

Manual for Sustainable Management of Clumping Bamboo Forest

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INTERNATIONAL BAMBOO
AND RATTAN ORGANISATION



The International Bamboo and Rattan Organisation

The International Bamboo and Rattan Organisation, INBAR, is an intergovernmental organisation dedicated to the promotion of bamboo and rattan for sustainable development.

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PREFACE

Bamboo is a plant that belongs to the true grass family Poaceae, a subfamily of Bambusoideae. Bamboo is one of the fastest growing plants in the world. There are over 1600 bamboo species naturally distributed in tropical and subtropical belts, and they are commonly found in Africa, Asia and Central and South America. Some species can also successfully grow in the temperate regions of Europe and North America.

Bamboo has a unique, dense rhizome structure that helps in accelerating the growth rate of bamboo shoots and culms annually. Thanks to special biological characteristics of the rhizome, when a bamboo culm is harvested, the bamboo rhizome system is still alive and continues to produce shoots. Bamboo matures in 3–5 years, and thereafter, it can be harvested annually for about 20 years or longer, depending on the gregarious flowering period, after which bamboo dies. Bamboo's gregarious flowering interval can be between 20 and 120 years depending on the species and location.

There are two main types of bamboo rhizome, which are as follows: (a) monopodial (running) and (b) sympodial (clumping). Running bamboo has a rhizome that spreads horizontally and forms dispersed bamboo culms, whereas clumping bamboo has a shorter rhizome, is formed together and generates bamboo clumps. Running bamboo can spread quickly, while clumping bamboo stays together in its cluster. This means that harvesting clumping bamboo is more difficult than harvesting running bamboo is, especially because in clumping bamboo, most of the mature culms are located in the centre of the clump.

Bamboo is a perennial plant that easily adapts to different site conditions. It can grow in a wide variety of soil types, ranging from organic-poor to mineral-rich and from drought to flooding conditions where many plants cannot grow. Bamboo can grow rapidly in hot and humid rainforests and even in cold climates with temperatures around -20°C . It has an extensive rhizome and root system that makes it capable of stabilising loose soil to prevent soil erosion.

Bamboo is a versatile multipurpose plant, with over 10,000 products and applications ranging from timber substitute, construction materials, food and beverages, bio-energy, pulp and paper, fibre composites, textiles, lifestyle products and traditional sustenance use products. With recent technological innovations, a wide range of high end industrial products have been produced and traded globally.

Annual bamboo trade was estimated at a value of USD 60 billion in 2017, half of which was conducted in China. Many countries realised the socio-economic and environmental benefits of bamboo; however, due to a lack of knowledge for establishment and management of bamboo, especially for clumping bamboo, the potential of bamboo is still untapped in many countries.

This manual aims to support people who work in the field for the establishment and management of bamboo plantation. The manual has been developed based on the International Bamboo and Rattan Organisation's projects, especially the Dutch-Sino East Africa Bamboo Development Programme in Ethiopia, Kenya and Uganda and South–South Knowledge Transfer Strategies for Pro-Poor Bamboo Livelihoods in Ethiopia, Madagascar and Uganda. The manual guides step-by-step for production of bamboo seedlings and planting, maintaining and sustainably harvesting bamboo plantations.

This manual comprises five chapters. Chapter one provides an explanation of terms in the manual, and chapter two offers step-by-step instructions for propagating bamboo through culm cutting, branch cutting, air layering, macro-proliferation, rhizomes and seeds. Chapter three provides guidelines for the establishment of bamboo plantations. Chapter four explains how to maintain bamboo plantations and inter-crop other crops in bamboo plantations. Chapter five provides instructions for sustainable management of bamboo plantations.

The Authors

Chapter 1. BAMBOO TERMINOLOGY

1. Bamboo terminology

Clump: A cluster of bamboo poles that are interconnected or belong to a single bamboo plant.



Culm or stem: An individual bamboo pole; hollow cylinder or main stem above the ground.



Inter-node: Portion of bamboo between two nodes. The internodal portion has linear fibres.



Node: Projected or joining portion of two inter-nodes. This is the growth point of the vegetative axis. Nodes have a cross or interwoven fibre structure (horizontal and vertical).



Shoot: New emerging culm.



Bud: Eyelike formation located on a culm node or rhizome node.



Rhizome: Underground portion of bamboo.



Culm sheath: Protective layer on newly emerging culms. The layer drops off on maturity.



Chapter 2. PROPAGATION OF BAMBOO

2.1. Propagating bamboo through branch cutting

2.1.1. Introduction

Branch cutting is a non-destructive method of propagating bamboo that is mainly employed for bamboo species with swollen branch bases, aerial roots and prominent branching. This method, using primary and secondary branches, is effective for thick-walled bamboo species, such as *Dendrocalamus spp.* and *Bambusa spp.* The most ideal time to practice this method is in the early monsoon (after pre-monsoon showers or within two months of the onset of the monsoon).

Normally, there are not many swollen branches in the bamboo clumps. In order to stimulate the development of swollen branches, a portion of about 2-3 m can be cut from the top of healthy culms between one and two years' old. This will induce lateral branches, including swollen branches. Topping off should be executed about one year before carrying out branch cutting.



2.1.2. Propagation medium

It is advised to propagate branch cuttings in sand beds because sand is locally available, chemically inert and comparatively cheap. Sand accelerates drainage, improves aeration, allows easy rooting and rhizome formation and minimises damage of roots and rhizome while transplanting. Alternatively, branch-cutting propagation can also be carried out in well-drained sandy soils.



2.1.3. Sand beds

Use three layers of bricks to hold the sand. The size of the sand bed could be as follows: height = ≈ 20 cm, width = 1.2 m, length = 5-10 m or more (depending on requirements).

2.1.4. Selection of branches

1) Select bamboo culms with prominent branches; the best swollen branches are between six to eight months old and come from bamboo stems of one to three years old. (Do not use old swollen branches older than one year). Check for a swollen branch base; it will look similar to rhizomes of bamboo (aerial roots, buds, leaves).



2) Cut the branches with swollen branch bases using a hacksaw. Do not split the swollen base. Secondary branches with the same characteristics as the primary branches (swollen base, buds and leaves) can also be used.



3) Keep three to five nodes from the swollen base with viable buds. Trim all tertiary branches and leaves after cutting the branches from the main culm (to avoid water loss). Use a hacksaw to cut big branches and secateurs for pruning the smaller branches and leaves.



Store the cuttings in shade, cover with litter/straw and keep moist.

Transport the cuttings to a nursery site as early as possible.



2.1.5. Nursery process

1) Dip or immerse the cuttings in rooting hormone solution (indole butyric acid [IBA], concentration 200 ppm, or naphthalene acetic acid [NAA]) for a few hours (preferably overnight). Soaking helps in better root formation and higher survival.

If propagation is carried out during the pre-monsoon season, there is no need for rooting hormones.



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2) Before planting, dip the cut ends of the branch cuttings in fungicide (1 ml/g/L of water) for five minutes.



3) Place the swollen branch base inside the sand propagation bed (make holes by hand).



4) Use cow dung or sticky clay to cap the cut end in order to minimise drying and water loss.



5) Establish a sand bed in partial sunlight.



6) Shower water on the bamboo cuttings at least three to four times a day.



7) Check for roots and rhizome formation. Remove the branch cuttings from the bed without damaging the roots.

Sprouting of branch buds happens in 10 to 20 days. Depending on the species of bamboo and season of branch cutting collection, the root formation time ranges from 25 to 90 days.



8) Transplant the rooted cuttings into polybags (size: 15 × 20 cm or bigger) filled with the potting medium (soil, sand and manure: 1:1:1 or soil and compost: 3:1).



After transplanting, plants must be regularly watered and kept in partial shade for the first month, before shifting them to direct sun light.

Bamboo saplings will be ready for planting in the field after four to six months.



2.2. Propagating bamboo through culm cutting

2.2.1. Introduction

Culm cutting is a vegetative propagation method that is highly suitable for thick-walled bamboo with prominent nodal buds (picture on left) or branches with aerial roots.

The best season to practice this method is pre-monsoon/early monsoon as the culms have high growth hormones and carbohydrate reserves during this time.

2.2.2. Propagation medium

Propagate culm cuttings in a sand bed (pictures below). Use locally available, cheap and chemically inert sand, which accelerates drainage, improves aeration and allows easy rooting and rhizome formation with minimal damage to roots and rhizomes while transplanting. Culm cutting propagation can also be carried out in well-drained sandy soil.



2.2.3. Sand bed

Use three layers of bricks to hold the sand. The size of the sand bed (pictures above) could be as follows: height = ≈ 20 cm, width = 1.2 m and length = 5 or 10 m or more (depending on requirements). Alternatively, locally available material like flattened bamboo can be used instead of bricks.



Please note that sticky or clayey soil should be avoided.

2.2.4. Propagation steps

1) Select a one- to two-year-old bamboo culm. To avoid younger or older bamboo stems, it is advised to mark the age of the bamboo culms using different colours of paint. Cut the selected poles at their base with an axe, knife or hacksaw. Avoid splitting of culms.



2) Discard the top of the culm. In most species, the middle portion of bamboo is highly suitable. Now, prune its foliage and retain the branches (up to three to five inter-nodes) close to the culm portion.



3) A culm cutting can have one, two or three inter-nodes with buds or branches. Cut at the half inter-nodal point on each side. Avoid damage to buds or splitting of poles.



4) Cuttings should be stored in shade and be covered in wet rice sacks during transport to the nursery.



5) In the nursery, leave the cuttings immersed in rooting hormone mix (IBA or NAA solution, 200 ppm) for a few hours (preferably overnight).



Soaking in rooting hormone combinations improves root formation and increases the survival rate. However, if propagation is carried out during the pre-monsoon season, rooting hormones are not needed for most of *Dendrocalamus* spp.



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6) Just before planting, dip the cut ends of the culm cuttings in 0.1% fungicide solution (1 g/L). Fill the hollow interior part of the culm with wet soil/sand to facilitate moisture availability.



7) Ensure that the culm cuttings are placed flat on the sand bed at a distance of 10 cm to avoid overcrowding and root overlap. Cover the cuttings with sand/soil.



8) Sprouting usually takes 10–20 days from the day of planting and continues for two to three months. Depending on the variety of bamboo, root and rhizome formation takes approximately one to three months.



Partial shade is necessary to avoid drying of cuttings and to maintain humidity.

Water the sand beds twice daily but avoid water logging in case of soil beds.

9) Check for root and rhizome formation before removing the cuttings from the propagation beds. Scoop the cutting with roots, rhizome and stem intact. In the case of soil beds, water them thoroughly for a few days before transplanting.



10) Keep the potting mixture ready (soil, sand and compost; 1:1:1 mixture) beforehand. Carefully separate the bamboo plant (roots, rhizome and stem) using a hacksaw or sharp knife.



11) Immediately after separating the bamboo plants from the cuttings, transplant them into polybags. Water the plants immediately and place them in partial shade. Water them regularly.



Keep the plants under partial shade for a month and then expose them to direct sunlight.

