Biology and Management of Indigenous Bamboo Species of Ethiopia

Based on Research and Practical Field Experience

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This book is our first version; comments from readers, if any, are welcomed and will be duly considered while producing revised versions.

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Preface

One of the problems influencing bamboo cultivation and regeneration in Ethiopia is associated with inadequate knowledge on biological aspects and management requirement of bamboo species in the country. Lack of management on mature bamboo stands and stands after mass flowering has hampered the productivity of bamboo stands; belowground and aboveground stand congestion, and unregulated stand structure have reduced stand growth thereby lowered down stand value. These problems are primarily caused by lack of awareness and lack of technical management packages that help to render technical support to bamboo growers.

There are two versatile indigenous bamboo species that have been utilized for many applications in Ethiopia. The Forest Research Directorate of the Ethiopian Institute of Agricultural Research had been conducting studies on biological aspects and field trials on silvicultural management of these bamboos since 2008. Research information obtained from these research activities and practical experiences helped to develop this book at this time when the Forest Research Directorate has grown up to an institutional level, the Ethiopia Environment and Forest Research Institute, by the merger with the Soil Laboratory and Environmental Pollution Management Directorates of Ethiopia Environment Protection Authority.

This book provides basic information about biological and silvicultural management aspects of indigenous bamboo species. It is developed to support foresters and extension staffs that are responsible for providing training, monitoring and supporting local people on management of bamboo forests thereby increase technical skill and knowledge about this important resource. It has four chapters: chapter one provides overview of bamboos; chapter two address biology of indigenous species mainly their morphology, growth and flowering characteristics; chapter three deals with ecological aspects and chapter four deals with silvicultural management of bamboo stands of indigenous species. Nursery management, propagation and field planting and stand maintenance are discussed in another book entitled "Propagation of Bamboos in Ethiopia" by the same authors.

Chapter I

OVERVIEW OF BAMBOOS

1.1. Overview of bamboos in global context

Bamboo is a perennial grass belonging to the *Poaceae* (*Gramineae*) family and *Bambusoideae* subfamily. The term bamboo comprises more than 1,500 species that are widely distributed in the tropical, subtropical and temperate regions of all continents except Antarctica, in wide agro-ecological conditions starting from sea level to 4,000 m. The highest diversity and area coverage of bamboo is recorded from the Asian continent, followed by America and Africa (Ohrnberger, 1999). Africa possesses about 43 species on over 1.5 million ha of land; 40 of these species are primarily distributed in Madagascar while the remaining three species are found in mainland Africa (Ensermu, *et. al.*, 2000). Ethiopia possesses two indigenous bamboo species. Managed bamboo forests cover more than 22 million ha of land worldwide, in addition to wild bamboo (Toensmeier, 2016).

Bamboo has a long history as an exceptionally versatile and widely used resource in the world with high social, economic and environmental values. Nowadays, it is becoming so increasingly important in the world's forest economy, because it is (1) a superior wood substitute, (2) cheap and efficient to produce and utilize, (3) environmentally friendly. Besides, the world forest is shrinking and thus potential alternative species is needed.

The proportion of the total of industrialized bamboo products in the international trade (export) rose from \$414 million in 2009 to \$547 million in 2013 (INBAR, 2012). It contributes 35% to the GDP, with per capita income from bamboo \$1,000 in Anji County, China (Yipping and Zhiyong, 2013). It is widely used in large quantities for pulp and paper production, as a roofing material, particle board, mats, scaffoldings, ladders, sticks, hand tools, brushes, pipes, umbrellas, toys, sports goods, musical instruments, spears, arrows, rafts, fishing rods, caps, baskets, flower pots and many other items (Ohrnberger, 1999). Bamboo is officially recognized as a carbon offset, and as a tool for climate change mitigation. It also provides valuable environmental services, which are increasingly recognized.

1.2. Over view on uses and prospects of indigenous bamboo species of Ethiopia

As compared to other African countries, Ethiopia possesses considerably wider bamboo cover. The two indigenous bamboo species found in the country have been applied to different uses by the community since time immemorial. Highland bamboo is considered as bank account of the communities, providing ready cash required for households and purchasing agricultural inputs (UNIDO, 2007). Lowland bamboo is used in the day to day life of bamboo growing regions.

In their traditional application, the two species are used for house construction (wall, rafters, floor mats) and house materials (shelves, baskets for different uses), furniture, bed, farm implements, load carrying beams, fuel (that is used in daily basis), fencing (homesteads, irrigated and rainfed farms), piling bed for grain before trashing, storing grain, etc..

The two species are also used for food and animal feed. Lowland bamboo shoot (*Quntsu* in Berta language and *Kampa* in Gumuz language) is a common food for aborigines, in the Benishangul Gumuz region, during the shooting season. Research reports also indicated that highland bamboo is used for food in Masha area of southwestern Ethiopia.

Though utilization of these species in the country to date has been mainly limited to customary uses and cottage industries, currently their industrial application as wood substitute is also recognized. The two species fulfill the ISO standards for industrial products such as ply board, laminated bamboo lumber (LBL), oriented strand board (OSB), medium density fiber board (MDF) and floor boards (FRIM, 2008; Seyoum, 2008). They can also be used for pulp and paper, charcoal, furniture, edible shoots. There is a good start to manufacture modern bamboo products mainly floor boards, window blinds, tooth pick and incense-stick by two modern bamboo industries in Ethiopia. The two indigenous species are also used to maintain the environment by safeguarding loss of other species and ameliorating environmental conditions in lowland and highland areas of the country.

Currently there is better awareness about the potential advantages of the bamboo resource for economic development and environmental protection in Ethiopia. Besides, forest-based investment in the country is better facilitated. Provisions have been made to encourage potential activities for private investors in commercial forestry and establishment of integrated forest-based industries (UNIDO, 2007). Moreover, currently there is critical shortage of wood products from other forest sources in the country. Combined with the created awareness about the potential of bamboo for economic development, this critical shortage of wood may create a good opportunity for the bamboo sector to develop.

Chapter II

BIOLOGY OF INDIGENOUS BAMBOOS

2.1. Taxonomy of bamboos in Ethiopia

There are two indigenous bamboo species in Ethiopia, namely *Oxytenanthera abyssinica (lowland bamboo)* and *Arundinaria alpina (highland bamboo*). Besides, some bamboo species are introduced in the country since recently.

Oxytenanthera abyssinica has different synonyms (Phillips, 1995): *Bambusa abyssinica A. Rich*. (1850)-Type Ethiopia, *Oxytenanthera borzii* Mattei (1909), *Houzeaubambus brozii* (Mattei (1910)-Type-Eritrea, *Bambusa schimperana stead.ap*. Murno.
Common name and vernacular names of the species include English: *savana bamboo, bamboo, plains bamboo*; French: *Bambou;* Italian: *bambu*. In Ethiopia local names include Amharic: *shimel*; Sodo gurage: *betre*; Tigre: *arkay*; Wolayta: *tamia, sankara*.

A. alpina has other new names (Synonyms): *Yushania alpina, Sinarundinaria alpina* (K.Schum.) C.S.Chao & Renvoize. There is inconsistency in naming this species by isolated botanists working in different parts of the world; because of such problems, the old name *Arundinaria alpina* is still maintained by flora books in Ethiopia and by the National Herbarium of the country.

The vernacular names of *A. alpina* include English: *African alpine bamboo/mountain bamboo/highland bamboo;* French: *Babou Creux*; Kiswahili: *Mianzi/Mwanzi*. In Ethiopia local names include Agew: *Anini*; Amharic: *Kerkeha*; Gamu: *Kias*; Kefigna: *Shineto/Shinato*; Oromigna: *Lemmen, Shimela*; Wolayita: *Shenbek'wa*; Konso, Kembata, Sodo Gurage and Sidamo: *lema*; Kefa: *werye/shikaro/Shinato*; Nuwer: *lewu*.

A. alpina has different landraces that have been cultivated under farmers' conditions with clearly defined and varying attributes. In the Choke Mountain, three landraces differing in their morphological characteristics, utilization, regeneration and management need from one another are recognized by the community and through detailed morphological research.

