarily feed on culm nutrients for survival. Storage of harvested culms in a river or tank can require take days or weeks for their preservation.
xiii. When there are no rivers or reservoirs of water at the site to treat them, they can be hauled to a flat-surface area where they can be air dried to aid in the reduction of biodegradation of the culms. The culms should be placed on the wall horizontally at an angle of 60% to allow for adequate ventilation to dry the culms.

xiv. The branches and leaves produced from the culms as waste material should be used as a mulching material on the remaining group of clumps, as it may serve as organic manure after its decay and hence enrich the soil.

2.7 Attacks on Harvested Bamboo

Immediately once bamboo culms are harvested, they are exposed to various forms of attack by pests, fungi, and insects since it is a weak material, and these pests, fungi, and insects can cause decay in a culm when it has not been treated on time (Mohanan 1997; Xu and Wang 2004). Some examples of fungi and insects include powder post and beetles, respectively. Bamboo culms lose quality as soon as fungi or insects attacks the culms, deteriorating its properties and applications value. There are different kinds of fungi and pests that may attack and destroy the entire culm if not properly treated. Also, when bamboo is harvested and the culms packed on each other without proper treatment, they become more vulnerable to these insects, fungi, and pests.

2.8 Insect Attacks

An insect is a small arthropod with three parts (head, thorax, and abdomen), having two pairs of wings and three pairs of legs. They are noticeably the most destructive pests that attack wood or bamboo culms (Wang et al. 1998). They usually survive well in the moist and warm tropics for reproduction or breeding. There have been several different groups of insects reported as attacking harvested woods, as well as bamboo culms and their products. Two of the principle types are wood borers and termites. The wood borers can be classified as wood boring beetles, bostrychid, moths, cerambycids, horntail wasps, ambrosia beetles, and lyctids. They can be described as organic material recyclers, but they cause great damage to wood and its products because they chew the internal cells and leave the wood or the culm devalued in quality. The process starts as the larvae develop inside the wood and penetrate into the culm further, chewing the tissues inside the wood or the culm. The larvae, after some weeks or months, then change from pupa into borer beetles which continue feeding on the tissues until they reach the cortex, where they then exit through a hole created on the surface. Observing drops of pills from the hole tunnel on the surface of the culm is the only means by which one can detect that there is an ongoing attack on the bamboo culm. The main function of female adults beetles is to breed which does not itself destroy bamboo tissue (Liese and Kumar 2003).

2.8.1 Beetles

Powder-post beetles can destroy a stored culm of bamboo reducing the tissue to a flour-like powder, with the outer cell becoming thinner, over without being noticed. They easily enter the bamboo culm within a day or two of harvest and feed on the starch and the carbohydrates within the parenchyma cell of the culm. This insect does destroy the culm tissue, as they create tunnels through the tissues of the culm leaving only a thin hard cortex of surface, which is misleading when taking into consideration the extent of the damage caused. They usually exit the culm after shredding the internal starchy tissues of the culm through to the hard cortex via circular boreholes (Liese and Kumar 2003). The effects of beetle attacks on bamboo culm are influenced by seasonal factors because the larvae rely mostly on the existence of starch to survive, and this is affected by the season. Beetles easily attack young culms because of their high moisture content as compared to older culms with less moisture content, as well as starch (Liese and Kumar 2003). It has been reported that the intensity of beetle attacks on bamboo culms depends on the species, with flowering bamboo culms having low moisture content and starch being hardly attacked. This is because the culm utilises its starch for seed production and therefore has a high resistance to beetle attacks. Beetle hardly attack some flowering species such as Pleioblastus because of its low moisture and starch content. On the other hand, *Bambusa vulgaris* is easily attacked by these insects due to its high content of starch and moisture. Other known wood-boring beetles do demolish the culms of bamboo by creating bigger holes inside the culm cells; these beetles includes Lyctus spp., Dinoderus spp., Wasps, and Carpenter bees which can seriously destroy bamboo and its products.