After four to six months, the bamboo saplings are ready for planting in the field.



2.3. Propagation through layering

2.3.1. Introduction

Layering comprises a set of techniques where the culm (nodes) and branches (nodes) are brought in contact with the rooting medium (soil, sand, litter) to enable sprouting and rooting at nodes/buds. This can be a successful method of getting new plants to grow at the nodes/buds while attached to the parent plant. There are three methods of layering, which are as follows: (a) simple layering, (b) air layering/ marcotting and (c) seedling layering.

2.3.2. Methods of layering

a) Simple layering

- 1) Identify bamboo culms of one to two years of age.
- 2) Make a partial cut at the bottom portion of the culm (two to three nodes above the ground) to enable bending.
- 3) Bend the culm to the ground; chop the top portion of 2–3 m of the culm to induce lateral branches.
- 4) Keep branches (two or three inter-nodes) close to the culm.
- 5) Trim the leaves and branches to avoid water transpiration.
- 6) Place the culm on the shallow trench and peg with stone or any other local material.
- 7) Cover with soil or any other rooting medium (5 cm deep in sand, soil, dense leaf litter, etc.). Rooting medium should be kept moist by watering (if no rain) and should not be waterlogged.
- 8) Once the new plant is established (roots, rhizome, stem and leaves), the plants can be separated and transplanted to polybags.





b) Air layering/ marcotting

- 1) This involves rooting of the branches with strong buds and aerial roots while attached to the parent plant; cutting a portion of the culm's top can be applied to increase the number of suitable branches.
- 2) Select branches aged 4–10 months old. It is better to select branches aged 6–8 months old.
- 3) Top off the branch, keeping three to five nodes from the culm and cutting off all lateral branches at the main branch.
- 4) Cut one-third of branches (where the culm and branches are connected) on both sides.
- 5) The rooting medium can be soil, manure or a combination of leaf litters, rice straw and so on. The rooting medium should be moist at all times, so undertake marcotting only in the rainy season.
- 6) Once roots are well developed, the plant can be separated from the mother culm and transplanted to polybags.



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2.3.3. Transplanting steps

1) Use a handsaw or sharp knife to dissect each plant from the mother stem. Each plant should have well-developed rhizomes, roots, stems and leaves.



2) Before separation of plants, trim branches/leaves to minimise water stress. Separation and transplanting should be carried out in the evening or on rainy days.

3) Immediately after separation, transplant the plants to polybags and water thoroughly.



Keep the separated plants in partial shade (50% shade) and water them daily.

After one month, the plants can be transferred to direct sunlight.



2.4. Macro-proliferation of bamboo

2.4.1. Introduction

Multiplying bamboo plants by rhizome separation is called macro-proliferation. Using this technique, one bamboo plant (with multiple stems) can be separated into two or more viable plants. A bamboo plant flowers and produces seeds only once in its lifetime (monocarpic plant), and its seeds are not regularly available. The vegetative methods of propagation (rhizome, branch cuttings, culm cuttings and layering) take longer and can only be applied successfully during the pre-monsoon and early monsoon periods, when the starch content and rooting hormone in the bamboo culms are high. Using this method, bamboo plants can multiply on a regular basis.



2.4.2. Propagation steps

Preliminary Preparation

Four- to six-month-old, well-managed bamboo plants having multiple culms (three or more) with well-developed roots and rhizomes are suitable for macro-proliferation. Before starting macro-proliferation, bamboo seedlings (from seeds) or transplanted saplings (by vegetative propagation) should be free of weeds and watered thoroughly.



A few days before multiplication, water the plants thoroughly; this will loosen the soil particles and minimise root and rhizome damage.

1) Trim nearly 75% of leaves and branches to minimise water loss.



2) Remove the polybags and soil particles attached to the roots and rhizome. Avoid damaging the rhizome, emerging shoots and roots.



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3) Wash the underground portion (roots and rhizome) thoroughly in water. This aids in clearly identifying the rhizome neck for dissection or separation.



4) Use secateurs or a sharp knife to dissect each plant at the rhizome neck. After rhizome/culm separation, keep the rhizomes in water in a container to avoid drying. Each plant should have well-developed rhizomes, roots and stems. Shorten the roots to 2–4 cm; this will stimulate rooting from rhizomes and prevent root damage while re-planting.



5) To minimise mortality, rhizome/culm division should be carried out in the evening or on selective days when the temperature is cool (rainy days).

6) Immediately after rhizome division, re-plant the bamboo in separate polybags and water.



Keep the separated plants in partial shade (50% shade) and water them daily.

After one month, the plants can be transferred to direct sunlight.



2.5. Bamboo rhizome propagation and planting

2.5.1. Introduction

Bamboo offsetting (or rhizome propagation) is a traditional and commonly used method practiced by farmers across the world. An offset consists of an underground rhizome with the roots and bottom portion (three to five inter-nodes) of the bamboo culm. The separated portion or offset contains all the necessary elements required to establish itself as a new plant.

2.5.2. Planting season

The best time to undertake rhizome propagation in nursery is the pre-monsoon or pre-rainy season, as during this period, the food reserves and growth hormones in bamboo rhizomes and culms are high. With the onset of rains, bud elongation and shoot formation occurs (rhizome buds develop into shoots). The chances of bud damage are high, and the stored food or nutrients can be used or transferred for new shoot or culm growth.

2.5.3. Preparation steps

1) Identify young bamboo culms (one to two years old) from a healthy bamboo clump with desirable qualities.



2) Cut down identified bamboo poles at three to five nodes above the ground. Check for prominent culm buds at the nodes. If buds are not available, cut after the node locations with buds and/or branches.



3) Excavate the surrounding covering soil without damaging the rhizome and buds and identify the rhizome neck.



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4) Cut the neck portion with a saw or sharp knife without harming the rhizome buds or emerging shoots.



5) Detach the rhizome with roots and culm from the clump. Use scissors to shorten the roots to 2–4 cm; this will stimulate rooting from rhizome and prevent root damaging while re-planting. Immediately cover the rhizome portion with wet rice sacks or any locally available material and store the offset in the shade and transfer the offsets to the plantation field or nursery.



6) **Temporary maintenance in nurseries:** Offsets or rhizomes can be temporarily maintained in nurseries (sand beds or bags) for a period of one to two months. The sand beds or bags must be established under partial shade and regularly watered. With the onset of rains/the monsoon, offsets can be transferred to the plantation fields.



7) **Planting of rhizomes:** Early rainy/monsoon season is the best time for direct offset planting because the rhizome buds are elongated at this time.

It is advised to avoid damaging the rhizome buds during excavation. For planting, the pit size varies with the size of the rhizome. For small bamboos like *Oxytenanthera spp.*, the pit size is 40 × 40 × 40 cm, whereas for medium-sized bamboo like *Bambusa spp.* and *Dendrocalamus spp.*, a pit of 60 × 60 × 40 cm is required.

The rule of thumb is to dig a planting pit that is twice as deep and wide as the size of the rhizome. During planting (in a nursery or the field), use cow dung/soil cap or polythene bags to cover the top cut end of the bamboo offset to prevent drying. Offsets must always be planted vertically in the pits and should be made to stand firm.



The survival and growth rate of plantations using the rhizome propagation method is high. This method is destructive to the bamboo clump. It is not suitable for large-scale plantations, considering the cost and availability of planting material.



If the ideal season for plantation has passed, a “part clump method” can be adopted, wherein two or three interconnected offsets can be collected and planted. This method is suitable for thin-walled bamboo species.

2.6. Propagating bamboo from seeds

2.6.1. Introduction

Bamboo is a monocarpic plant (i.e. it flowers and produces seeds only once in its lifetime), and the length of its flowering cycle is in the range of 3–120 years (depending on the species). In addition, bamboo seeds are short lived, and they lose viability in one to three months, making it difficult to propagate bamboo from seeds. Bamboo seeds vary in size and shape according to the species. Some seeds are grain-like, similar to rice, while others can be like berries or mangoes.



2.6.2. Medium of sowing

Seeds should be sown in a raised soil bed platform with good drainage to ensure there is no waterlogging. The propagation medium should be a mixture of soil, sand and compost (1:1:1); the ratio can be altered depending on the type of soil. The seeds should be germinated in partial sunlight (shade net or under tree shades).

2.6.3. Preliminary preparation

It is advisable to sow the seeds immediately after collection. Delay in seed sowing will result in a rapid loss of viability. Before sowing, it is necessary to soak the seeds in normal water (overnight), remove the floating seeds and only germinate the seeds that have settled at the bottom.

2.6.4. Propagation steps

- 1) Create a shallow trench or holes in the seed bed using twigs or fingers (≈ 5 mm deep).
- 2) Place the seeds shallowly beneath the soil and ensure that they are not exposed.



3) Refill the trench with the displaced soil.



4) It is important to keep the seed bed moist, and therefore, daily watering is advised.



5) Seed germination starts after 5–7 days and continues up to 25 days. As soon as the seedlings attain the stage of having four to six leaves, the plants can be transplanted.



6) The potting medium in polybags should be a mixture of soil, sand and manure (1:1:1). In the case of sandy loam soil, potting medium can be soil and manure mixture (3:1). Add 30% in volume of fine coconut fibre/peat or rotten leaf mould. These will stabilise the medium in the polybag. Bags will not burst during transport and planting.



7) Keep the potting medium filled in polybags before removing seedlings from germination beds. Water them thoroughly to enable settling of soil medium.



8) Make a hole using tree twigs or the fingers. Gently place the underground portion of bamboo seedlings inside the holes. Press the surrounding soil with the fingers. The size of polybags should be 6 × 8 inches or bigger.



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9) Keep the seedlings in partial shade (50–75%) or under trees or shade nets for one to two months. The seedlings must be exposed to direct sunlight for at least one month (all shade should be removed) before transferring to direct sunlight.



10) Daily watering and regular weeding is necessary to maintain the health of seedlings.



11) Approximately six- to nine-month-old seedlings are most suitable for planting in the field.



Chapter 3. BAMBOO PLANTATION ESTABLISHMENT

3.1. Introduction

Bamboo is a multiple-use species; it is climate resilient, adaptable and can grow on degraded land, large areas, marginal land, farm boundaries, slopes, riverbanks and so on. Different bamboo species are suitable for different agro-climatic conditions, ranging from coastal regions (sea level) to high mountains (up to 4000 m above mean sea level [AMSL]).

Bamboo plantation can provide jobs and generate significant income and other ecosystem services to the people, particularly rural people. The benefits include stopping land degradation, soil erosion control, flood and wind protection, and particularly, providing sustainable materials annually for many uses, such as construction, furniture and renewable energy.

The establishment of bamboo plantations should be properly carried out through several steps, including soil matching for identification of suitable species, socio-economic feasibility studies and environmental impact assessments. However, this chapter only provides a technical guideline for how to establish bamboo plantations.

3.2. Models of plantations

Bamboo planting/plantations can be undertaken by adopting different models and/or scales, as described below.