Besides the two indigenous species, there are about 23 different bamboo species, from seven genera, introduced since 2008. The genera of the species include *Bambusa* (six species), *Dendrocalamus* (seven species), *Guadua* (two species), *Gigantochloa* (three species), *Phyllostachys*, *Schizostachyum* and *Thyrsostachys.* The first entries were by the Ministry of Agriculture/the then East Africa Bamboo Project and the European Union-Energy Project/INBAR. The species are under evaluation in many agro-ecologies by the Ethiopian Environment and Forest Research Institute. Among the species *Dendrocalamus hamiltonii, Bambusa vulgaris* var. *green, Dendrocalamus asper* and *Dendrocalamus membranaceus* showed best adaptability and growth performance under field conditions. The second entries were introduced by Morel Agro-industries LTD. These species are under multiplication at Holetta, Addis Ababa.

2.2. Morphology

2.2.1. Parts of a bamboo plant

Silvicultural management, productivity and utilization of bamboos depend on the basic nature of the species, i.e. on the manner the underground rhizome and aboveground parts develop (the morphology) and on the internal anatomy. The underground part, generally called rhizome, comprises the rhizome proper and all its appendages while the above ground part comprises culms, branches and rarely reproductive parts. Each part of the bamboo plant, except the root and the leaf, is segmented; it constitutes nodes and internodes as basic building blocks. A bamboo plant consists of five basic parts, as indicated in Figure 1A:

1. the rhizomes; 2. the roots; 3. the culms (aboveground stems);
4. the branches; 5.the leaves. In addition, it may also bear flowers or fruits, sometimes both at the same time.

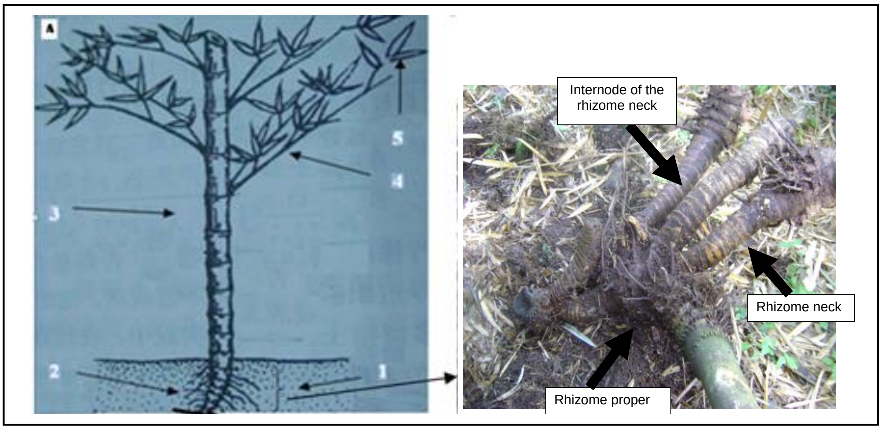

Figure 1: Basic parts of a bamboo plant (A); parts of the rhizome: the rhizome proper and the rhizome necks (B) (photo B: an old highland bamboo plant)

2.2.2. Rhizome systems and rhizome morphology of indigenous bamboo species

Rhizomes are typically subterranean and the rhizome system constitutes the structural foundation of the plant (McClure, 1966). They are of great importance in bamboos, because bamboos have no central trunk as in trees, and the rhizomes become the foundation of the plant. Like most of the aboveground plant parts, rhizomes are divided into internodes by regularly spaced nodes. The buds formed on these nodes develop into either new rhizomes or culms.

Rhizomes do no penetrate to greater soil depth; generally, rhizome depth is limited within the uppermost soil layer, often 45-60 cm deep (Kleinhenz and Midmore, 2001). They grow and branch away from the bamboo plant, thus enable new territory to be colonized. They spread horizontally in an interconnected fashion in their successive growing years hence anchor the big plant from blowing winds and any external forces and gravitational attractions especially when grow on sloppy terrain. Research indicated that the average rhizome depth of highland bamboo ranges from 44 to 72 cm depending on the landform (Yigardu and Masresha, 2011).

The rhizome system assumes, in plants of different species and genera, a number of more or less sharply distinct forms and habits of growth. McClure (1966), after long years research on bamboo, described that two main systems of rhizome formation predominant in bamboos, namely clump forming rhizomes and running or creeping rhizomes. Clump forming bamboos have rhizomes that exhibit a sympodial branching pattern. Running bamboos, on the other hand, have rhizomes with a monopodial branching pattern.

In sympodial branching, new rhizomes turn upward and develop into a culm and become dominant. While in monopodial branching, the rhizome is long and slender and usually hollow, and the apex extends and grows horizontally. Each internode has a solitary bud giving rise to either a culm or a rhizome. The clump has a spreading habit. When the slender 'necks' elongate, the culms are distant and form a very open or diffuse clump in monopodial bamboos.

Although the terms monopodial and sympodial describe the morphology and behavior of rhizome systems, taxonomists use these terms to describe the branching pattern of all parts of the bamboo plant, not only the rhizomes. Scientists also use the concept of "pachmorph" (Figure 2, left) and "leptomorph" (Figure 2, right) to describe the rhizome system.

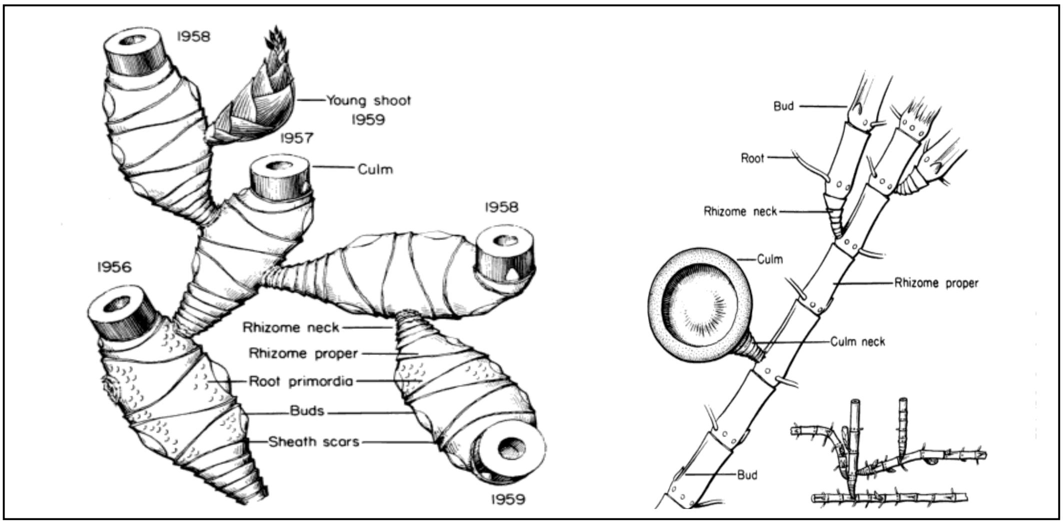

Figure 2: Rhizome systems: Pachymorph rhizome (left) represents the two indigenous species in Ethiopia; Leptomorph rhizome (right).The sketch on the pachymorph rhizome system was produced for *Bambusa tuldoides (McClure, 1966)*.

The most recent study (Yigardu and Masresha, 2011) characterized the rhizome branching type of *A. alpina* as sympodial with spacer length (length of rhizome neck) between mother plant and the new plant up to 30 cm. The number of rhizome necks attached to the rhizome proper reaches up to 11 (Figure 3A). *O. abyssinica* has the same rhizome branching pattern as *A. alpina* but it has pseudo or very short rhizome necks developed from buds at the culm base of the mother rhizome (Figure 2B).