2.8.2 Termites

This type of insect can be characterized as silent destructive ants that cause chaos to wood and fabrics made from wood, as well as other products made from plants, not excepting bamboo. They are said to have wings which they shed upon discovering a habitat and also have the trait of eating, throughout their lifespan, for 24 h a day. They are made up of several different species, with the most commonly known species relevant to this discussion including subterranean termites, damp-wood termites, dry-wood termites, and Formosan termites. The subterranean and Formosan species of termites are soil-dwelling species while dry-wood termites can live in wood or bamboo culms without contact to the ground and feed on the cellulose. This they can doas they do not require moisture for their survival, unlike the damp wood termites which require much moisture.

Subterranean termites are described as the most destructive species of termites which live underground and roam above ground in search of food; they also need high humidity and water to build their nest's as large mounds (Liese and Kumar 2003).

They can form galleries very fast, and, through these, they search for food, reproducing continuously so that some group of offspring flys off to start new colonies elsewhere. They consist of workers, soldier, and a reproductive group which feeds on all products made from plants, including bamboo part. Because their destruction can cause very costly damage regarding to bamboo culms and products, it is important not to allow the culms to have direct contact with the ground. Also one must make sure the culms are not stacked close to water sources, and, when any discovery of galleries leading to their home is made, it must be destroyed.

Dry-wood termites, on the other hand, create their home mostly inside the wood of plants including bamboo culms and other wood products which they feed on. This type of termite does not require moisture or ground for their survival. Their invasion of the wood or bamboo culms and its products is typically initiated by the flying adults, who penetrate through openings and then create nests by dig tunnels in the culm. They can easily destroy culms, even those used in constructions above ground level, and can only be detected at an advanced stage of its destruction. Dry-wood termites recycle their body moisture while feeding on the culm and can survive on the nominal quantity of humidity found in the culms of the bamboo (Liese and Kumar 2003). It is suggested to treat bamboo culms with chemical before their application, which may prevent this insect from getting near where they are stored or used for products, as well as to seal all openings or cracks on the culms and in the perimeters of storage rooms.

Damp-wood termites are similar in form to dry-wood termites but a bit larger as compared to others. Most damp-wood insects require high moisture content for their survival, and, due to this reason, they feed on the moist woods as well as group in dying woods or finds their way into bamboo culms that are wet after harvesting. Given this, it is advisable always to keep environments in which bamboo culms are stored dry to prevent damp-wood termites from attacking them.

Damage caused by termites on wood and wood products can be very expensive. Hence it needs to be prevented on bamboo culms and its products too. Attacks by termites on wood and its products are caused by the working groups, which create tunnels in the wood to look for food to feed the queen. They usually leave thinly walled layers after attacks on the culms of bamboo which leads to fast disintegration.

2.9 Fungal Attacks

Fungi can be described as a classified group of living organisms. They are not animals, plants, or bacteria. Fungal attackes are characterised by staining and decay of bamboo culms (Zhou et al. 2010). There are different types of fungai that operate under different environmental conditions.. Bamboo culms are easily infested by fungi when not treated well to provide resistance to attacks from fungi (Xu et al. 2006, 2007). They use the cell walls of the culm as their source of energy for their survival by feeding on the organic components in their contents (moulds and blue

stain fungi). Fungi are microorganisms that are sexually propagated from bodies of fruits or through asexual reproduction. They are universal and develop under wet environments consisting of a vast number of hyphae. Fungi have a branching filamentous structure possessing a primary mode of vegetative growth in which a network ifs formed that together is called Mycelium, a result of enzymatic decomposition. The consequence of decomposition on the culm wall is mostly realised, at a late stage, as a discolouration when it already has been destroyed, and physical damage has occurred to the culm.

Mostly, mould fungi breed on the surfaces of the harvested bamboo. Decay fungi, which include brown-rot and white-rot, do live inside the culm of the bamboo breeding within the substrate, while others also live on the surface of the culm where the environment is moist. These bacteria can live anywhere globally under those conditions that promote their development, as well as enzymatic degradation.