1) Large-scale plantation/wood lots: Bamboo plantations of any scale (from 1 ha to thousands of hectares) can be aimed at commercial production of bamboo poles for generation of timber, shoots, pulp, bio-energy and so on, as well as ecological restoration (degraded lands, mined sites, ravines, riverbanks, etc.). Bamboo has shallow roots (about 60 cm in depth); therefore, it uses mostly surface water (from rain or irrigation systems), which will reduce the water exchange capacity between surface and groundwater. Interactive water exchange between the surface and ground will enhance the water supply during the dry season and soil fertility, especially via mineral enrichment. Therefore, for the establishment of large bamboo plantations (50 ha or more), bamboo should be mixed with some deep-rooted tree species, such as figs, legumes or palms. These trees could be planted in bamboo plantations with spacing of 20 × 50 m and a distance of 3–5 m to the nearest bamboo plants. Mixed strips or patterns of deep-rooted tree species will also be good.



2) Smallholder farm block plantation: Smallholder farmers can establish bamboo as agro-forestry or block planting of different scales (a few bamboo clumps to any scale).



3) Farm boundary and shelter bed planting: Smallholder farmers can plant bamboo in farm boundaries, contour lines and shelter belts in the case of streams, rivers and so on.



4) Household planting: A few bamboo clumps can be planted close to homesteads to meet daily fuel wood, fodder and other sustenance needs.



3.3. Choices of species

It is important to consider the end use and agro-climatic regime (geographical location [latitude and altitude], climate, rainfall, soil type and other variables). Kindly consult local research agencies to understand which bamboo species could grow well in the plantation site. Attached is a matrix showing bamboo species, their suitable agro-climatic conditions and their end uses for reference (Annexure 1).

3.4. Site selection criteria for bamboo

When selecting a plantation site, the points outlined below must be considered.

1) Soil: The most suitable soil type for bamboo is sandy loam to clay loam due to its porosity (permeability), fertility (high organic content) and water/moisture-holding capacity. The depth of soil should be at least 30–45 cm. Highly compact or sticky or clayey soil, rocky, and extremely sandy soils are not as suitable.

2) Light requirements: Bamboo does not grow well under deep shade. It needs direct sunlight for rapid growth. It is advised to plant bamboo in an open area (direct sunlight) or in locations with sparse canopy (<10%).

3) Drainage/ water inundation: Bamboos can survive flash floods (days), but most cannot survive under water inundation for prolonged durations (weeks/months; however, some Guadua bamboo species can grow in water-inundated areas for some months). Therefore, select a site that is well drained.

4) Topography: Flat land and gentle slopes are best suited.

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5) Groundwater level: The groundwater table/level should be lower than 50 cm.

6) Location and accessibility: Easy to access and approach by road.

3.5. Plant material selection and preparation

Select healthy seedlings and/or rhizomes (bamboo seedlings: six to nine months old; 50–80 cm in height; multiple stems) with well-developed rhizome and root systems.

Harden the selected plants in direct sunlight (similar to the plantation site) for about two to four weeks to acclimatise the plants to field conditions.



3.6. Transportation of seedlings

Trim about 50% of the foliage to minimise water transpiration loss.

Always carry the plants by holding the polybags/pots to minimise disturbance to the rhizome and roots and avoid breakage of stems.



Wrong / incorrect practice



Right/ correct practice



Right/ correct practice



Proper stacking of plants (polybags) during loading in trucks/vehicle.



For long distance transport, cover all sides of truck, including top, to avoid drying of plants due to air flow.

3.7. Site preparation

Site preparation is necessary to ensure better survival and faster growth, as well as to provide optimal conditions for performance of plantation.

Site preparation includes (1) land preparation (bush clearing), (2) soil preparation (soil loosening and weed control), (3) fencing to control access for cattle and (4) fire prevention.

1) Land preparation: Clear shrubs, bushes, weeds and any unwanted vegetation to ensure space availability.



2) Soil preparation: Soil preparation should be done at least one month prior to planting to provide sufficient time for weathering of soil. Three options are possible depending on the land and resources; which are as follows: (a) ploughing/tillage, (b) strip preparation and (c) spot preparation.

a) **Ploughing/tillage:** Plough the plantation site thoroughly (30 cm deep), which helps in churning/rearranging soil layers and soil loosening, as well as improving soil quality.



b) **Strip preparation:** In this method, first mark the rows of planting. Clear out the weeds by ploughing or clearing vegetation in strips (at least 1.5–2 m wide).



c) **Spot preparation:** This is usually applied in sites where it is impossible to plough. The spots should be large (1–1.5 m in radius) from the centre of the pit.



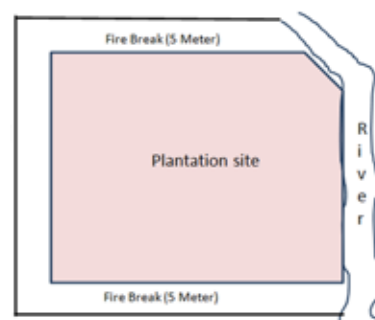
3) Fencing: Bamboo is a good fodder liked by many small and large ruminants; it is necessary to guard the site by fencing it to prevent any risk from damage by domestic and wild animals (especially when plants are young).

The following points must be kept in mind at the time of fencing:

- a) If barriers already exist, only fence the places where animals can enter; and
- b) Fencing must be done before any pit digging and planting.



4) Fire prevention: Clear all kinds of woody shrubs, grass and other vegetative materials, which can catch fire in the 5-m range around the site.



3.8. Spacing

Spacing is important to reduce above-ground competition for light and below-ground competition for water and nutrients.

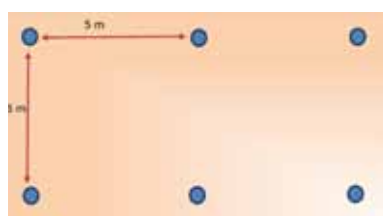
If spacing is too narrow, bamboo will mostly grow tall, but it will not produce large-diameter stems/culms. If the spacing is too large, sunlight will penetrate the canopy, allowing grass to colonise the site and increasing the risk of fire in the dry season. Spacing of plants depends on the species and purpose.

a) 4×4 m: Small-diameter bamboo: 4–8 cm (e.g. *Oxytenanthera abyssinica*, *Dendrocalamus strictus*, *Bambusa multiplex*, *Thyrsostachys oliveri*).

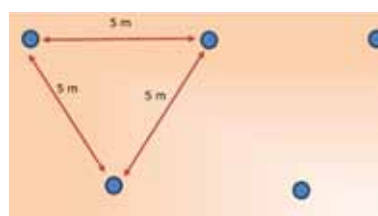
b) 5×5 to 7×7 m: Medium-diameter bamboo: 8–15 cm (*Yushania alpina*, *Bambusa vulgaris*, *Dendrocalamus asper*, *Dendrocalamus hamiltonii*, *Dendrocalamus membranaceus*, *Bambusa tulda*, *Bambusa polymorpha*, *Cephalostachyum pergracile*, *Dendrocalamus brandisii*, *Bambusa balcooa*, *Bambusa bambos*, etc.).

c) 7×7 to 10×10 m: Large-diameter bamboo: >15 cm (*Dendrocalamus giganteus*).

Two patterns of spacing can be employed, which are as follows: (a) rectangular spacing and (b) triangular spacing. For large-scale commercial planting, it is recommended to adopt triangular spacing, which allows maximum utilisation of land area and spreading space between clumps.



Rectangular spacing



Triangular spacing

3.9. Pit posting

A few weeks prior to planting, use ropes /measuring tape to accurately position the planting holes in the required spacing. Use bamboo splits or sticks to post or mark the location of pit digging.



3.10. Pit digging

The size of the planting pits (length, width and depth) is crucial as it facilitates initial growth of the plant rhizomes and roots. Pits must be prepared at least 15 days before planting to facilitate weathering of soil.



Seedlings/saplings in polybags: 30 × 30 × 30 cm (L × W × D).



Rhizomes: 60 × 60 × 40 cm (L × W × D).



Rule of thumb: The size of the pit should be two times the size of the rhizome.

Ensure topsoil and bottom soil/sub-soil are kept on different sides of the pit.



3.11. Planting

a) Manure and fertiliser can be applied during planting. Apply one basket (5 kg of manure/compost) to the topsoil. Mix them thoroughly.



b) Fill the topsoil mixture into the bottom portion of the prepared pit and compact it.



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c) Remove the polybags.



d) Place the bamboo plants on the pit.
The neck of the polybag should be on the same level as the top of the pit.



e) Fill the remaining topsoil mixture on the sides; then fill the bottom soil above it.



f) Compact the soil in the pit.



g) Prepare soil mounding around the plant; trench around the pit to enable water availability.



Best time for planting: Early rainy season is the right time for planting, as the plants will have sufficient moisture availability for a longer time to become established.



Chapter 4. BAMBOO PLANTATION MAINTENANCE

4.1. Introduction

Maintaining bamboo plantation (years 1–5) is important to increase the survival rate, accelerate early maturation of the plantation and ease the harvesting operation later. Bamboo plantation maintenance is carried out in two stages, as described below.

a) Seedling stage (years 1–3): This is the phase between planting and canopy closure, which usually lasts for about one to three years, depending on the planting material, site condition, species, density of planting and growth. In some sites, this phase can occur during years 1–2. During this phase, maintenance practices focus on protecting the young clumps from competing vegetation and provide them an enabling environment for rapid growth.

b) Early maturation stage (years 3–5): During this phase, maintenance activities are focussed on clump management (cleaning, pruning, thinning to reduce clump congestion).

4.2. Maintenance during the seedling stage (years 1-3)

During this phase, maintenance will be carried out twice a year.

a) Just before the end of the rainy season: Eliminate weeds and loosen soil during the end of the active rain period (to accumulate and increase soil moisture; and to eliminate unwanted seeds, when seeds of weeds are not completely mature enough to produce more weeds).

b) Beginning of the rainy season: Eliminate weeds and shrubs in the initial period of growth and enable bamboo plants to grow vigorously during the active rainy season.

The maintenance practices aim to ensure the survival of plants and enable an environment for planted bamboo to grow and regenerate faster. Key maintenance practices are described below.

4.2.1. Re-planting

Re-planting should be carried out during the first and second years. Any dead and weak planted seedlings should be replaced with new ones. It is important to reserve seedlings for replacement planting. Normally, about 10–15% of planted seedlings will be re-planted during the first year and about 5% of seedlings for the second year.



4.2.2. Weeding and soil loosening

Growth of young bamboo plants in the early stage can be hampered by weeds and any other competing vegetation. Weeds weaken the root and stem development, as well as contributing to the occurrence of insects, pests and disease. Weed clearance should be done at least twice during each of the first two years. Weeding eliminates climbing vines as well.

Weeding and soil loosening improves the sanitary environment (turning soil reduces pests and insect attack), enables free expansion of roots and rhizomes and increases the moisture retention capacity of soil.

There are two options for weed clearing and soil loosening, which are as follows: (1) ploughing and (2) spot weeding.