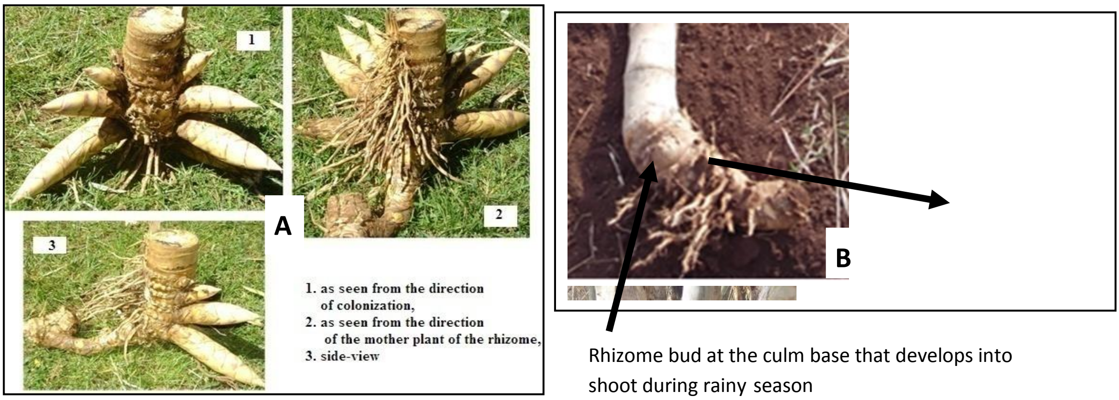

Figure 3: Rhizome morphology of highland bamboo: Three different views of a six month old young rhizome: Note the newly developed collective feet or elongated rhizome necks, longer towards the base and the rhizome neck that connects the new plant with the mother plant (A); The basal part of lowland bamboo severed from the clump (indicated by arrow) . Note the bud at the culm base or rhizome proper of the plant (B)

2.2.3. Culm spacing and clump growth

Culm spacing refers to the spatial relation of the culms that make up the visible part of an individual bamboo plant. It is classified as diffuse (widely spaced) and caespitose (closely spaced) by Stapleton (1998). The external appearance of clumps formed by a group of culms is therefore determined by spacing of culms in the clump. When the spacing between culms is long, clumps are not recognized, rather they form a grove or continuous bamboo forest. Patterns of clump growth under the two rhizome systems is generally classified in to four categories as shown in Figure 4. Based on this classification, bamboos with pachymorph and leptomorph rhizomes can have the same clumping habit. Conversely, bamboos with same rhizome morphology can have different clumping habits depending on the length of the rhizome neck of the particular species

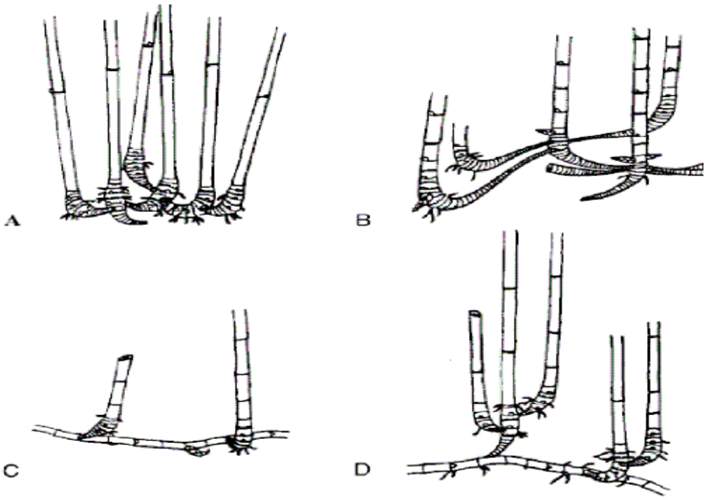

Figure 4: Patterns of clump growth under the two rhizome system (Stalpeton, 1998):
A – Rhizome pachymorph with short necks, culms unicaespitose (representing Ethiopian lowland bamboo)
B– Rhizome pachymorph with consistently long necks, culms diffuse, representing Ethiopian highland bamboo).
C – Rhizome leptomorph, culms diffuse,
D – Rhizome leptomorph, culms pluricaespitose

2.2.4. Morphology of the aboveground plant parts

Morphological features of the aboveground parts, mainly of the culm, branches, and reproductive parts of a bamboo plant vary from species to species and also change with age. The bamboo plant passes through the shoot stage (Figure 5) before it maintains culm shape and produces other parts. Brief description of each of the aboveground plant parts is presented here below.

The bamboo shoot: It is a short, massive and little-differentiated stem protected by numerous sheaths. The sheaths completely embrace the developing shoot and protect the delicate internodes while elongating. The shoot is either used for human food, in this case it is harvested at early tage, or allowed to grow into culm if the objective is for culm or timber production. The inside part of the sheath is smooth and shiny while the back side is usually covered with irritant hairs which may be white, pale brown, golden brown or black.

Figure 5: Shoots of highland bamboo, during the onset of the main rainy season at farmers field in Koffale area of central Ethiopia (top); shoots of lowland bamboo in Pawe research site, north western Ethiopia (bottom)

The culm: The main stem of a bamboo plant above the ground is called a culm. In connection with the rhizome, it supports the branches and leaves. It consists of a series of segmented parts called internodes that are adjoined by respective nodes (Figure 6). The nodes of a bamboo plant are always solid but the internodes can be hollow as in highland bamboo or solid as in lowland bamboo.

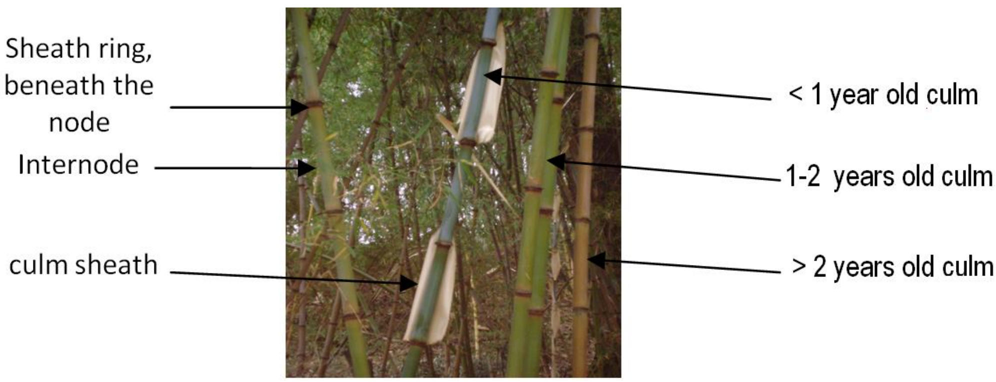

Figure 6: Morphological features of highland bamboo culm at three age categories

The Branches: Branches emerge from the branch complements found on culm nodes that have been subtended by the respective culm sheathes. Branches develop on alternate sides of the culm. They are smaller in size than culms; successive branches dwindle in size, finally terminating in foliage leaves or the food producing organs.

Plant age is an important aspect to be considered by bamboo growers while harvesting and using them as vegetative propagation materials in the nurseries and for field planting. There are some aboveground morphological features that can be used for age determination such as internode color, internode cover, culm sheath, internode epiphytes and number of branches at culm nodes. Descriptions on morphological features of highland bamboo that vary with age and can be used for age determination are characterized for north western Ethiopia highland bamboo forests (described in Table 1 and also portrayed in Figure 6 above). Indigenous knowledge of bamboo growers and characterization by the research helped in this regard to characterize these features.

Table 1. Main morphological features of highland bamboo that can be used for age determination

	Age of plant		
Diagnostic feature	< 1 year	1- 2 years	> 2 years
Internode color	light green	gets yellowish or darker	yellow, dusty or dark depending on landrace
Internode cover	covered with white flour	flour is falling off	no flour left
Internode epiphytes	No internode epiphytes	has lichen and epiphytes	has lichen and epiphytes
Culm sheaths	all or part of the culm sheath kept	begin to fall off until none are left	no culm sheath remaining
Sheath ring	whole sheath ring or part of it kept	remaining sheath ring gets harder	no culm sheath ring , it falls off
Branches	light colored, not tough; no secondary branches	existing branches feel soft, turning to yellow-green or dark after wards	has secondary branches

2.3. Growth

2.3.1. The lifecycle of bamboos

Considering their life history, bamboos are classified as monocarpic plants, in which seeds are produced only once, after which the plant dies; they are perennials that live for many years or a few decades before they reproduce once and then die. When they flower, they expend a tremendous amount of food or energy producing flowers and seeds that stresses them to such an extent that they die. Thus, their survivorship is dependent mainly on the success of reproduction by regenerating seeds and in some cases coppices from remnant stumps on every occasion that they flower (Akifumi, 1992).