Though fungal organisms are present throughout the globe, they can only grow under certain moist conditions. Fungal attack on bamboo culm needs to be prevented, and it is important to dry the culm below the fibre saturation, as well as 20% below the moisture content, to enhance resistance to any fungi attack. However, the material moisture content must range from oven-dry mass in the range of 40–80%. These fungi can mostly be found in bamboo growing areas where the temperature range is suitable for fungal operations. Furthermore, when mycelium is exposed directly to the sun at temperatures above 55 °C, it results in the ruin of the enzyme system by protein denaturation, while other decay fungi have mycelia that can survive for hours in the temperature range of 95 °C (Schmidt 2006; Wei 2014).

2.9.1 Blue-Stain Fungi

These type of fungi lives and grow well in a humid environment and belong to the group of a fungi class known as the lower fungi, Deuteromycetes. They usually enter the bamboo culm at either end of the cut sections, while the culm is fresh and moist, as they pierce the parenchyma cells. These fungi normally are found living inside the freshly harvested culms because of their high relative humidity, moisture which is above 70%. Blue-stain fungi grow by feeding on nutrients from the culms, and this includes carbohydrates and sugar, as well as starch stored in the parenchyma cells (Liese and Kumar 2003). However, the internal tissue of the culm becomes blue-greyish black in colour as a result of the pigmented hyphae produced by the fungi. The effect of the discolouration of the internal tissues of the culm also spreads to the surface of the culms under shade, leaving spots or streaks in a uniformly distributed form. The effect on the culm of the infection of this fungi is that the aesthetic property diminishes, mostly resulting in culms with split and flakes.

2.9.2 Mould Fungi

These type of fungi lives and grow well in a humid environment. They usually live on the surface of bamboo culms mostly found on both cross edges of the green harvested culms that possess a high relative humidity above 70%. The high amount of sugar nutrient in the culm, as well as impurities on the surface of bamboo culm, help the hyphae to feed on them without penetrating into the culm. They also feed on the nutrients from the culms, while they develop in the inner section which is exposed at the cut ends, as well as dwelling in some finished bamboo products which are transported from one point to the other in containers. Moulds do not influence the physical properties of bamboo culms; however, their aesthetic appearance gets reduced by these fungi (Tang 2013). There are great varieties of mould fungi which produce huge numbers of microorganisms of many different colours, including black and blue. These organisms, when exposed in an indoor environment, can cause skin irritations as well as respiration difficulties to humans. Mould fungi produce some mycotoxins substances which are poisonous to people's health.

2.9.3 Decay Fungi

These type of fungi can penetrate deeply into the culm tissue using their hyphae, and they belong to the group of a fungi class known as the higher fungi, the Ascomycetes and Basidiomycetes which are actually bamboo-destroying fungi. The Basidiomycetes lives in the lumen of the bamboo cells as they feed on it, grow, and produce various enzymes depending on the type of fungi that disperse into the cell wall. The enzymes may then decay elements such as cellulose, hemicellulose, and the lignin as the culm turns into white-rot type or may only deteriorate the cellulose and the hemicellulose without affecting the lignin. But the culm colour finally turns brown as it decays. The white-rot fungi are the major destroyers of bamboo culms. (Ashaari and Mamat 2000). The decrease in culms' strength is the result of enzymatic degradation due to the damage of the cell-wall elements. Deterioration in the colour of culms or weight changes are evident, and the strength properties of the culm might have decreased when subjected to bending test. The effects of weight reduction and a decrease in mechanical strength in culms lead to limitations in its application more than in the stems of timber, because the weight loss in bamboo directly lessens the strength of the fibres. Mostly, the initial decay of culms is ignored but later leads to high costs linked to the diminished safety and the maintenance of affected elements of the construction (Ashaari and Mamat 2000).

The other form of fungi is in the group of Ascomycetes, which is the soft-rot fungi. These fungi hyphae live and grow inside the cell wall of the bamboo and require a smaller amount of oxygen to survive by enduring higher moisture content up to 80% where other fungi cannot survive. They normally produce some form of

change of the lignin molecules, consuming the cellulose or the hemicellulose walls elements, and have a high resistance to various forms of toxic concentrated chemicals used as preservatives. The infested culm gives no sign of surface mycelium as the colour of the culm turns from it natural cream yellow to a dark brown-black. (Liese and Kumar 2003). When culms are left on the floor, they are easily destroyed by soft-rot fungal, as well as termites.