1) Ploughing and soil loosening: If ploughing is possible, undertake ploughing in the bamboo plantation area or site. Along with ploughing, clear all the weeds and loosen the soil around bamboo clumps.



Ploughing the entire plantation.



Weed clearance and soil loosening close to bamboo plants where ploughing may not be possible.

2) Spot weeding and soil loosening: In the sloping area, it is advised to prepare soil and weed planted bamboo locally. Do not plough the full area, and do not clear vegetation that is not competing with the planted bamboos. Weeding and soil loosening should be done around planted bamboo only.



If ploughing is not possible, undertake spot weeding in a radius of 1 to 1.5 meters around the bamboo clumps.



Soil loosening must be done starting from the plant to a distance of at least a 50-cm radius, up to a depth of 15 cm.

4.2.3. Fertiliser application

Manure and fertiliser application stimulates the rapid growth of plants.

All sorts of soil amendments, including organic (cow dung, compost, farmyard manure, ash) and inorganic fertiliser (NPK) can be applied.

Thoroughly mix the applied manure/compost with loosened soil. Alternatively, fertiliser can be applied by creating trenches or holes



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around the bamboo clump. Make a shallow trench around the planted bamboo for applying fertiliser (20 cm depth × 20 cm width and 60–100 cm diameter); after application of manure /fertiliser, cover the trenches/holes with soil.

4.2.4. Trenching

Heap/mound the soil mixture around and over the base of the plant; prepare a trench (at least 50-cm radius) around the bamboo plant to retain water.



4.2.5. Mulching

Spreading a thick layer (≈5–10 cm) of organic matter (green and/or dry matter: straw, trees leaves and twigs) on the surface of the soil helps in conserving soil moisture (reducing evapo-transpiration), controlling weed growth and improving soil fertility and organic carbon.



Amount and timing of manure / fertiliser

First application: One month after planting (when plants resume regrowth after planting), apply one basket (5 kg) of well-rotted manure or compost. In addition, 50 g of NPK can be applied.

Second application: At the beginning of the next rainy season (year 2), apply two baskets (10 kg) of manure or compost. In addition, 100–150 g of NPK may be applied.

Third application: At the beginning of the next rainy season (year 3), apply five baskets (30 kg) of manure or compost. In addition, about 500 g of NPK can be applied.

Repeat the process in the following years.

Please note: Bamboo has a high demand for silica. Bamboo leaves, rice husks and so on are rich in silica. Compost prepared using bamboo leaves and rice husks is good.



Caution:



- Make sure sufficient soil moisture is available: Apply inorganic fertiliser (NPK) only when there is sufficient soil moisture and/or rain. In case of dry conditions, application of NPK will result in fertiliser poisoning causing mortality of plants.
- Do not apply the inorganic fertiliser (NPK) directly to sensitive parts of the plant, like the rhizome.
- Always mix the fertiliser well with soil and manure and/or cover with soil.

4.2.6. Irrigation

Irrigation: Irrigation helps in reducing mortality in young plants and facilitates growth. Especially during year 1 of plantation establishment, irrigate bamboo plants during long, dry spells at an interval of 10–15 days. Apply water (15–20 L) in trenches created around bamboo plants by channel irrigation or spot irrigation.



Trenching for increasing water retention and soil moisture: In drier locations or semi-arid regions, rainfall is relatively scanty. Trenches can be created to collect and store more water to increase soil moisture by collecting the run-off generated.



“V” trench: In sloping land, create a trench 30 cm above the bamboo plant, following the slope. The size of trench will be approximately 1.5 m (length) × 30 cm (width) × 30 cm (depth).



“Half-moon” trench: In sloping land, create a trench 30 cm above the bamboo plant, following the slope. The size of the trench will be approx. 1.5 m (radius) × 30 cm (width) × 30 cm (depth).

Flat land: Create a rectangular trench (1.5 m in length × 30 cm in width × 20 cm in depth) or create a circular trench around the bamboo clump (1-m radius).



Flood management: Prolonged flood conditions will cause rotting of the rhizome and root systems due to abnormal respiration metabolism caused by a shortage of air flow. First, do not plant bamboo in locations prone to floods. In case of accidental flood, creating a drainage system is essential.



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4.2.7. *Inter-cropping with bamboo*

Inter-cropping is highly encouraged as it is beneficial for farmers to generate income until the bamboo plantation provides regular income. In addition, inter-cropping helps in weed control, reduces evapo-transpiration, and increases soil organic matter. With inter-cropping, there will be regular maintenance of the plantation site (without additional work), which favours the survival and growth of bamboo. Depending on the site condition, species and scientific management practices, harvesting of bamboo can start after four to six years. Inter-cropping can be practised until complete canopy closure.

During the initial two years, due to large spacing, any crops (including high light-demanding crops) can be grown.

During years 3 and 4, with canopy closure, shade-loving crops can be inter-cropped.

Commonly grown inter-crops (years 1 and 2): Soya beans, cassava, mustard, tobacco, chilies, watermelons, vegetables, tuber crops, pineapples, bananas, peas, green gram (mung bean), lentils, pigeon peas, peanuts/groundnuts, moringa, papaya are commonly grown in ter-crops in the first two years. Corn and wheat can also be grown (but they are intense consumers of nutrients and belong to the same family as bamboo).



Commonly grown inter-crops (years 3 and 4): Ginger, turmeric, shade-loving sweet potato and yam, medicinal plants and other shade-loving crops are commonly grown in the second two years.



Other control measures during years 1–2 or 3 (depending on growth of plantation)

- Don't trim foliage and branches or collect shoots; this will allow the bamboo stands to build sufficient energy/food reserves for optimal growth.
- Maintain fencing and fire breaks; and prohibit cattle or animals from intruding, as bamboo is an excellent fodder for cattle/animals.



Rule of thumb:

- To avoid competition, avoid planting inter-crops within a radius of 1–1.5 m around the bamboo clump.
- Avoid inter-crops belonging to the grass family (maize/corn, wheat). Both bamboo and inter-crops compete for nutrients and are attacked by mostly the same insects and pests.



4.3. Early maturation phase (years 3–5)

The focus of maintenance during the early maturation phase (about years 3–5) is to reduce clump congestion and coppicing and train the clump to make it easier to harvest the matured bamboo poles, which are commonly found in the centre of the clump. Clump congestion is not a serious problem in running bamboo or long-necked rhizome bamboo, such as *Yushania alpina* (highland bamboo), but it is a serious problem in short-necked clumping bamboo, such as lowland bamboo (*Oxytenanthera abyssinica*), and bamboo species belonging to the genera *Bambusa*, *Cephalostachyum* and *Dendrocalamus*.

If the clumps are not managed from the beginning (first three to five years), clump congestion is likely to happen.



Congestion of bamboo culms/poles in a clump is one of the most serious problems in sympodial bamboos, making it difficult to harvest the mature poles (inside the clump, close to the centre).

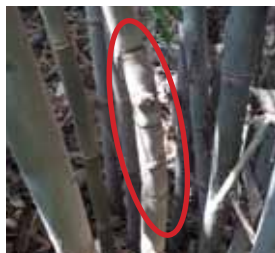
When young culms (usually found in the periphery of the clump) are injured or felled, many coppice shoots develop creating clump congestion.



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4.3.1. *Cleaning and thinning*

Start thinning from year 3 or 4 of plantation. Remove/cut dead, old or damaged culms/poles (in the middle of the clump) and malformed culms. Usually, new shoots are produced towards the outer side, and those located in the inner portion are the older ones.



The cleared clump will allow easy access to the centre of the clump for easy harvesting. Maintain this year after year.



4.3.2. *Pruning and de-budding*

Pruning branches and de-budding in the bottom one-third of the height of the bamboo culm reduces clump congestion and helps in providing a healthy and airy environment in the clump. It also reduces pests and diseases.

Pruning and de-budding should be introduced from year 3 of the plantation. The best time for pruning and de-budding is the end of the monsoon (once the new shoots develop into a well-grown culm).



Pruning- Prune/de-bud the branches/buds close to the node to avoid re-growing of sprouts for leftover branch buds.

Use sharp tools (hacksaw) to avoid damage to outskin.



De-budding

4.3.3. Shoot thinning

During shooting, there can be numerous shoots emerging from the same mother culm or pole. They usually develop into weak culms due to insufficient water and nutrient supply from the mother culm/pole and become congested. Keep one or two shoots to grow from a single mother, and dig out other shoots. Shoot thinning improves the quality of the emerging bamboo poles and creates space for culm management, especially for harvesting in the future. Completely remove any shoots (including rhizomes) that have the entire rhizome above the ground.



One bamboo rhizome has about 6–12 buds and has the potential to produce 6–12 bamboo poles, depending on the species.



Four bamboo shoots/poles emerging from a single mother results in poor quality (lesser diameter and height of bamboo poles).



Three bamboo shoots emerging from one mother culm (left) and two bamboo shoots emerging from one mother culm (right). Leave one strong bamboo shoot to grow into a culm (each mother) and dig out the weakest ones.



Only one shoot emerging from a mother culm; leave it to grow into a culm.

4.3.4. Fire control

After cleaning, pruning and thinning of clumps, remove the cut culms, branches and twigs from the bamboo plantation to avoid fire and incidence of pests, insects and diseases.

Maintain a firebreak of at least 20 m surrounding the bamboo plantation.



4.3.5. Soil loosening and soil mounding

Loosen the soil surrounding the bamboo culm; apply five baskets (≈30 kg of manure/compost/ash), and if available, an additional 500 g of NPK. Mix the fertiliser with loosened soil, carry out soil mounding at the base of the clump and trench around the clump.



Chapter 5.

SUSTAINABLE HARVESTING OF BAMBOO

5.1. Introduction

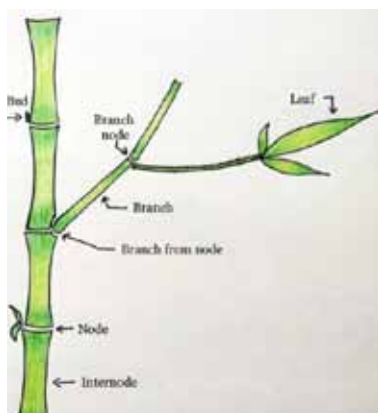
Bamboo is a “woody grass” that produces new shoots or culms (bamboo poles) annually. A bamboo culm matures in three to five years. The mature culms will no longer produce shoots. The lifecycle of the culms is about five to eight years; this means that if old culms are not harvested, the plant will die after five to eight years. Therefore, it is important to harvest old bamboo culms (three years and older). Harvesting old culms will improve the quality of bamboo forests and bamboo poles while preventing fire.

This chapter provides the basic terms and techniques for sustainable management of bamboo plantations/forests for culm harvesting and bamboo shoots.

5.2. Basic terms (Morphology)

It is important to understand the terms used throughout the document to sustainably manage bamboo plants.

“Morphology” refers to the outward appearance of the plant’s components. The vegetative parts of the bamboo plant consist of the clump, culms, roots, rhizomes, culm sheaths, branches, nodes, inter-nodes, buds and leaves.