Field observations made in north western Ethiopia, in a particular place called Sherkole (Homosha district) in 2014, showed that the density of germinating seedlings or wildlings of lowland bamboo within previously mass flowered and mass died stands was found to be as high as 6 seedlings per 50 cm^2, i.e. on average, about 9 cm^2 area per seedling. Thus, under natural condition, such crowded seedling density, together with the overcrowded weed population of the area, pass under different phases of the seedling stage.

Thus, during the early regeneration process (seedling phase), under natural condition, different processes can be recognized: the establishment of seedlings, thinning of competing seedlings and stabilizing density to the nearly constant mortality of seedlings. Progressively, the seedling phase transforms into the mature vegetative phase as indicated in Figure 7.

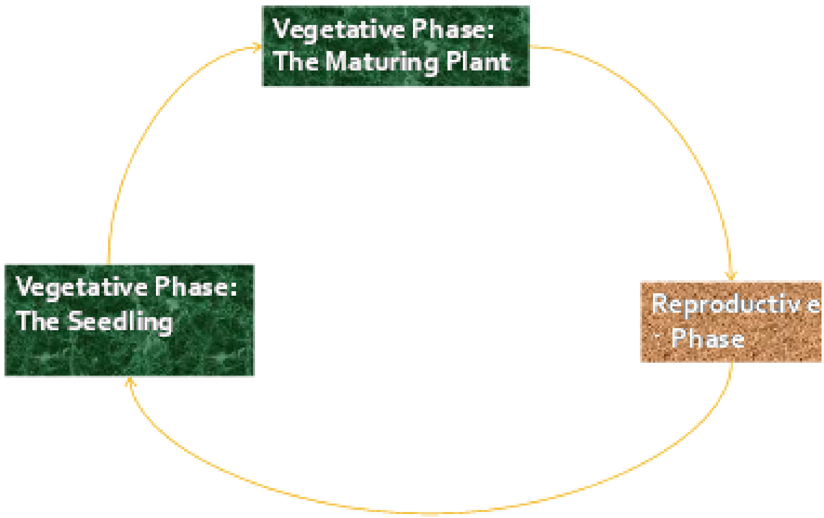

Figure 7: The three important phases in the lifecycle of bamboos; the vegetative phase: seedling and mature stages, and the reproductive phase (flowering and seed bearing stage)

2.3.2. Plant size and Yield

Mature stands of *O. abyssinica* can attain a maximum diameter of 10 cm (a range of 5-10 cm) and maximum height of 9 m (a range of 3-13 m) (Figure 8). It is solid stemmed bamboo with thick-walled culm. Scientific information on stand structure and productivity of lowland bamboo is limited. Under natural conditions, where there is no management, the number of culms per ha of this species was reported to be only 8000 (LUSO, 1997). However, plot level records indicate that plantations of this species with a 4 m X 4 m spacing and an average medium sized clump, with 73 culms/clump, can have at least 40,000 culms per ha.

Figure 8: Stand structure of lowland bamboo (*O. abyssinica*): left, at the age of one year after planting; right, luxurious growth with 93 culms, at the age of six years after planting under Pawe condition, Benishangul Gumuz region.

A. alpina is a very large and perennial woody grass; woody culms up to 12 cm in diameter at the base and rising to 20 m (Figure 9) from a stout branching rhizome; culms are thick walled but clearly hollow. The number of culms per hectare varies based on management regime and site conditions. In plantation bamboo forests in north western Ethiopia, it ranged from 11,000-20,000 culms/ha (Yigardu and Masresha, 2012) and in natural bamboo forests of Masha, southwestern Ethiopia, it ranged from 5,869-8,840 culms/ha (Kassahun, 2003; LUSO, 1997). Undisturbed bamboo stands of this species have 10,000-17,000 culms/ha (Wimbush, 1945).

In north western plantation bamboo forests of Ethiopia, the total biomass, dry weight basis, ranged from 65-117 ton/ha with aboveground total dry weight of 56-99 ton/ha (Yigardu and Masresha, 2012); in a natural bamboo forest of Masha, southwestern Ethiopia, total aboveground biomass ranged from 51-110 ton/ha (Kassahun, 2003; LUSO, 1997). The increment or biomass of less than 1 year old plants investigated ranges from 6-26 ton/ha in north western Ethiopia plantation forests and 8.6 ton/ha in Masha natural bamboo forest, south western Ethiopia.

Figure 9: Stand structure of highland bamboo (*A. alpina).*Three dominant landraces in the Choke Mountain, Northwestern Ethiopia: top: *Wonde*; bottom left: *Tifro*; bottom right: *Setie* or *Wolele* landraces

2.3.3. Plant growth and stand development

Bamboo growth is characterized by its increment in weight, length, and quality of the rhizome system underground and the culms aboveground. In general, both vegetative propagation and yield formation of bamboos are achieved by growth of vegetative meristem. During the vegetative growth phase, plants are at the peak of their metabolic activity (photosynthesis, respiration, uptake of mineral substances). In bamboos, it is the food from the rhizome-culm system, i.e. the food from the current photosynthesis of the mother plant and to some extent the stored food in the rhizome that is utilized for the speedy growth of the young shoot that is completely within the enclosing sheath (Kleinhenz and Midmore, 2001) hence does not produce food by itself. That bamboo is "one of the fastest growing plants" is attributed to the speed of culm growth. This fast growth phase results from expansion of individual internodes (Liese and Weiner, 1995) by intercalary meristem.

Growth of bamboo culms starts from underground shoot growth that is followed by shoot-culm growth. In Ethiopia, time for shooting has slight variation from place to place, depending on the starting time of the main rainy season. Basically, shooing starts at the onset of the main rainy season, May to July, in different parts of the country. After shoot emergence, particular environmental conditions, such as higher temperature, greater moisture availability and higher air humidity promote the shoot- culm growth. Height growth of the shoot-culms in mature stands reaches maximum, 20 m for highland bamboo and 10 m for lowland bamboo, within 3-4 months.

The amount of annual production of culms shows irregularities from year to year. It can be very prolific one year (on-year) and quite sparse in another year (off-year). Despite adequate rainfall during the rainy season, some years may have very low or no shoot production, hence the number of recruited culms becomes scanty or none. Studies conducted on shoot production trends across production years indicated that production of new shoots or culms is highly linked with the leaf growth cycle but not necessarily by climatic conditions. These seasonal fluctuations are quite pronounced in undisturbed stands, but less marked in areas where the plants are regularly managed. This uneven distribution of bamboo culm production across season or years indicates the clear need for silvicultural management intervention to create even-year stands.

The amount of annual production in a particular stand may also be affected by management related problems such as eco-physiological stresses such as competition for space, food and moisture. If older culms are not removed from the clump, they restrict the development of the rhizome system and subsequent emergence of new shoots. Despite shoot emergence might be high, shoot mortality reaches up to 60% for *A. alpina* (Yigardu and Masresha, 2011) under stressed conditions.

The growth of newly established bamboo stands is progressive till it reaches at mature stand phase. Up to a certain age, after establishment, height and diameter of the annual flush of culms increase progressively and attain maximum size and number after a couple of years. Once the mature growth phase is achieved and appropriate management practices are applied, the maximum plant size is maintained and optimum density is reached.

2.3.3.1. Highland bamboo

The initial growth of bamboo stands developed from seedling and offset methods greatly varies in highland bamboo. Associated with the rare seed production of highland bamboo, establishing stands using seedlings is not common. However, it is observed that productivity of out planted seedlings under field condition takes longer time to produce larger size culms. Stands established using offsets could produce one to two plants during the first season. Both the number and size of plants in the newly established stand exponentially increase during the next three to four years, in good sites, till the maximum stature of the stand is reached.

2.3.3.2. Lowland bamboo

The initial growth of lowland bamboo stands developed from seedling and offset methods may slightly vary. Rhizomes of newly planted seedlings in the field develop shoots, which reach more than 1 m in height and with many thinner culms forming clumps in the first year. Afterwards, during the next rainy season, both culm size and clump size increase considerably.

Lowland bamboo is a vigorously growing species that produces huge biomass in a short period of time.