2.10 Post-harvest Treatment and Preservation

Post-harvest treatment and preservation of bamboo culms are essential to its conservation and life expectancy. Because bamboo is prone to insects and fungal attacks, especially beetles and termites, as well as mould fungal infection, preservation treatment is required (Xu and Wang 2004; Mohanan 1997; Yu et al. 2011a, b). The attacks on the bamboo culms by these fungi and insects lead to the reduction of the durability of the culms and also their usefulness. It is for this reason that post-harvest treatments are required for bamboo to help mitigate the likelihood of danger of insects attack, thus extending its lifespan and increasing culm quality (Garcia 2005). Depending on the end use of a bamboo culm, a particular preservation technique is adopted for its processing before being applied for industrial utilisation.

The post-harvest treatment requires drying of the culms first to attain 12% moisture content, which is critical for any load bearing applications in manufacturing andarchitectural design work. The culms are also subjected to seasoning before the machining processes and finishing of the products to improve their durability and stability (Moran 2002; Liese and Kumar 2003). Two drying techniques used in the drying of bamboo to the required degree of moisture content are air-drying within a well-ventilated environment or in the sunlight and kiln drying.

2.10.1 Air-Drying of Bamboo

This method of culm drying is a traditional technique employed since ages into remove moisture content from the culm of bamboo by exposing it to the conditions of the environment. The air-drying process of bamboo culm is more economical as compared to the kiln-drying method. However, the challenge associated with air-drying of culms is that it takes longer than kiln drying, i.e., weeks through to months to reach the required moisture content. As a result of taking longer to become sufficiently dry, there is a likelihood of the culms being attacked and infected by fungi, especially the mould fungi.

The air-drying process only requires proper stacking for air circulation around the culms to dry them without the addition of any other heat apart from the ambient air. The two methods of air-drying bamboo culms are namely; horizontal and

vertical stacking. In the case where culms are horizontally stacked to air-dry, it takes longer to dry, almost double the drying period than those which are vertically stacked. Bamboo drying by air depends solely on the weather to reach its required moisture content, and, since the weather cannot be regulated, the process of drying may take longer to achieve the humidity below 12%, as required for products processes (Montoya-Arango 2006).

Another approach used to enhance bamboo culm drying is by splitting bamboo culms into halves or strips to speed up drying operations (Fig. 2.8). The culm can also be air-dried under the shade with ambient air in a well-ventilated environment. Drying of large volumes of bamboo culms by air-drying requires tying of the culms

Fig. 2.8 Traditional air drying of bamboo strips in Ghana

into bundles and placing them alternately on each other to prevent bending. The drying of bamboo culms to lose their moisture content by air-drying and without the application of other heats requires several days and weeks to reach the moisture content below 12%. Another approach to air-drying of a green harvested culm bamboo is by placing them on the flat platform with heavy objects laid on them during the entire drying period to attained moisture content below 12%.

2.10.2 Kiln-Drying of Bamboo

This method of reducing moisture content in bamboo culms is an improved method over the air-drying process since it offers a shorter and more efficient means of drying culms to the required measurement. The process employs the use of a boiler or electrical power to inject heat into the chambers housing the packed culms. The culms are cut into the given dimension, either split or whole, before being arranged in the chamber for drying. The elemental conditions, including relative humidity, temperature and air circulation in the chamber, are kept constant throughout the drying process until the 12% measure of moisture content is obtained (Tang et al. 2013; Yosias 2002). It is a recommended technique for drying large numbers of culms where high demand for production and high-level bamboo quality are needed (Yosias 2002; Tang et al. 2013).