5.3. Major classification of bamboo

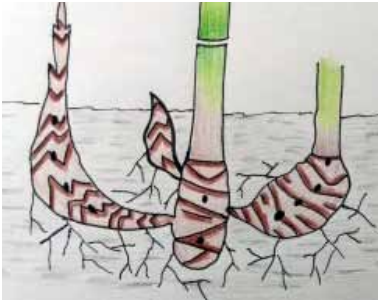
Bamboo is based on a rhizome, and the underground structure, which constitutes the structural foundation of the plant, can be classified into the four following types:

- 1) Pachymorph/sympodial tufted (short-necked pachymorph)/clumping bamboo;
- 2) Pachymorph/sympodial scattered (long-necked pachymorph)/clumping bamboo;
- 3) Leptomorph/monopodial/running bamboo; and
- 4) Amphipodial mixed/mixpodial/clumping and running bamboo.

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1) Sympodial (pachymorph: short-necked rhizome)

The rhizome proper is short and thick; the rhizome neck is short (and the diameter is smaller than either of the axes it joins together). In these bamboos, new culms emerge close to each other because of small rhizome necks, thereby forming tight clumps. Mostly found in tropical and sub-tropical climatic zones. Bamboos of the genera *Arundinaria*, *Bambusa*, *Cephalostachyum*, *Dendrocalamus*, *Gigantochloa*, *Oxytenanthera*, *Thyrsostachys* and so on belong to this category.



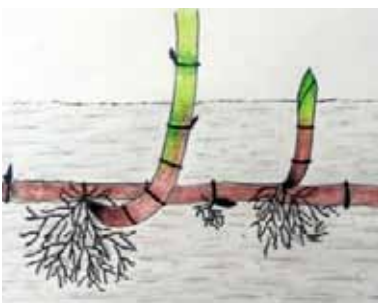
2) Pachymorph (sympodial scattered or long-necked rhizome)

These are typically clump-forming bamboos with long rhizome necks. The culms within clumps are a bit scattered due to the long rhizome neck. Mostly found in the tropical and sub-tropical regions. Bamboos of the genera *Melocanna*, *Yushania*, *Fargesia*, *Valiha* and so on belong to this group.



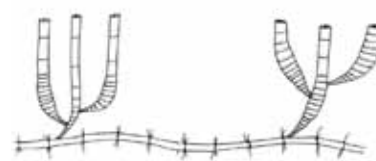
3) Monopodial (leptomorph or running bamboo)

Monopodial or running bamboo is usually found in temperate zones (cooler climates) and grows as "single, free-standing culms". In these bamboos, the underground rhizome runs beneath the soil, and new culms emerge from the underground rhizome nodes at long, uniform distances, thereby giving the appearance of a single culm plantation. Bamboos belonging to the genera *Phyllostachys*, *Indosasa*, *Semiarundinaria* and *Acidosasa* are in this category.



4) Amphipodial (mixed)

This type of rhizome is composed of both pachymorph/sympodial and leptomorph/monopodial bamboos. The subterranean axis consists of both sympodial and monopodial parts. The culms above ground are partly clumped and partly scattered.



5.4. Growth pattern of bamboo clumps

Bamboos are monocarpic plants that flower and produce seeds once in their lifetime, after which, the culm/clump/bamboo forest dies. Broadly, the gregarious flowering cycle of bamboo is in the range of 25–45 years. Some species flower once in 120 years, while others do not flower and seed. Therefore, bamboo is a perennial plant that produces bamboo poles without re-planting.



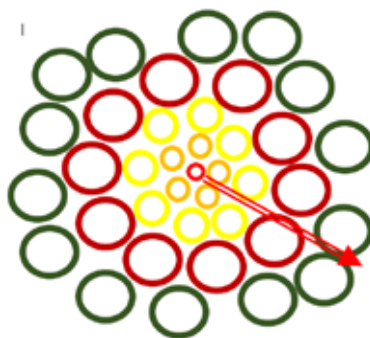
Bamboo flowering



Bamboo dying

Once planted, depending on the site condition and management, most sympodial bamboo clumps require about four to six years to reach maturity (when the bamboo culms within clump reaches their maximum height and diameter; the bamboo clump reaches its girth); thereafter, they remain more or less static.

The number of culms and diameter at breast height (DBH) and height gradually increase in subsequent years after planting, reaching the maximum in about five years. The expansion of the clump girth is rapid during the first four to six years after planting and then slows down. If there is no harvesting after clump maturity, culm production gradually decreases. In the case of undisturbed clumps, crowding and congestion happens (new shoots/culms emerge every year and old culms die every year). Due to congestion, yields decrease and culms are more often bent and twisted, making the plant unsuitable for high-end value addition.



Cross sectional representation of a culm

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Bamboo clumps produce new shoots/culms/poles annually, and at the same time, old bamboo culms/poles (over five years old) start deteriorating and dying. If bamboo poles (mature) are not harvested regularly, the productivity and quality of poles and shoots reduces drastically. If over-harvested, the productivity drops, which can lead to the degradation of clumps. Therefore, sustainable and selective harvesting coupled with proper management practices is key for healthy bamboo clumps, which can provide annual income opportunities for harvesters, growers and processors.



Year 1



Year 2



Year 3



Year 4



Year 5



Year 6

5.5. Sustainable management and harvesting

How to conduct sustainable management and harvesting of bamboo forests and farms depends on the objective. Broadly, this guidelines document illustrates the management guidelines of the following: (a) management for timber production and (b) management for bamboo shoot production.

5.5.1. *Management for timber production*

i) Basic harvesting rules

- 1) No clear felling should be allowed.
- 2) All older or matured bamboo culms should be harvested (three years +).
- 3) Current-year culms should be retained for reproduction.
- 4) At least a minimum of six culms over one year old, spaced uniformly over the clump, should be retained. When there are large clumps, proportionately more mature culms can be retained.

- 5) The number of harvestable culms should not exceed the number of poles that emerged in the last year.
- 6) Digging of young rhizomes is not permitted, except for propagation purposes. (Old and dead rhizomes can be removed to create space for new shoots).
- 7) Culms should be felled/cut at the first inter-node from the ground (about 10 cm from ground level).
- 8) A sharp instrument (knife or saw) should be used when felling to avoid splitting and damage of culms.
- 9) All dead and dry bamboo, as well as all debris as a result of harvesting and high cuts (due to lopping), should be removed from the clump.
- 10) Bamboo forests should be protected from fires.

ii) Culm age

Although individual bamboo poles or culms stand apart, the underground portion (rhizome system) of the bamboo clump is interconnected.


Due to annual production of new shoots, different-aged culms/poles are observed in a bamboo clump. Age determination of these culms is important to sustainably manage and harvest bamboo, as bamboo culms of different age categories have the following attributes: (a) different physical, mechanical and chemical properties and (b) unique functions in a clump.

Difference in properties for value-addition

- 1) The age of the culm is an important factor for its suitability in different applications. Bamboo shoots emerging from the ground take about 60–120 days to reach their full height, diameter and wall thickness. Thereafter, only mechanical and chemical property changes occur in mature bamboo poles.
- 2) Uniformity of raw material is critical for production of high-quality, standardised/industrial products. Bamboo poles of similar physical, mechanical and chemical properties (with age grading) will ensure production of uniform and standardised products.


Different purposes of age classes, functions and applications

Bamboo culms or poles of different age groups in a bamboo clump perform different functions to ensure the suitability of the bamboo clump.

| Age | Properties | Function | Usage Application | Visible Identification |
|-------------|--|-------------------|--------------------------------|---|
| 0 – 30 days | Bamboo shoots: Soft like vegetable, more than 90 % water. | Future generation | Food for humans and animals |  |

Manual for sustainable management of clumping bamboo forest

| | | | | |
|-------------------------------------|---|--|---|---|
| Current year: 0 - 1 year (juvenile) | Internal tissues are slender, branches, roots and leaves are not fully developed. Cell wall of fibre with lamellae is very small and culms are immature. Starch and moisture content is highest. | Future generation | Production of ropes and baketry (8 - 12 months old) |  |
| 1 - 2 years (adult) | Root system, branching and leaves are well developed; thereby has higher capacity for photosynthesis and nutrient absorption. Culm is at its peak of metabolism and shoot production. Cell wall of fibre is small, deposited with additional lamellae; high lumen left. Starch content is high, susceptible to decay and insect attack. Moisture content high. | Highest shooting capacity; supply of food and nutrients for rapid growth of shoot | Basketry, mats |  |
| 2-3 years (late adult) | Abundance of nutrition, physiologically active. Lower shooting capacity compared with year 1-2 poles. Strength and density of timber is augmented (cell wall of fibre is slightly bigger, deposited with additional lamellae). Starch content is comparatively lower than bamboo of year 1-2, susceptible to decay and insect attack. Moisture content comparatively lower. | Production and supply of food for growing shoots; established root and rhizome systems provide protection from winds and shade | Furniture products and non-structural applications; paper and pulping |  |

| | | | | |
|---------------------------------|---|--|--|---|
| 3-4 years (old age) | Cell wall of fibre is optimal, with high structural stability and only a small lumen left. Leaf production start to decline. Starch content is lower. Moisture content is lower. | No shooting capacity; right age for harvesting | Structural applications, industrial products |  |
| 4 years + (advanced old age) | Cell wall highly lignified, fragile due to lack of elasticity. Starch content lowest. Moisture content lowest. Leaf volume reduced, physiological activity declined, timber quality diminished. | No shooting capacity; quality of timber start to decline; decline in weight; culms starts to die and deteriorate as age progresses | Too brittle (lack of elasticity) |  |

iii) Age-marking system (especially for non-farm bamboo)

Bamboos lack the vascular cambium layer, and thus, lack the secondary growth in diameter seen in trees. Under field conditions, it is not always easy to distinguish the age of a bamboo culm, since culms in a mature clump tend to have the same girth, length and nodal structure.

The culm age can be identified based on certain features of the culm sheath, development of branches and leaves, external colour of the culm, position of new culms and so on. For example, in sympodial bamboos, younger/current-year culms are usually on the outer side, while older culms are towards the inner side. Culm sheaths are usually absent on older culms. The accuracy of such a distinction, however, depends on the skill and experience of the person and is not always reliable. Therefore, other guaranteed methods have to be adopted to determine the age of bamboo. Age can also be determined by the following methods: (a) marking the culms with different colour paints, (b) writing the year and month of shoot emergence using colour/paint and (c) inscribing the year of shoot emergence. Alternatively, other innovative approaches can be adopted.

Different colour paints: Three different colour paints are required, one for each year of a three-year cycle. Culms that are older than 3–4 years should be logged, as they become weak and brittle and can be expected to die. After the culms attain full height during the first year, they are marked with paint. A scheme for identifying culm age is shown in the table below. Please note, this is mostly suitable for on-farm bamboo plantation, as well as intensely managed forest plantation.