Maximum height of lowland bamboo culms at the age of two in Sherkole area of Homosha district was recorded to be more than 5 m and the number of culms per clump more than 12. At Jimma observation site, planted seedlings produced 15 culms/clump with an average height of 4 m and a diameter of 3.5 cm, at the age of two years. Both plant and clump size dramatically increase in the third rainy season. Surprisingly, at the age of three years a clump produced an average of more than 36 culms with maximum height of 8 m and diameter of 4.5 cm. Culms reach full height and diameter within 4-8 years. Often, in bamboos, stands established using offsets reach harvesting in shorter time than from seedling origin. Thus under good management, stands established using offset methods are expected to get into production starting from the fourth year.

2.3.4. Characteristics of bamboo growth

Growth of bamboos is distinguished to have two levels, i.e. individual and stand growth (Maoyi *et. al*., 2005).

2.3.4.1. Individual vegetative growth

The individual vegetative growth of bamboo means the development of the different parts of the plant namely the rhizome, culm, branch, leaf, and root.

2.3.4.1.1. Rhizome growth

For sympodial bamboos, since the rhizomes cannot run for a long distance, the culm base or the rhizome proper is the main part of the rhizome. Starting from the onset of the rainy season, when adequate soil moisture of the bamboo stand is achieved, to the continued few rainy months, the buds on a culm base sprout and elongate their rhizome necks, and then the shoots grow erectly from the ends of the clump. In long-necked sympodial bamboos like highland bamboo, elongated rhizome necks develop during the previous rainy season while the shoot-culm of the plant grows in height. Thus, the newly formed rhizome should develop from the apex of previously formed elongated rhizome necks. Further research on rhizome growth of long-necked sympodial bamboos is required.

The buds on the middle and lower part of a rhizome proper usually are more vigorous and sprout earlier, and also have longer rhizome necks and could produce bigger shoots than those on the upper part of rhizome proper (Figure 2A, section 2.2.2.).

The capacity of lateral buds forming new rhizomes and shoots is closely related to rhizome age, vigour and nutrient storage. The potential capacity of produce rhizome and shoot greatly depends on the rhizome diameter, which gives much important influence on the quality of new rhizomes and culms. The buds on a culm base of 1 or 2 years old usually are vigorous and could produce often 1-2 shoots, despite the number of collective necks reach more than 10 for highland bamboo. The buds at culm base and the apex of elongated rhizome necks of culms at 3-4 years old, almost lose the capacity of producing shoots.

The size of rhizomes depends not only on the size of the culm-rhizome system, but also the site condition, especially on the precipitation and soil condition. In loosen and fertile soil with well drained and moderate moisture content and less mechanical obstacles, the rhizome apex grows fast and the yearly elongation could reach maximum. Also, they are less tortuous, more vigorous and thick, and have long and straight internodes, strong buds, and well-developed roots. On the contrary, in hard or compacted and dry soil with more mechanical obstacles, rhizome growth cannot be as good as the above.

2.3.4.1.2. Young-culm growth

The growth of the bamboo shoot starts from underground. Underground shoot growth covers a period that a bud in soil differentiates and grows up to the soil surface. The lateral buds, born at adolescent rhizome nodes, differentiate to become shoots. The apical meristem of buds divides and elongates to produce sheathes, auxiliary buds, nodes, diaphragms, and intercalary meristem, and form a new shoot. During bud differentiation stage, a shoot grows in length and diameter in the soil, but primarily in diameter.

Aboveground growth comprises growth of the shoot after emerging from the soil surface, i.e. the height growth of the shoot, till it reaches maximum height attaining a full culm size. This growth is also called shoot-culm growth of the newly growing plant. Height growth of indigenous bamboos is adapted to restrict culm elongation to the mid- to late-wet season when soil moisture is greatest and most reliable. A young culm, usually connected to a strong rhizome grows vigorously. The enhanced nutritional status brought about by particular environmental conditions, such as higher temperature, greater water availability, higher air humidity and adequate photon flux density, makes culm elongation faster. Research showed that the growth ascending period for Ethiopian highland bamboo (Figure 10) is during the 45 days time, after reaching those particular environmental conditions, preceded by 15 days slow growth period of the emerged bamboo shoot.

Much of the grand period (period of rapid elongation of culms by intercalary expansion) is elapsed before sheathing-off or removal of culm sheaths from the bamboo culm. Branch and leaf development follows shortly after the end of shoot elongation. One year old culm have scanty branches and leaves at the top part of the culm height. As the plant gets older (at its 2^{nd}, 3^{rd} years), branches develop also downward. The overall average of the 60 days shoot-culm growth rate of *A. alpina* ranged from 10 to 18 cm/day. But the average maximum values for peak elongation reach 19-52 cm/day with maximum value of 45-58 cm/day (Figure 10).

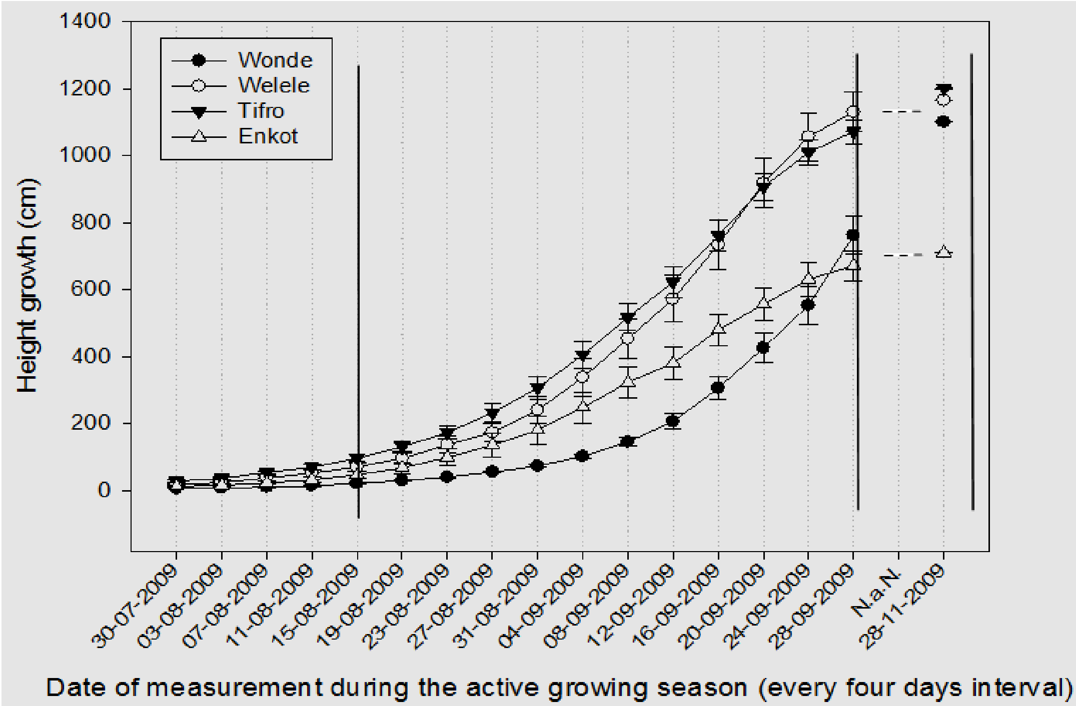

Figure 10: Height growth of Ethiopian highland bamboo, measured at every four days interval for the 60 days shoot-culm growth period; the slow 15 days shoot growth or the 45 days ascending period and the slight height increment obtained during the two months period is indicated by vertical lines and in dotted lines. The four growth curves are recorded from four landraces found in one locality.

2.3.4.1.3. Culm quality growth

There is no capacity for growth in height, diameter, volume, and wall-thickness once the culm is matured because bamboos do not have secondary meristem. Growth, after one year is therefore purely on quality, i.e. increase in weight by maximizing the fiber proportion of bamboo cells, minimizing paranchmatoes cells that store food and reducing the moisture content. Culm weight gets double in two to three years time. During this period, bamboo culm is in a stable state during which the culm has rich nutrients and active physio-chemical process. Mechanical strength and the bulk density of culms becomes at the highest level. After this period, the culms and their connected rhizomes lose the capacity of sprouting shoots and new rhizomes.