2.10.3 Drying Rate and Defects of Bamboo

The rate of drying in bamboo when compared to wood shows that bamboo takes a longer time to dry the same mass of culms. A bamboo culm is characterised by an anatomical shape consisting of a cylindrical culm with a hole inside, resulting in a prolongation of the process in culms (Kumar et al. 1994; Liese and Kumar 2003). Also, the drying rate of thin-walled culms is faster than thick-walled culms, because the wall thickness enhances and also controls the speed of drying. (Laxamana 1985; Tang et al. 2013). It was also observed that younger culms have a slower drying rate due to the high moisture content in them when compare with the mature culms' lower moisture content. Drying of culms occurs quite rapidly at the start and later slows down gradually as drying advances.

There are defects associated with the drying of bamboo. These defects could be encountered during or after drying. The most common defects include rupture of culm tissues, node cracks, cell collapse, surface cracks, splits in culm, and end cracks. The difficulty of not having a consistent moisture content within an individual culm can result in discolouration during kiln drying, which does affect the quality of the dried culm (Tang et al. 2013). The green bamboo culms tend to be vulnerable to collapsing, due to tension in the vessels during the process of drying. Bamboo cells containing liquid collapse, leading to significant shrinkage in the cell

walls (Tang et al. 2013; Liese and Kumar 2003). When bamboo culms are dried under low temperature conditions, the cell walls do not collapse but instead uniformly shrink in the radial and tangential directions. Different bamboo species require different drying temperatures, as well as varying drying rates since their drying characteristics are dependent on the wall thickness (Liese and Kumar 2003).

2.11 Preservation of Bamboo Culm

From various studies, it has been realised that culms of bamboos as natural materials are susceptible to natural and physical deterioration when harvested, especially at the young stages. The weakening of the bamboo culm is mainly a result of attacks by beetles, decay caused by staining fungi, and powder-post beetles, as well as termites. In an attempt to increase the bamboo-culm durability and serviceability, as well as its lifespan, there have been numerous techniques of conservation methods that have been introduced in the areas where they are cultivated. These methods used to extend the lifespan of bamboo culms are comprehensively classified into chemical and non-chemical methods.

2.11.1 Non-chemical Techniques

There are diverse bamboo treatments based on this technique that are less expensive but do not cause the reduction of carbohydrates, starch, and sugar content in bamboo culms. This treatment process has the advantages for the bamboo culm because most of the nutrients get removed during the treatment process and enhance its resistance to attacks by decay and mould fungi, as well as insects including beetles and many others. Below are some non-chemical treatment processes briefly discussed.

Curing This method involves the harvesting of the culms by cutting them from the base. After harvesting, the culms are allowed to remain together with the branches and leaves at the clump, as the respiration process continues to function and the starch and the sugar content in the culm reduces. This technique, when appropriately applied, will help prevent attacks by insects, but the possibility of fungi and termites' attacks cannot be eliminated entirely. Curing also helps improve the life span and quality of the bamboo culms.

Waterlogging More simple techniques used to treat green bamboos harvested from a plantation exist. The green harvested culms are soaked in water (running or standing water) for weeks or months to leach out the starch and carbohydrate content from the culm. The treatment of the culm by this process gives a high resistance to the bamboo culm against attacks by insects such as borers, but mostly there is a limitation to its resistance when it comes to dry-wood termites and mould or decay fungi (Ashaari and Mamat 2000; Nguyen 2002). Globally, these methods

of preservation of bamboo culms are still being employed where the plants are distributed, more especially in Asia and some African countries. The method is commonly used in rural communities in Africa and Asia where bamboo resources are common. Hence, this is still a common practice used for treating bamboo culms for use in the construction of houses, handicraft, architecture works, and furniture. The waterlogging process is a comparatively cheap method of preserving the culm, and traditional artisans mostly employ this technique in the rural areas for their handicraft works. A study on the water treatment of bamboo species such as *Bambua vulgaris and Dendrocalamus strictus* was recently conducted in a village in Ghana. During the treatment process, the logged bamboos were left in a stream of water for eight weeks (Fig. 2.9). From the studies, it was observed that, after comparing it with the untreated culms which were also left for the same period of months in the seasoning process, the waterlogged culms had a higher resistance to insect and decay than the untreated. The result of the waterlogging treatment process can partially be compared to chemical treatment, though the life expectancy cannot provide for long-term preservation. This technique of preservation is only adequate for short-term products and therefore should be integrated into the treatment of long-term preservation technologies in order to reduce cost, as well as provide a high-quality resistance to insect attacks (Kaur et al. 2013). However, it was observed that the submerged culms in the running water after some time produce bad odours, as a result of bacteria activity on the culms, so this is one of the main defects associated with this the waterlogging process.