Colour schemes for identifying the age of culms

| Colour | Age (Year) | Rotation-2 |
|--------|--------------------|--------------------|
| Red | Current: 0-1 years | Current: 0-1 years |
| Yellow | 1-2 years (2019) | 1 – 2 years (2022) |
| Blue | 2-3 years (2020) | 2 – 3 years (2023) |

Different colours /year marking used for identifying culm ages



Writing the year and month of shoot emergence: Using single colour paint (black), write the year and month of shoot emergence. This method is widely adopted in China.

Please note: Marking should be done after the culm attains its full height, that is, after it has stopped growing. The indication of the stoppage of further dimensional growth (length) is when branches begin to appear, normally first in the upper portion of the culm.



- Detach the culm sheath from the culm before beginning to paint.
- Mark the different-aged culms with the thick paint by making a 2–3-in band at breast height in the inter-nodal portion of the culm, taking care that paint does not drip down the culm.
- Use different colours (as given in the table and figure above) for marking different ages.



iv) Sustainable management and harvesting practices (timber stands)

Sustainable management and harvesting practices of clumping bamboos are focussed on measures to accomplish the following: (a) regulate the population structure of bamboo clumps and culms and (b) improve the growing conditions.

Bamboo forest/farm structure management

Maintaining the inter-clump density (number of clumps in a hectare), intra-clump density (number of poles in a clump) and (c) age composition (composition of different age-class bamboo culms/poles in a clump) is critical for optimal growth and regeneration.

a) Inter-clump density/structure of bamboo stands

Plantations with low clump density will suffer from canopy exposure and short culms due to a lack of light competition, low soil moisture and strong competition from weeds. This may result in poor productivity and necessitate a lot of labour during tending. Plantations with high clump density/over-stocking at planting will also result in low productivity from smaller plants due to the intense competition among the plantlets for light, space, soil moisture and nutrients. Maintaining an optimal density of the clump is crucial for optimal yields.



Low-clump-density bamboo stand
with extensive weeds



High-density bamboo stand with
stunted growth of clumps and culms

Optimal inter-clump density: Stocking or density of clumps or spacing between clumps varies across sympodial bamboo species.

Small-diameter bamboo species (< 6-cm diameter DBH): 4 × 4 m or 3 × 4 m spacing: 600–800 clumps per hectare: Bamboo species like *Oxytenanthera abyssinica*, *Dendrocalamus strictus* and *Bambusa multiplex* belong to this category.

Medium-diameter bamboo species (6–10-cm diameter DBH): At least 5 × 5 m or 4 × 5 m spacing: 400–500 clumps per hectare: Bamboo species like *Yushania alpina*, *Bambusa vulgaris*, *Bambusa polymorpha*, *Cephalostachyum pergracile*, *Dendrocalamus hamiltonii*, *Dendrocalamus membranaceus* and others belong to this category.

Large-diameter bamboo species (>10-cm diameter at DBH): 7 × 7 m or 6 × 7 m spacing: 200–250 clumps per hectare: Bamboo species like *Dendrocalamus giganteus*, *Dendrocalamus asper* and so on belong to this category.

b) Intra-clump density

A reasonable number of standing bamboo poles in a clump is necessary for bamboo shoot/culm production (optimising quantity and quality). Depending on the species, it is recommended to retain 12–20 culms per clump. In the case of large-, medium- and small-diameter bamboo species, about 12, 16 and 20 bamboo culms can be retained. However, the most critical factor is the age composition. If clumps are located in a steep slope area, the number of culms in a clump could be 1.5 to 2 times higher for increasing the function of soil erosion control.

c) Age composition

Year 1: Year 2: Year 3: Year 4 = 1:1:1:1

Why is maintaining clump composition or age structure necessary?

One- to two-year-old sympodial bamboos usually have well developed rhizome buds, which will be transformed into shoots/culms. Three-year-old and older bamboo culms are in the mature phase, and most rhizome buds are already transformed into bamboo culms or poles; the remaining buds have no shooting capacity. The main function of three-year-old and older poles is to provide shelter and protect the young culms and shoots from strong winds.

Broadly, an equal number of bamboo poles/culms of different age classes can be retained, as the number of bamboo poles harvested and shoots recruited for growth into bamboo culms could be balanced.

The composition of the clump after harvesting: Current year 1 (0–1 years), year 2 (1–2 years), year 3 (2–3 years) can be in the proportion of 1:1:1. In addition, one of two old bamboo poles (year 4) could also be retained.

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To illustrate this, for example, an annual harvesting clump has 12 bamboo poles; the number of bamboo poles for year 1 = 4, year 2 = 4 and year 3 = 4. Allow four strong shoots to grow into a bamboo culm/pole; the clump will have 16 poles, and when harvesting season arrives, harvest four mature bamboo poles that have passed year 3.

The composition of the clump after shooting season and before harvesting can vary depending on the harvesting rotation (one, two or three years).

v) Clump management

a) Culm/shoot retention

Why strong bamboo shoots should be selected to grow: The diameter of the future culm is established when shoot activation and partial elongation of new shoots are underway. For the growth of rhizome buds into shoots and bamboo culms, all the nutrients are supplied by the connected mother culm. If more shoots are produced from a single mother culm, it is more difficult for the mother to supply nutrients and food, resulting in stunted growth and death of some shoots/culms. It is recommended to allow one or a maximum of two shoots to grow from a single mother culm and cull the rest.

It is also advised to thin out weak shoots, congested shoots and shoots emerging in the late shooting period as the shoots will be less vigorous and generally develop into a poor bamboo culm.

b) De-budding

In the case of some sympodial or clumping bamboo species, such as *Bambusa bambos*, *Bambusa blumeana*, *Oxytenanthera abyssinica*, *Dendrocalamus hamiltonii*, *Bambusa vulgaris*, *Guadua spp.* and others, there is profuse and prominent branching in the bottom portion of the bamboo clump, creating congestion and difficulty in harvesting and management. In those species with prominent branching at the bottom portions, de-budding can be done to stop proliferation or growth of branches in the bottom one-third of the height of bamboo poles. De-budding can be done when the bamboo culm reaches its entire height and culm buds start to sprout. This will improve the clump accessibility, management and harvesting.

In the case of *Yushania alpina*, *Dendrocalamus giganteus* and other bamboo species, no branching is found up to half the height of the bamboo culms, and therefore, no de-budding is necessary.



Congested clump



Sprouting of culm buds



De-budding

c) Weeding, soil loosening and mounding

In the case of sparse bamboo forests or plantations, weeds and shrubs tend to grow, and these compete for water and nutrients. They are also hosts and habitats for insects and pests. Cut/cleaned weeds and shrubs will decompose and help in improving soil fertility.

Soil loosening in bamboo plantations is important, as maintaining a good soil structure in the stand will be beneficial to the growth of shoots and root systems, as well as water conservation. Inside the bamboo clump, do shallow digging and soil loosening (<10 cm deep), and for surrounding bamboo clumps, deeper digging of approximately 20 cm is recommended. At the same time, old and decayed cut bamboo handles and rhizomes can be removed. Please note that, due to the desire to avoid soil erosion, soil loosening is not recommended for bamboo clumps on steep slopes.

Fertilisation: With the extraction of bamboo poles for value addition, soil minerals and nutrients are also extracted. Two to three baskets (15–20 kg) of manure or compost can be added to the clump.

Alternatively, in the case of on-farm or high-intensity managed matured bamboo plantations, 0.5–1 kg of NPK fertiliser can be added per well-grown clump.

Soil mounding: After mixing the manure or fertiliser with soil, mound the bamboo clumps with excavated soil and create a small trench surrounding the clump to hold water.

Weed cutting, soil loosening and mounding can be done once a year—just before the rainy season. Alternatively, this could also be done twice—once before the beginning of the rainy season and again before the end of the rainy season.



vi) *Harvesting methods*

a) Harvesting season

After the rainy season or in the early dry season is the best time to harvest bamboo poles. During the post-rainy season, starch content is comparatively lower (since the new shoots consumed most of the nutrient in the clump). With low starch content and relatively less moisture content, the bamboo poles are least susceptible to attacks by fungi, borers, termites and other pests.

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Harvesting or felling should not be done during shoot emergence and growing periods as harvesting operation will damage the tender growing shoots.

Harvesting should not be done at the end of the dry season or in the early rainy season as the bamboo plant body has a lot of accumulated starch and nutrients to feed the emerging shoots. Bamboo poles harvested during this period will be susceptible to borer and insect attacks due to the high starch concentration.

b) Harvesting methods

New culms are commonly produced on the periphery of the clump (young culms/rhizomes are the ones that produce new shoots (one to two years old). The tendency of bamboo collectors and harvesters is to harvest the bamboo poles on the outside periphery of the bamboo clump, which is young and immature, affecting the sustainability of the clump and durability of the bamboo products/poles used.

Mature bamboo poles in sympodial bamboo clumps are commonly found at the inner core of the bamboo clump.

In the case of sympodial bamboo with a long rhizome neck, such as *Yushania alpina*, penetrating inside the clump and harvesting mature bamboo poles is relatively easy due to the sparse nature of the plant's growth.

In the case of unmanaged sympodial bamboo with a short-neck rhizome (genera like *Bambusa*, *Oxytenanthera*, *Dendrocalamus*, *Cephalostachyum* and others), the bamboo clump is congested, prohibiting the entry into the clump.



Dendrocalamus membranaceus clump showing younger bamboo poles outside the clump



Unmanaged *Bambusa vulgaris* clump with dead bam-boo poles on the inside of the clump and young culms on the outside

Two techniques for managing congested or clustered bamboo are as follows: (a) the tunnel technique and (b) the horseshoe technique.

Tunnel technique

Make a 60-cm-wide path from one end of the clump to the other. Make sure the tunnel created passes through the central part of the clump. As most of the mature bamboo poles are created in the centre of the clump, the tunnel is created so that one can enter, harvest and drag the bamboo poles.



Bamboo clump with tunnel

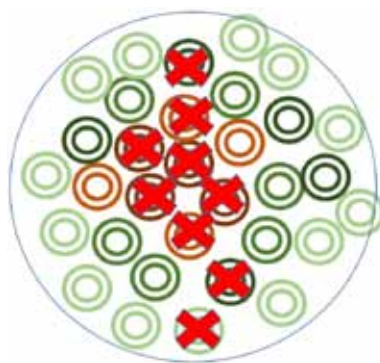


Illustration of bamboo clump showing bamboo culms to cut to create a tunnel

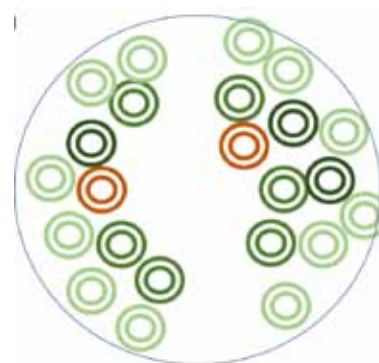


Illustration of a bamboo clump with a tunnel

Horseshoe technique

Make a 60–100-cm-wide path from the periphery or outside of the bamboo to the centre of the clump. Select the location or side of the clump where there is the smallest number of young bamboo poles, to avoid cutting of young poles.