2.3.4.1.4. Growth-declining due to aging of culms

Aging of culms is associated with significant chemical and structural changes in the parenchyma and fiber tissues, which include decreases in moisture content, cell wall thickening, decreases in the percentage of holo-and α-cellulose and sugars, accumulation of silicon and increases or decreases in certain nutrient ions (Othman, *et. al.,* 2012). In contrast to trees, bamboos have no secondary meristem, the cambium, thus they lack especial tissues to shade or accumulate metabolic residues. Consequently, conducting tissues of bamboo have to function for many years without forming any new tissue (Liese, 1998). They accumulate metabolic residue substances in metaxylem vessels that progressively decrease the conductivity of the xylem for water and nutrients and that of the phloem for assimilates, and finally lead to the breakdown of the transport system and death of culms (Liese, 1995; Liese and Weiner, 1995).

2.3.4.2. Stand growth

The growth of the stand is characterized by the increase in volume, number and biomass for each organ, including shoot emergence, number of newly growing culms, branch and leaf spreading and the growing of rhizomes, buds and roots. Bamboo biomass is composed of photosynthetic accumulation. Part of biomass, which has economic value, is called economic yield. The biomass depends on stand structures in age and density, site condition and management practices applied.

2.3.4.2.1. Stand structure

Bamboo stand structure is mainly concerned with the number of plants per unit area (stand density) and the age composition (age structure) and the resulting parameters such as plant size, evenness of culms and the amount of photosynthetic area. There are different parameters of bamboo stand structure that have their own magnitude of effects on productivity and effectiveness of bamboo stands (Maoyi *et. al.*, 2005). The parameters include density of the standing bamboos, the bamboo ages, size of culms, size-regularity of culms, evenness of culms distribution, leaf area index (LAI), and rhizome composition.

These are key aspects of growth and development of bamboo stands that is why studies on the bamboo stand structure are mostly aimed at regulating these factors by applying different plant and soil management techniques.

2.3.4.2.2. Density of standing bamboos

It means the number of standing culms in a unit area. In general, density is closely related to the culm shape, plant size and intended use of the stand. Within a range of density, the dense standing culms in a bamboo stand will produce more biomass, and form high and clear boles with less leaf and branch weight. Therefore, the economic output is also high.

2.3.4.2.3. Age composition of bamboos

A bamboo stand is composed of standing culms of different ages. Plants of more than two years old do not have the capacity to produce shoots, thus, the suitable age composition of bamboos becomes a basic factor to obtain high yield. So, where there are more young and strong culms in a stand, there is higher yield.

2.3.4.2.4. Size of culms

The size of culms is a main factor to indicate the stand condition, usually expressed by mean breast-height diameter (DBH). In general, at all and big bamboo can produce and accumulate more nutrients for stand growth because it occupies more space and absorbs more mineral elements.

2.3.4.2.5. Size-regularity degree of culms

Size-regularity degree of culms (can be denoted by letter 'U") refers the size variation of culms in a bamboo stand. Under good management, culms maintained in the bamboo clump or grove achieves uniform diameter and height, each culm having its own role in the economy of the bamboo grower and productivity of the stand. Thus, the size-regularity degree (U) is an expression of the mean breast-height diameter (DBH) of culms and their standard deviation (SD). It can be expressed as follows:

$$U = DBH / SD$$

Accordingly, the higher the U value, the less the size variation of culms in the unit area, which will favor to utilize space, photo-energy and fertilizers.

2.3.4.2.6. Evenness of culm distribution

It indicates the distribution regularity of culms in a unit area. If there is a higher evenness of the culm distribution in a stand, usually, the space in this community is efficiently occupied.

2.3.4.2.7. Leaf area index

It is characterized by the sum of leaf area in a unit area of land. In a certain condition, the high value of LAI may result in more efficient utilization of photo-energy and accumulation of organic matter, so that the bamboo stand will make a greater increment. Usually, the LAI varies greatly with the density of the standing bamboos, the mean breast-height diameter of culms and their age.

To summarize the effect of the above factors of stand structure, any among the factors can affect productivity and effectiveness on the stand yield of bamboo stands. All component factors impact productivity and effectiveness of bamboo stands, each with different effects. According to report by Maoyi *et al*. (2005), the effect component of density of standing bamboos is 31.91%, the age of the standing culms 27.28%, LAI 21.45%, size-regularity degree of standing bamboos 10.25%, and other factors 9.11%. Thus, these factors need to be regulated by applying different management practices that will be discussed on Chapter V of this book.

2.3.4.3. Site factors affecting productivity of bamboo stand growth

The locality class is determined by the soil, topography and climatic conditions of the stand. The most important soil factors are the soil mineral, moisture and drainage. The soil mineral and moisture of valleys and plain land, hillsides and ridges and soil texture created on these land forms are different.

The topography or landform of the stand has significant but indirect effect on bamboo stand yield. The conditions of the landform or topography such as the altitude, aspect, slope and physical properties such as texture and moisture holding capacity have considerable effect on bamboo growth (Kleinhenz and Midmore 2001). Research shows that bamboo stands on level lands have more stand density, but smaller sized plants (Table 2). On steep slopes impedance might cause low recruitment rate, hence may result in lower stand density. However, plant size was observed to be higher in sloppy areas that might resulted in higher biomass.

Table 2: Effects of landform on stand growth of Ethiopian highland bamboo in north western Ethiopia

Landform (Topography)	Stand density (No. of plants/ha)	Biomass (ton/ha)	Shoot recruitment rate (%)	DBH in cm (Average, max)	Height in m (Average, max)
5-15% slope (level to slightly slopping land)	20,300	90	87	5; 6.2	9.6; 12.7
40-60% straight slope (ridge)	11,300	64	72	6; 8.6	10.7; 13
40-60% concave slope (ravine area or valley)	10,667	117	65	8.4; 9.2	15.2; 18

Topography affects moisture and texture of soil. Research indicated that in North West Ethiopia, the 5-15% slope (level to slightly slopping land) has seasonal water logging problems that bamboo does not prefer. Whereas the steep slope landform found in ravine areas (40-60% concave slope) is well drained, besides often such lands have more clay washed away from the upper part of the watershade. Interestingly, ravine areas have also better soil moisture that might be associated with the shorter direct sunlight hours because of shading on the other side during the before noon and after noon hours as compared to the other landforms. On steep slopes impedance cause low recruitment rate, hence lower stand density. Despite low shoot recruitment and lower density, higher biomass on steep slopes is mainly associated with the big size of plants.

Good performance on steep slopes has many comparative advantages for the ecology and community. The community can use level-slopping lands for food crops such as fababean, barley and potato production and for high quality bamboo production on steep slope landforms.

2.4. Flowering of Indigenous Bamboo Species

2.4.1. Bamboo flowering

Flowering in bamboos is an intriguing phenomena. It is because it is unique and very rare occurrence. Bamboo exhibits two types of flowering: gregarious flowering, or mass flowering and sporadic flowering. All plants in a grove or all clumps in a bamboo forest may flower simultaneously, regardless of outside conditions that may be present. According to the extent of flowering on a branch, flowering can also be roughly divided into two types, i.e. flowering with leaf and flowering without leaf. The latter blooms a lot with few leaves and its culms are prone to die easily while the former blooms partially or with less flower branches and its vegetative twig continues to grow.

The gregarious flowering is generally accepted to be connected with the vegetative propagation, the way in which bamboo spreads both in the wild and by human cultivation. Forests that utilize successive vegetative propagations, by using same domain plant or clones originated from seeds of the same age. Thus it is the genetic source and age of the bamboo used for forest development that results in flowering of bamboos either gregariously, sporadically. Some cases are also observed in which bamboo flowers recurrently.

This mass flowering is likely connected with vegetative propagation, the way in which bamboo spreads both in the wild and in human cultivation. Propagation is typically conducted by splitting the rhizome-attached propagoules or cuttings of the plant and transplanting into a new location. This method essentially creates clone plants, as the genotype is identical to the domain plant. Timing of flowering is likely programmed into the plants genetic structure, causing all plants to flower within the exact same timeframe.