Fig. 2.9 Waterlogging treatment of *Bambusa vulgaris* species

Construction methods This method of using bamboo for construction purposes has been in existence for centuries, consistent with an appropriate selection and use of an effective method for construction to prevent damage over time. If the moisture content of a bamboo culm is less than that which makes it prone to insect and fungal attacks, and is kept below the fibre saturation point, then it can be used for construction. There exists a long-standing technique for treating these culms, without any application of chemicals as well as an efficient technique for construction suitable to be employed by many designers and architect (Janssen 2000; Amada and Untao 2001; Lobovikov et al. 2007; Heinsdorff 2010; Sharma and Gatóo 2014). The common practices include the placement of culms of bamboos on the foundations of walls or stones, which have been laid as preformed concrete footings for structures, rather than allowing them to have direct contact with the ground (Sen et al. 2011). It is advisable to harvest bamboo culms below a node base for firmness. It is also important to have continuous ventilation throughout the structure (Janssen 2000; Heinsdorff 2010).

Roofing overhanging will shield bamboo mats from the rainwater, and, usually, bamboo culms used for roofing are halved to foster run-off during of rain. They have a water-repellent cortex that improves their lifespan for several years until fruit bodies initiate internal degradation (Janssen 2000). Bamboo culms are used traditionally by experienced artisans for stable structures with appropriate roofing techniques. This method of preservation is very efficient, with high resistance to fungal and partial resistance against insects including beetles, but dry-wood termites can penetrate at certain stages. However, anytime subterranean termites attack a structure, it is recommended to remove their earthen tunnels and then use soil poisoning barriers to destroy their foundation (Nguyen 2002). With this method of treatment, bamboo culms sometimes are treated with boron against beetles, over four-to-five days, by piercing the internodal walls for complete diffusion (Heinsdorff 2010; Gutiérrez 2000).

Plastering is one of the oldest methods commonly practised in rural villages to protect the bamboo culms from being attack by fungi and insects. The process simply involves using whole, split, or mat bamboo for structures and then covering it with mud mixed with lime or any other organic materials for solidity. This method has often been employed globally bamboo resources are widely distributed. After making the framework of the structure, mud or the clay is then used to cover both sides of the structure's walls (Gutiérrez 2000). The purpose of the mud or cement technique being used, on the whole, split, or mat, bamboo panels, is to completely seal it. The bonding of the culms by the cement or the mud prevents raindrops from making direct contact with the bamboo material, preserving it from rotting, as well as from attacks by insects and fungi. Houses built with bamboo that has been sealed in cement or mud and have their surfaces finished with a lime wash have survived for decades (Jayanetti 2005; Liese and Kumar 2003).

Smoking This method of treating bamboo has been in existence for centuries. The technique is employed by stacking freshly harvested bamboo culm at the top of

a building or kitchen above a fire source toe enable the smoke to penetrate into the culms tissues. This method is mostly practised in rural areas on freshly harvested culms to preserve them from attacks by insects. The treatment of the culm with smoke (carbon) forms a layer of protection on the culm and helps to reduce moisture content, thus providing high resistance to attacks by insects and fungi. The continuous interaction between the smoke from the fire and the heat leads to darkening of the colour of the culms. The technique has been adopted in the conservation of green bamboo culms as they are stacked in a furnace with temperatures ranging 120–150 °C. The process of producing soot, as well as pyrolytic chemicals on the surface of the culms, basically protect the culms against beetles (Leithoff and Peek 2001; Liese and Kumar 2003). During this treatment process, a strong chemical, which is acidic in nature, is infused into the culms sitting in the furnace, and this has a positive effect on their usefulness. These treated culms are basically for external uses, and, due to the chemical changes in the carbohydrates, they have high resistance to insects. Culms that are processed by smoking, when exposed to direct contact with the ground for a long period, will be vulnerable to attack by fungi and termites (Leithoff and Peek 2001). Smoke drying also reduces splitting of the bamboo culms (Liese and Kumar 2003).