Bamboo clump showing horseshoe technique



Illustration of bamboo clump showing bamboo culms to cut to create a horseshoe opening

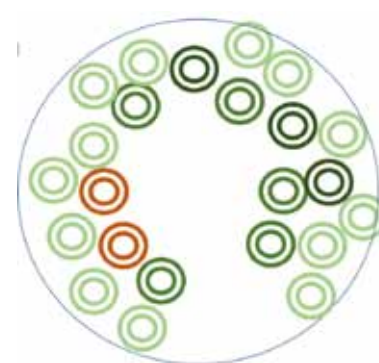


Illustration of a bamboo clump

Felling / Cutting method

Cut the culms in a slanting manner (45°) at the first inter-node (about 10–15 cm above the first node) to minimise wastage, avoid sprouting and prevent rainwater from stagnating in the cavity of the stump portion.

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When felling is done far above the ground, buds on the nodes of the cut stump will be activated, producing branches and bushy clumps; this will hinder future harvesting and management operations.



Right harvesting method



Wrong harvesting method

Care during felling / harvesting

- 1) Branches and twigs from harvested poles need to be cleared from the mother culms.
- 2) Dead, rotten and deformed culms and stumps should be cleaned.
- 3) Harvesting and felling operations should not be undertaken in the culm emergence period.

Rotational harvesting in bamboo forest management

- 1) Clear cutting should not be allowed.
- 2) Rotation cycle can be two to three years. The rotation cycle should not be longer than three years to avoid culm congestion and slowdown of shoot production.
- 3) Leave all the one-year-old culms and an equal number of mature culms (two and three years combined); harvest the rest.
- 4) In managed bamboo forests, the regeneration (quantity) and quality of bamboo poles will be better.
- 5) In locations with unregulated or over-harvested bamboo forests over years, stopping harvesting for a few years to allow the bamboo forests to recoup.

5.5.2. Sustainable management of bamboo for bamboo shoots or bamboo juice

The primary objective of bamboo shoot clump management is to maximise sustainable bamboo shoot production. This technique can also be applied to bamboo juice production (especially in Tanzania), as the bamboo juice is tapped from bamboo shoots.

Depending on the species, there are about 6–12 buds or more in each rhizome; among them, several buds will be activated and elongated into shoots or culms. If they are harvested, the remaining ones will be activated and grow as new shoots, enabling harvesting of bamboo shoots and sustenance of bamboo stands.

The shooting period lasts for about two to six months (varying according to the species, site conditions, geographic location and management techniques). It occurs in three distinct phases, which are as follows: (a) the early phase, (b) peak phase and (c) final phase. Nearly one-fourth of shoots are produced in the early phase, one half during the peak phase and one-fourth during the final phase. Select the best, strongest shoots during the peak stage and leave them to grow into new mother bamboo plants.

Sustainable management and harvesting practices of clumping bamboo shoot stands focus on measures to accomplish the following: (a) regulate the population structure of bamboo clumps and culms and (b) improve the growing conditions.



Bamboo rhizome with buds



Shoot sprouting in a bamboo clump

i) Clump density and structure

Bamboo stand structure: Bamboo shoot clumps need to be diffuse or open compared with timber stands due to the need for better site conditions, such as heat, light, nutrients and moisture.

The bamboo stand structure comprises the following: (a) inter-clump density, (b) intra-clump density and (c) age structure in a clump (clump composition—different aged bamboo poles), which are similar to timber stands.

a) Inter-clump density

Clump density: Distance depends on species and growing conditions.

Small-diameter bamboo (<6-cm diameter at DBH): 4 × 4 m to 3 × 4 m spacing: 600–800 clumps per hectare: Bamboo species like *Oxytenanthera abyssinica* and *Dendrocalamus strictus*, preferably mixed with some leguminous species.

Medium diameter (6–10 cm): 5 × 5 m to 4 × 4 m: 400–600 clumps per hectare: Bamboo like *Yushania alpina*, *Bambusa vulgaris*, *Dendrocalamus hamiltonii*, *Dendrocalamus membranaceus* and other. Preferably mixed with some leguminous species.

Large diameter (>10 cm): At least 7 × 7 m to 5 × 5 m: 200–400 clumps per hectare: Bamboo species like *Dendrocalamus giganteus*, *Dendrocalamus asper* and *Dendrocalamus latiflorus*. Preferably mixed with some leguminous species.

b) Intra-clump density

For **large-diameter bamboo** (> 10 cm diameter), four to six mother culms are usually retained.

For **mid-size** and **small-diameter bamboo** (<10 cm diameter), 6–12 culms are usually retained.



c) Age composition

Model 1: At the beginning of shooting season, the ratio of year 1 and year 2 is 2:1.

Only one- to two-year-old sympodial bamboos have the potential to produce bamboo shoots (well-developed rhizome buds/eyes with intensive germinating capacity). Older bamboo culms/poles (three years and older) are in the mature phases, and most of the rhizome buds are already transformed into bamboo culms or poles; the remaining buds have no shooting capacity.

For example, if the intra-clump density is 9 culms after culms are harvested, there will be 6 year 1 culms and 3 year 2 culms. After shooting season, 6 shoots are retained, and the clump will contain 15 culms, including 6 culms from 1 year, 6 culms from year 2 and 3 culms from year 3. Six culms will be harvested during culm-harvesting season, including 3 culms aged 2 years and 3 culms aged 3 years.

Model 2: At the beginning of shooting season, the ratio of year 1 and year 2 is 1:1.

In *Dendrocalamus latiflorus* shoot production in Vietnam, for example, after shooting season and before culm-harvesting season, an intra-clump has six culms, with two year 1 culms, two year 2 culms and two year 3 culms. Two culms of three years old will be harvested. Two culms of one year old and two culms of two years old are retained in the clump.

ii) Management techniques

a) Weeding

Weeding of other vegetative growth, including weeds, climbers and shrubs, should be done one to two months before the active rains.



b) Soil loosening and sun basking



One to two months before active rainfall season, remove the soil cover (dig up soil cover starting from outside to the clump centre). Expose the bamboo rhizome and shoot buds to sunlight. Remove messy roots around shoot buds and expose the shoot buds/eyes to direct sunlight and wind. This promotes burgeoning of shoot buds, resulting in early sprouting and increases in number of shoots.

Soil loosening is done by loosening up to the top 20 cm of soil to improve soil ventilation.

c) Manure and fertiliser

A bamboo shoot clump generally needs more nutrients as large numbers of bamboo shoots are extracted.

Smallholder farmers: Two to three baskets of manure or compost can be applied mixed with soil during soil mounding.

d) Soil mounding

Expose the rhizome to sun and wind for about 2 weeks. After sun basking, some rhizome buds/eyes start to expand and turn blue to form little shoots. It is the right time to pile the earth to cover the shoot buds; this will enable sprouting shoots to grow in dark soil. Soil mounding of bamboo clumps is done by adding soil to the whole bamboo clumps to cover the roots and rhizomes and 20 cm above the surface. Surrounding leaf litter can also be added.



e) Fertilisation

In the case of intensive farming, fertiliser application can be applied in addition to manure/compost along with soil mounding, as the fertiliser instantly releases nutrients compared with manure or compost.

NPK is the ideal combination; the ratio required by bamboo stands is 5:4:3. Disbursal of fertiliser three times instead of one time is better.

Fertilisation schedule

| | | |
|-----|---|------------------------|
| 1st | 2 weeks after sun basking | 1 kg per clump (NPK) |
| 2nd | Early period of rain (just before shoot harvesting, during bud differentiation and expansion) | 1 kg per clump (NPK) |
| 3rd | Before end of rainy period (after shoot harvesting period) | 1.5 kg per clump (NPK) |

f) Irrigation

For increasing shoot yield, during the dry season; irrigate bamboo clumps once in two weeks to induce early shooting and increased production of shoots.

In case of no rain during the active shoot period, clumps should be regularly irrigated to ensure maintenance of high soil moisture.



Pictures of burgeoning bamboo shoots

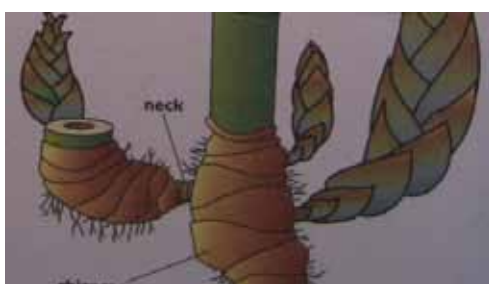
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iii) Shoot harvesting

1) Depending on the bamboo species, bamboo shoots are harvested when they reach a height of 15–50 cm. In the case of *Dendrocalamus* species, the height is about 15–30 cm; for *Yushania alpina*, it is about 40–50 cm.

2) Soil surrounding the shoots is removed until the shoot buds. Then, the shoots are cut with a sharp and clean knife, without damaging the mother rhizome.

3) Select the best/strongest shoot during the peak stage and allow it to grow into a new mother bamboo. For example, if we are maintaining an intra-clump density of six culms with a 2:1 ratio, four bamboo shoots should be allowed to grow into a full culm/pole. This will produce bamboo shoots for the coming year. Allow shoots from different locations of clumps to grow rather than allowing all shoots from one location to grow to avoid congestion.



Bamboo shoots from mother rhizome



Cutting bamboo shoots



FOUR BASIC RULES OF THUMB TO REMEMBER

- 1) Cut the small, keep the big.
- 2) Cut the old, keep the young.
- 3) Cut the crowded, keep the scattered.
- 4) Cut the sick, keep the strong.