2.4.2. Flowering characteristics of lowland bamboo

The type and pattern of flowering of Ethiopian lowland bamboo is observed to be gregarious, causing the death of huge areas of bamboo forests within few years time. The species flowers gregariously at long time intervals, every 30-35 years. The most recent gregarious flowering is observed in the north western part of Ethiopia mainly in the Benishangul Gumuz region, where almost all natural forest has been regenerating using vegetative means. Mass flowering (Figure 11) occurred starting from 2010 in Ambesa Chaka, lion's forest in Amharic, the famous bamboo growing area which spreads over 7,500 ha of land in Bambasi district, of the region. It started about seven years after flowering occurred in other areas, namely Guba and Mankush districts of the region. By 2010, mass flowering thereby mass death has reached over 85% of the estimated total 400,000 ha bamboo in the region.

Figure 11: *Oxytnatheraabyssinica*flowering over vast area of Homosha district, Benishangul Gumuz region (Photo: Demissew Sertse).

When *O. abyssinica* flowers, every leafy branch develops in to a flowering shoot and leaves turn to brown and gradually drop off. Each branch develops the flowering units called pseudo-spikelet or spikelet at its node and apices. A flowering culm with all of its originally leafy branches is transformed in to flowering shoots and buds at culm and branch nodes can also develop directly in to pseudo-spikelete clusters.

The fruits are arranged in to aggregate that are composed of spikelets. Fruits are also spiny at one end, opposite to the embryo, which poses a problem for collection and processing. The inflorescence is a dense star-shaped cluster 4–9 cm in diameter, with 10–20 spikelets (Figure 12, left). Spikelet are sessile, narrowly lanceolate, 1.5-4.5 cm long, pungent, 1-4 flowers with upper floret, bisexual and lower florets male or sterile; lower glume 5–8 mm long, upper glume 8-10 mm long, lemma narrowly lanceolate, the lowest 12–20 mm long, tapering into a rigid spine up to 7 mm long, palea narrowly lanceolate, somewhat shorter than lemma; floret with 6 stamens, filaments united into a tube, and a glabrous ovary extending into a hollow style terminating in 3 stigmas. Its fruit is a spindle-shaped caryopsis, 10–15 mm long.

Figure 12: Flowering type of *O. abyssinica* (left); photo taken from mass flowed stands in Benishangul Gumuz Region; Seeds of *O. abyssinica* (right).

Field observation made in 2014 and later showed that some remnant un-flowered mature clumps are found green and in their mature vegetative phase around Anbesa Chaka. Even a few clumps were reported to be recurrently flowering in the area. These clumps will have big genetic importance in the locality.

2.4.3. Flowering characteristics of highland bamboo

Highland bamboo flowers less frequently than lowland one. The recent mass flowering and mass death of bamboo in occurred in Dawro zone southern Ethiopia in 2009 (Figure 13). There had been mass flowering of highland bamboo in the zone before 100 years during which also the entire bamboo was devastated in the area. Then after, bamboo was reintroduced from Kefa by the local king named Haile-Tsion (locally, Kao Kenssa) at a place called Tuta in Tocha district. Some respondents claim that the source of all bamboo in Dawro zone was Tuta which is also currently in mass death. Presently, it has been estimated that more than 66% of the total 1,483.25 ha of bamboo in Tocha district is under mass flowering and mass death. This mass flowering expanded to the neighboring district named Merkan, vanishing all the plants synchronously.

In Enjibara, north western Ethiopia, there has not been record of mass flowering of cultivated bamboo so far despite the fact that there is a long history of bamboo cultivation in the area. However, some of the local community members recall mass death of wild bamboo before 45-50 years. The areas where they mentioned mass flowering are currently covered by other vegetation and no bamboo is observed in these areas. Flowering of highland bamboo in small patches happens every year in many places in the country without being noticed by the wider community, indicating highland bamboo flowers both gregariously and sporadically and in minor cases recurrently (Figure 14).

Figure 13: Mass flowering event at Tuta area, presumably the first population in Dawro Zone, used as planting material source for other stands that are also flowering at this time in Tocha district (Photo: Demissew Sertse, 2010).

Figure 14: Sporadically flowered highland bamboo clumps; only two clumps observed flowering in Sinan district, East Gojjam zone from 2009-2011 (left), (Photo:Yigardu Mulatu); the recurrently flowering highland bamboo at Enjibara, St. Johannes Church (right), (Photo:Demissew Sertse).

Inflorescence: paniculate, panicles 10-15 cm long, loose to fairly compact; spikelets 4-11 flowered, linear-elliptic, 1.5-4.8 cm long; glumes ovate; lemmas lanceolate-oblong, 0-12 mm long, pubescent, acute, acuminate or awn-pointed (Figure 15, left). The seed are like seed of any other members of the grass family, consists of endosperm and an embryo comprising a radicle, a plumule and a scutellum (Figure 15, right)

Figure 15: Inflorescences (left) and seed (right) of highland bamboo

2.4.4. Effects of bamboo flowering in Ethiopia

Most of the local communities in Ethiopia perceived the phenomenon of bamboo flowering as abnormality caused by certain disease infection or an epidemic disease. Most local people do not expect that the phenomena produces seed. On the other hand, associated with seed production in a "big bang" in gregariously flowered lowland bamboo forests, excessive increase of rat population was resulted, in the Benishangul Gumuz region. The rat population multiplied feeding on bamboo seed was highly damaging maize plants and also food stuff in houses the community, in later stages, while seed production stopped. The rat population had also been highly disturbing humans by eating parts of the human body while sleeping. On the other hand, animal populations that have been feeding on bamboo leaves were challenged by lack of feed during and after mass flowering.

Chapter III

ECOLOGICAL ASPECTS OF INDIGENOUS BAMBOO SPECIES OF ETHIOPIA

3.1. Distribution and area coverage

A study made 15 years ago (LUSO, 1997) estimated bamboo cover of the country to be about one million, however, afterwards many changes were observed. In some regions and agricultural landscapes, bamboo stands that were not included in the previous inventory are observed; on the other hand, associated with bamboo flowering and many anthropogenic factors, bamboo stands have been observed shrinking down. The current forest cover of the country, including bamboo, is under inventory, by the newly established Ministry, Ministry of Environment, Forest and Climate Change (MEFCC) in collaboration with the Food and Agriculture Organization of the United States (FAO).

In Ethiopia, lowland bamboo is confined to the western side of the central highlands in Moist and Wet Kolla agro climatic zones. The species is found in savanna woodlands, often forming extensive stands (Phillips, 1995). Through discussion made with regional experts and by consulting reports, many districts found in different zones of different regions are identified for their lowland bamboo potential:
(1) Benishangul Gumuz region: Assosa zone (Bambassi, Assosa and Homoshadistricts); Metekel zone (Mankush, Mandura, Guba, Pawe, and Dibatedistricts); Kemash zone (Kemashdistrict); Mao-Komo especial district; (2) Oromiya region: Gimbi, Guten, Kelkon, Leka; (3) Amhara region: Awi zone (Jawi, Guangua, Ankeshaand Zigem districts); East Gojjam zone (Debre Elias and Baso-Libendistricts); West Gojjam zone (Bure, Wombera, and Dembecha districts); North Gondar zone (Metema, Quara, Alefa, Tach-Armach'ho, Tsegede and Adiarkay districts); (4) Tigrai region: Mierabawi Tigray zone (Tselemti, Welkait, Tahtay Adiabo, Asgede-Simbala, Tsegede, Kafta Humera); (5) Gambela Region: in many areas.

In African countries such as Sudan, Kenya and Tanzania *O. abyssinica* has been planted by local farmers, but in Ethiopia this species is growing as natural forest, except in research plots and some starts in the Benishangul Gumuz region.

A. alpina is found in different places in Ethiopia: It covers a large area between Bale Mountain, Bonga and Metu in south west part of Ethiopia and up to Dangla in the North. This bamboo stands are situated in important agricultural zones with former (high) forests, where rainfall is adequate, with *Podocarpus* in upland and with *Juniperus* in drier forest. It is frequently planted along roads and villages.

Through discussion made with regional experts, many districts found in different zones of different regions are identified for their highland bamboo potential.