2.11.2 Chemical Methods

This process involves the use of various types of chemicals that are efficient in expanding the durability of treating the culms , as compared to non-chemical techniques. This method of treatment is more expensive than non-chemical treatments. Hence, its application aligns with more vigorous treatments where a higher valued product is required. The following are some of the chemical methods which are employed in the chemical preservation of bamboo.

Butt Treatment This method of preservation is employed on both dried and freshly harvested bamboo culms immersed in a tank containing a preservative for their treatment. The bamboo culms are put into the tank or container for about one week. A Ghanaian company which manufactures furniture and other bamboo products employs this method of treatment of material for their products. They use a mixture of a chemical called Dursban and engine oil to treat the culms and so preserve them from insect attacks (Fig. 2.10).

Old Engine Oil The process of preservation involves the application of used engine oils to the green or dried bamboo culms, particularly those produced by rural farmers. However, this method of treatment has not scientifically been proven to be effective.

Steeping or Sap Displacement In this method, the chemical is poured into a basin or tank after which the culms are then positioned vertically in the reservoir

Fig. 2.10 Traditional Ghanaian method of preserving bamboo culms

and left for some days to the allow penetration of the chemical into the culms. This process is applicable to both freshly harvested bamboos and dried culms.

The Open-Tank Treatment This process of preservation involves the use of a water-soluble solution whereby bamboo culms cut into given dimensions, and then immersed in the chemical solution for days or weeks, experience adequate penetration of the chemical. The diffusion process takes place in all directions within the culms, with the highest rate being at the top and bottom end of the culms.

2.12 Treatability

The anatomy and moisture content of bamboo makes its treatment process different from normal wood and critical for selection of suitable preservation techniques. The culm outer layer is covered with cuticula which prevents solution penetration. This makes the use of simple treatment processes such as only soaking inadequate. The sclerotic parenchyma cells on the inner layer of the culm also hinder to some extent, penetration (Liese and Schmitt 2006). Unlike wood which has ray cells aiding in the uptake of preservatives, bamboo lacks these cells and relies on only the metaxylem vessels for preservative uptake. These vessels, however, constitute only 6–8% of the total volume of fibres. The remaining tissues, namely the fibre bundle and parenchyma must be treated by diffusion.

2.13 Preservatives

Bamboo culm needs a higher degree of antibacterial preparation as compared to wood. There are various ways by which bamboo culms can be preserved, and this includes the water-solution process, as well as chemical preparations needed for particular applications. The choice of preservatives is determined by the type of material being treated, as well as the life expectancy for particular products. These chemicals are either in the form of pastes or liquids, as well as tablets. The use of salt as one of the preservatives currently minimises the risk of hazardous chemicals being released into the environment by other preservatives, as well as consequent health problems. The application of water-solution preservatives has more advantages over other chemicals because they appear to be clean and odourless and more efficiently applied, as well as being less expensive (Liese and Kumar 2003; Liese and Schmitt 2006).

2.13.1 Waterborne Types

In this method of preservation, a salt solution is used to treat the bamboo culms by immersing them in the given solution with the aid of a weighting element. The water is allowed to evaporate, and the salt then remains inside the culms. This treatment process is categorised into two main types, i.e. the fixing and non-fixing method of bamboo tissues.

Non-fixing Types In this method, the application of preservative chemicals is mainly applied on the bamboo during the drying season for effectiveness, because, during the wet season, its efficiency might be reduced due to rains washing the chemical off. (Liese and Kumar 2003; Liese and Schmitt 2006).

Fixing-type In this method of preservation, chemicals bound in woody tissues both inside and outside are applied. This method is more useful for high and efficient preservation of bamboo culms.