ANNEXURE 1: Bamboo species, their agro-climatic conditions and their uses

| Bamboo species | Ideal altitude range | Introduced or observed altitude range | Site agro-ecological conditions | Specification of bamboo poles | Main uses | Propagation methods |
|--|----------------------|---------------------------------------|--|--|--|---|
| <i>Yushania alpina</i> (K. Schum) | 2200 – 3500 m AMSL | 1700 – 4000 m AMSL | Sub-tropical bamboo. Commonly found in higher elevations and mountain areas of East Africa, including Ethiopia, Kenya, Uganda, Tanzania, Sudan, Burundi, Camer-oon, Democratic Republic of the Congo (DRC), Rwanda, Malawi, Zambia. Grows well in mountain and volcanic soils. Rainfall ranging from 1250–3000 mm. Temperature is a limiting factor, with plants confined to areas of mean annual temperatures of 11.6–15.9°C tolerates down to –4°C. | Height: 2–19.5 m Diameter: 5–12.5 cm Thin walled with wall thickness ranging from 2 cm at the bottom to 0.3 cm at the top. | Bamboo flooring tiles, timber, handicrafts, furniture, bamboo stick-based products, bamboo sliver-based products, including mats and bamboo matboard, shoots, etc. | Rhizome / offsets; seeds. |
| <i>Oxytenanthera abyssinica</i> (A. Rich.) Munro | 1000 – 1800 m AMSL | 500–2200 m AMSL | Tropical bamboo species. Suitable for lowlands and mid-elevation, with rainfall of 900–1400 mm, drier and hot location. It is also found in drier locations of Ethiopia, Sudan and Uganda. It needs a minimum rainfall of about 700 mm. It can grow in poor and marginal soil. It is also drought resistant. Prefers comparatively warm temperature. Distributed widely in Eastern Africa; this species has been recorded in Ethiopia, Tanzania, Sudan, Uganda, Malawi, Zambia, Zimbabwe, Burundi. | Height: 7–10 m Diameter: 5–10 cm Solid bamboo poles when grown in drier climatic regimes; and slightly hollow in the case of wet climatic regimes. | Construction, furniture, basketry and handi-crafts, props, agricultural implements. Shoots edible. Leaves extensively used as fodder. Suitable for biomass, charcoal and energy. | Rhizome, seed, culm cuttings, layering. |

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| | | | | | | |
|--|-------------------|-------------------|---|--|---|---|
| <i>Cephalostachyum pergracile</i> | 500 – 1200 m AMSL | Up to 1500 m AMSL | Tropical lowland bamboo, thin walled. Commonly found in Indian sub-continent, Myanmar, Laos, etc. <i>Cephalostachyum pergracile</i> occurs in semi-humid to semi-arid regions on a range of soils; it is most common in well-drained, loamy soils in Myanmar. Mean annual rainfall: 800–1000 mm Mean annual temperature: 22–33°C, tolerates down to –6°C. | Height: 7–20 m Diameter: 5– 7.5 cm. | Bamboo stick- and sliver-based product line, bamboo shoots | Seed, offsets and culm cuttings |
| <i>Dendrocalamus membranaceus</i> Cv. <i>Grandis</i> | 50 – 1150 m AMSL | Up to 1400 m | Tropical bamboo growing in mixed deciduous or monsoon forest. Average annual temperature of 22–33 °C. Minimum rainfall of above 1000 mm/ annum. | Height: 20–25 m Diameter: 6–12 cm | Construction /pulp and paper; laminated boards; bamboo shoots | Seed, offsets, branch cuttings, culm cuttings |
| <i>Dendrocalamus barbatus</i> | 300 – 1100 m AMSL | | Tropical large diameter bamboo with medium wall thickness. Minimum rainfall of 1000 mm per annum. | Height: 15–18 m Diameter: 10 –15 cm | Craft, construction, plyboards, handicrafts, furniture, edible shoots | Seeds, offset, culm cuttings |
| <i>Bambusa polymorpha</i> | 0 – 1500 m AMSL | | <i>Bambusa polymorpha</i> grows naturally in semi-humid areas on medium to rich soils, well-developed soils. Grows in moderately high rainfall zones, higher than 800–6000 mm. Resistant to low temperatures (–3°C) and high temperatures (+53°C). Suitable average annual temperature of 18–30°C. Bamboo branch height of 12–20 m, particularly high rate of timber, making costs extremely low. | Height: 15–25 m Diameter: 5–15 cm Thickness: ≈2 cm at bottom and 0.3 cm at top | Bamboo stick-based products; mats, blinds, chopsticks and handi-crafts; edible shoots | Seed, offset, branch and culm cutting, layering, etc. |

| | | | | | | |
|--|-----------------|---|--|---|---|--|
| <i>Dendrocalamus yunnanensis</i> | 80 – 800 m AMSL | Also found at 1700–2840 m, in Baimahe (from 1800 to 2300 m) and in Xishan (China) around 2000 m | Tropical large-sized bamboo; requires rainfall in the range of 1000–3000 mm. Accumulated temperature is the total daily average temperature ($\geq 10^{\circ}\text{C}$) for the whole year. | Height: 18–25 m Diameter: 11–18 cm. | Bamboo shoot, construction, paper manufacture, pulp and wood | |
| <i>Dendrocalamus strictus</i> (Roxb.) Nees | 0–1200 m AMSL | 1500 m | Suitable for tropical and sub-tropical climates. Grows well in sandy loam soil. Rainfall of 750–4000 mm. Resistant to frost and drought (can withstand -5°C to 45°C). Optimum temperature: $20-30^{\circ}\text{C}$. Well-drained, coarse-grained/ stony/ degraded/dry soils. | | Furniture, construction, basketry products, shoots ed-ible. Good fodder. Highly suitable for charcoal and energy ap-plications. | Offsets; culm cuttings, branch cuttings and layering |
| <i>Bambusa bambos</i> (L.) Voss. | 0 – 1500 m AMSL | Up to 1800 m in Uttarakhand (India) | Suitable for tropical and sub-trop-ical climate. Prefers sandy loan and fertile soil. Can withstand frost; and it is simi- lar to <i>Dendrocalamus strictus</i> in its range. Rainfall of 750–4000 mm. Both <i>Dendrocalamus strictus</i> and <i>Bambusa bambos</i> have a wide range and are hardy. | Height: Up to 30 m Diameter: 10–18 cm Thick-walled bamboo Very densely tufted thorny bamboo pro-ducing large, dense clumps of packed culms | Construction, furniture, basketry, edible shoots. Ideal for wind break and bound-ary fencing (spiny) | Branch cutting and culm cutting |
| <i>Bambusa nutans</i> Wallich ex. Munro | 600–1500 m | Grows well around 2000 m in Uttarakhand (India) | Sub-tropical bamboo (sub-Himalayan regions). Grows well in moderate and high rainfall regions. Prefers a mean annual rainfall in the range of 2300–3000 mm, but tolerates 700–4500 mm. Temperature range of $4-37^{\circ}\text{C}$. | Height: 10–20 m Diameter: 5–10 cm Medium thickness and straight bam- boo poles | Construction, furniture, basketry | Offsets, branch cutting, culm cutting and layering |

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| | | | | | | |
|---|---|---|---|---|---|---|
| <i>Bambusa balcooa</i> Roxb. | 0–1000 m AMSL | Grows well up to 2000 m (Amhara, Ethiopia; Mbeya, Tanzania) | Grows well in high-rainfall regions of 1500–5000 mm. Can withstand drought (700-mm rainfall) and temperature down to –5 °C. | Height: 15–25 m Diameter: 8–15 cm Good wall thickness; high biomass production potential | Construction, furniture, basketry products. Edible shoots. Suitable for biomass, charcoal and energy | Culm cuttings, branch cuttings, layering |
| <i>Bambusa vulgaris</i> Schrad ex Wendl | 0–1500 m AMSL | Observed at 1900 m in North Kivu, DRC and 2000 meters in Madagascar | It is a pantropical species. Prefers moist tropical climate. Grows best in low altitudes; above 1200-m elevation, the size of culms reduces. Prefers a mean annual rainfall in the range 1200–2500 mm, but tolerates 700–4500 mm. Thrives in a wide range of soil and moisture conditions. Prefers moist alluvial soil; also grows well in well-drained sandy and clayey soils. Tolerant to salinity and water logging. It is drought resistant and frost hardy (–3°C). | Moderately tufted bamboo Dwarf green Height: 7–15 m Diameter: 4–7 cm Yellow type: Height: 7–15 m Diameter: 5–10 cm | Basketry and handicrafts; fencing and low cost application High biomass production capacity; suitable for energy (charcoal and biomass) | Very easy for propagation. Branch cuttings, culm cuttings and layering. |
| <i>Dendrocalamus giganteus</i> Wallich ex. Munro | 0–1200 m Can tolerate frost down to –1°C | Grows well at 1300–2100 m in North Kivu, DRC. | Tropical to subtropical bamboo. Grows well in humid tropical highlands and lowlands with high humidity and good alluvial soil. Can tolerate temperatures down to –2 °C. Prefers well-drained, loamy soils. Prefers a mean annual rainfall in the range 1800–3600 mm but tolerates 1200–4500 mm. | Height: 20–30 m Diameter: 15–30 cm Medium to low wall thickness | Construction, handicrafts, furniture, industrial panel products. Leaves good fodder. High biomass production capacity (charcoal and energy) | Layering, branch cuttings and culm cutting |

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| <i>Dendrocalamus hamiltonii</i> Nees & Arn ex Munro | 600 – 1500 m | Grows well at ≈ 2000 m in Western Himalayas (India) and Amhara Province (Ethiopia) | Suitable for sub-tropical climate. Requires moist and moderately good rainfall. Rainfall varies from 750-5000 mm in its natural range; temperature, maximum 46°C and minimum -5°C. | Height: 15-25 m Diameter: 9-19 cm; moderate wall thickness and very flexible bamboo. | Construction, handicrafts and furniture. Excellent bamboo shoots. Leaves-good fodder | Branch cuttings, culm cuttings and layering |
| <i>Dendrocalamus asper</i> (Schult.f.) Backer ex. Heyne | 400-1500 m Thrives well in 400-500 m | Grows well at an elevation of 2000 m in Madagascar. | Tropical to sub-tropical bamboo. Can withstand frost and cool temperature up to -4°C. Grows well in areas with good rainfall, prefers heavy and well-drained soils. It prefers a mean annual rainfall in the range 1800-3600 mm, but tolerates 1200-4500 mm. | Height: 15-20 m Diameter 8-20 cm Medium to low wall thickness | Construction, furniture, basketry and handicrafts; excellent shoots and fodder. Industrial panel products, chopsticks, toothpicks | Culm cutting and branch cutting |
| <i>Dendrocalamus hookeri</i> Munro | 700 – 1500 m | | Tropical to sub-tropical bamboo. Soil range: sandy loam to clayey loam. Grows well in humid tropical high lands with high humidity; minimum of 1200 mm of rainfall. | Height: 15-20 m Diameter: 10-20 cm Large tufted bamboo. | Construction, basketry and panel-based products, bamboo shoots, high biomass production potential suitable for energy | Culm cuttings |
| <i>Dendrocalamus brandisii</i> (Munro) Kurz | 700 – 1500 m | Grows well in moist and well-drained conditions | Tropical; sub-tropical bamboo. Tolerate frost and cool temperature up to -3°C. It prefers a mean annual rainfall in the range 1800-3600 mm, but tolerates 1200-4500 mm. | Height: 19-33 m Diameter: 13-20 cm Very large tufted bamboo | Construction, furniture, farm implements, basketry and handicrafts, edible shoots, high biomass production capacity, suitable for energy | Culm cuttings, branch cuttings |

Manual for sustainable management of clumping bamboo forest

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| <i>Guadua angustifolia</i> Kunth | 500–1600 m | Coincides with major coffee growing regions | Suitable for sub-tropical climate, can with temperature up to –2°C. Annual average temperature range is 20–26°C. Rainfall range: 1200–2500 mm/year. | Height: up to 30 m Diameter: up to 20 cm Good wall thickness (short internodes) | Construction and building material, furniture, handicrafts | Branch cuttings |
| <i>Thyrsostachys oliveri</i> Gamble | 500 - 700 m | Up to 1000 m in Uttarakhand, India. | Suitable for tropical climate, high rainfall and deciduous forest areas. Minimum 1000 mm to maximum 3000 mm+. | Height: 15–25 m Diameter: 5 cm Solid bamboo poles | Construction, furniture, props, agriculture implements, tools. Suitable for farm boundary fencing and agro-forestry; edible shoots | Offset planting |