2.13.2 Organic Acids

This form of preservation of bamboo culms is used to prevent attacks by moulding fungi on the freshly harvested bamboo. This preservation is only applicable for the prevention of mould forming on a freshly harvested bamboo culms, but only for short-term protection of the bamboo due to their high moisture content, during transportation from one point to another. The technique requires immersing the culms in a 10% acetic acid solution which especially fights against the growth of mould during the raining season (Tang et al. 2012).

2.14 Preservatives and Treatment

Bamboo treatment is very essential for the enhancement of its properties, so as to withstand all external attacks and also to improve its resistance to fungi and insect attack. The treatment processes with preservatives are categorised into two major categories, namely, pressure and non-pressure processes.

2.14.1 Pressure Treatments

This method of bamboo treatment is described as an efficient technique used to treat bamboo culms against conditions that are hostile to their quality. Pressure treatment accounts for deeper and even distribution of the chemicals through the entire culm, as well as retention of preservatives in the matter of the culm (Liese and Kumar 2003). This method is performed by forcing the preservatives into the bamboo tissue, by increasing the vacuum and the pressure upon the preservative in the treatment cylinder (Tang 2009).

The skin of the bamboo culm makes it difficult to accomplish this process, especially in the radial direction. However, to enable smoother penetration within the culms, holes on opposite sides of the lower and upper part of each internode must be made by drilling throughout the entire culm.

2.14.2 Non-pressure Treatment

There are various processes of non-pressure treatments, which include hot and cold treatment, soaking or diffusion, steeping or butt-end treatment, and sap-replacement processes. Two of the process have already been discussed briefly in this book.

Soaking/diffusion This treatment method of bamboo culms involves splitting green harvested culms into the required size and then after they soak in a water solution, chemicals enable diffusion to take place within the tissues of the culm (Liese and Kumar 2003). However, because specific gravity is less than 1.0 g/cm^3 in bamboo, it is advisable to bind the strips with a weight to help immerse them in the basin or reservoir before adding the chemical solution (Tang and Liese 2011). The diffusion process takes place in the axial direction, less in the transverse and slightly better radially than tangentially.

Steeping or Butt-end Treatment This treatment method of bamboo requires that green harvested culms be split into the required size and then, after soaking in a water solution of chemicals, for diffusion to take place within the tissues of the culm (Liese and Kumar 2003). However, because specific gravity is less than 1.0 g/cm^3 in bamboo, it is advisable to bind the strips with a weight to immersed them the

basin or reservoir before adding the chemical solution (Tang and Liese 2011). The diffusion process takes place in the axial direction, less in the transverse and slightly better radially than tangentially.

2.15 Sustainability of Bamboo and Its Products

The term sustainability of bamboo and its products is very important as there is a rising awareness of sustainable development on a global scale. The global and industrial concern in recent years is about attaining the ultimate goal of sustainability (Finkbeiner et al. 2010; Klöpffer and Renner 2009; Klöpffer 2003). The need for sustainable development of bamboo is urgent because consumption patterns of bamboo and its products have continuously increased in recent years. The multipurpose functions of bamboo have led to rising pressure from many industries for its application, especially in construction, materials, and manufacturing sector as well as other new areas of use (Finkbeiner et al. 2008; Schau et al. 2012).

Bamboo is a fast-growing plant; however, its sustainability is at high risk and hence the need for its renewability to meet current and future demands for the engineering industry and other uses (Schau et al. 2012). Bamboo sustainability is imperative. A look at the stages of its life cycle reveals a versatile plant with a short growth cycle that can be harvested in three to five years, as opposed to the ten to 50 years required for most soft and hardwoods. It grows in almost any climate, and it can replace itself very quickly (Gratani et al. 2008; Van der Lugt et al. 2009). The bamboo plant has been used for thousands of years and has not been depleted from the forests. However, the introduction of modern and advanced methods that affects its life cycle need to be critically examined in order not to ignore any negative consequences to meeting challenges to its sustainability. Bamboo cultivation and production is a far more environmentally safe and sustainable option than other modern industrial materials like corrugated metal, artificial plaster, and chemically treated wood (Van der Lugt et al. 2009).

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