(1) Amhara region: South Gondar zone (East and West Estie, Farta, Lay Gaiint); Awi zone (Banja, Fagita, Ankasha-Guagusa, Guagusa-Shikudad); East Gojjam zone (Sinan, Bibugn, Machakel); West Gojjam zone (Sekela, Dega Damot); North Shoa zone (Tarmaber); South Wollo zone (Debre-Sina); (**2**) Oromiya region: West Arsi zone (Koffale and Arsi-Negele), Bale zone (Goba), West Shoa zone (Dire Inchini and Shenen); Jimma zone (Dedo, Seka-Chekorsa, Mana, Kersa, Agaro, Gera, Gera-Lola); (3**)** South Nations, Nationalities and Peoples region: Sidama zone (Hula, Arbegona, Bensa); Gedeo zone (Bule, Yirga Chefe, Kochore); Gamo-Gofa zone (Chencha, Arbaminch zuria, Bonke, Kamba, Boreda, Kucha, Mirab Abaya, Deramalo, Dita, Geze-Gofa); Guraghe zone (Cheha, Gummer, Geta, Enemore, Endegagn); Hadya zone (Misha, Anlemo, Duna); Kembata zone (Angecha, Doyo Gena); South Omo (North Ari); Kefa zone (Gawata, Decha, Adiyo, Gesha); Dawro zone (Tercha, Esera), Segen Hizboch (Amaro), Wolayta zone (Sodo Zuria). Sheka zone (Masha, Anderacha, Debub Bech; Mizan Teferi-Kulish, Wushwush-Bonga, Bonga-Ameya)**.**

It is also recognized that many National Forest Priority areas of Ethiopia such as Belete-Gera, Jibat, Kolbu, Munesa, Sigmo, Tiro-Boter-Baecho, Bonga, and Wof-washa are worth mentioning for their highland bamboo.

3.2. Topography, Soil and climate requirements

O. abyssinica grows from 500-1800 masl with a mean annual temperature between 20 and 35 °C and mean annual rainfall of 1150 mm but also tolerating erratic mean annual rainfall down to about 600 mm (PROTA, 2016; Azene, 1993). The major portion of lowland bamboo forest is found in the *Combretum–Terminalia* deciduous woodlands of western Ethiopia together with other associated grasslands.

O. abyssinica grows on very poor soils and various types of the parent rock, but much of its distributional range belongs to the old crystalline basement complex. Soil fertility is not a major influence. It is associated with impoverished acrisols and ferralsols, moderately fertile luvisols, and younger relatively nutrient-rich cambisols and nitisols**.** The species is essentially absent from arenosols that have poor moisture retention and gleysols having poor drainage (PROTA, 1998). Key site factors are good drainage combined with access to a reliable water supply. Characteristic habitats are ravine areas, drainage lines, termite mounds and rocky slopes. Typical rocky slope microsites are gullies with deep soil accumulated between boulders. Saline conditions are unfavorable.

A. alpina is restricted to high elevations (2400-3500 m altitude). Average monthly maximum temperatures are 13–32°C, and average monthly minimum temperatures range from –4°C to 11°C, implying that some populations tolerate frost. Rainfall is seasonal, with 3–6 dry months (mean rainfall less than 50 mm) in eastern Africa (Phillips, 1995; PROTA, 1989).

A. alpina occurs on impoverished ferralsols, moderately fertile cambisols, richer andosols and nitisols (PROTA, 1998). It is often found in volcanic soils and forming extensive pure stands in Ethiopia. Well-drained humus-rich soil on gentle slopes and in ravines, with space for vigorous rhizome development, allows luxuriant growth. On shallow soils and rocky ground individuals are stunted. It grows on soils of various types of the parent rock, but much of its distributional range belongs to the old crystalline basement complex. Generally, climate requirements over-ride soil type requirements for growth of *A. alpina.*

Chapter IV

SILVICULTURAL MANAGEMENT OF BAMBOO STANDS OF INDIGENOUS SPECIES

4.1. The concept of bamboo silviculture

An important key in the implementation of sustainable forest development is the implementation of silviculture as an objective guide in the management of forest resources. Silviculture is the oldest conscious application of ecological science and the best known term before the term "ecology" was coined (Smith *et al*., 1997). It covers science, business, art and practice of deliberately creating and managing forest resources to provide sustainable benefit for the society.

Bamboo silviculture is a scientific discipline and methodology on bamboo afforestation and management, which comprises of the theories and techniques for planting, regulating the composition of bamboo stands and managing soil so as to develop bamboo stands thereby achieve economic and ecological benefits. Regulating composition of bamboo stands is important in silvicultural management of bamboo stands because limitations in the environment and stand structure can result eco-physiological stresses such as shortage of soil moisture, food shortage, inadequate photon flux density, and growing space that in turn bring about low stand productivity.

As of today, in Ethiopia, there is no management plan for government owned natural bamboo stands. No protection what so ever from illegal harvesting, wildfire, pests and disease; no protection from encroachment and clear felling; no practical arrangements exist to manage, protect and utilize natural bamboo forests(UNIDO, 2006); except some start by Oromiya Forest and Wildlife Enterprise and a community-based bamboo management supported by the Non-Governmental Organization- Farm

Africa- in Benishangul Gumuz Region. The government owned bamboo forests are actually nobody's forests that have been suffering from the "tragedy of the commons".

However, there is a visible effect to manage and harvest the private (planted) *A. alpina* bamboo forests. Yet, the quality of management and harvesting is limited by the relatively low level of knowledge and skills of farmers (Ensermu, *et. al*. 2000). Management practices are based on the knowledge transferred to them from their fathers and fore-fathers and common sense. Management is mainly limited to harvesting by selecting culms.

Bamboo nursery management and propagation techniques of the two indigenous bamboo species are important management aspects. These topics are separately discussed in a different book by Yigardu and Asabeneh (2016). Thus, under this section, main emphasis is given on theories and techniques of regulating composition of bamboo stands and managing soil of mature stands of the indigenous bamboo species and stands during and after mass flowering.

4.2. Why productivity of bamboo stands deteriorate?

Productivity of bamboo stands deteriorates because of different reasons such as clump congestion, inappropriate harvesting (both for timber and bamboo shoot stands), and lack of management after mass flowering, and due to biological deteriorating agents.

4.2.1. Clump congestion

Clump congestion is a serious management problem in bamboos. Once the number of mature plants reaches a certain limit, congestion of below and aboveground plant parts occurs. Research conducted on many bamboo species showed that the progressively growing bamboo clump or grove, starting from its planting date, reaches to its maximum biomass at the age of six years after planting (Shanmughavel, 1997). Unless mature culms are harvested out, new upcoming shoots will be challenged by lack of growing space and competition for above ground resources such as light and water from rain.

In congested bamboo stands, the growth of new rhizomes and culms physically interferes with mature rhizomes and culms; an increasingly greater proportion of new culms will be malformed, break, or die during expansion. Bamboo shoots in congested culms will be aborted. Culms have poor quality (thin and short but too many) that resulted in low stand value.

Besides, culms older than three years, maintained within congested stands, do not provide any support to the new culms (not produce new shoots). This results in stagnation of annual growth (Figure 16), and reduction of stand productivity. Congested clumps pose a problem for the felling of the culms and create favorable condition for fire due to the enclosed dead and dry culms.

Clump congestion may also be caused by (a) too much soil compaction mainly by animals, (b) insufficient soil depth for rhizomes and(c) development of too many rhizomes especially on river banks and if no harvesting or appropriate harvesting technique is used.

Figure 16: Stand congestion of highland bamboo created after the number culms reaches maximum limit (left); note: no young age culms and newly growing shoots are observed. Stand congestion of highland bamboo created by soil compaction by animals (right).

4.2.2. Inappropriate harvesting

Harvesting from plantations of highland bamboo is carried out all-year-round when required by resource-poor homestead bamboo cultivators in some areas. Harvesting from natural stands is unregulated and is resulting in severe depletion of the natural resources. Harvesting of lowland bamboo is haphazard, resulting in wastage of the resource (Figure 17) No harvesting design is followed to extract mature culms within the clump, rather cutting culms at the peripheries of clumps at higher positions, about 1.5 m high, is observed in natural stands.

Cutting bamboo culms at higher positions does not relieve bamboo stands from below-ground congestion. Higher stumps interfere with and hinder the possible robust newly coming shoots. It also leads to coppicing that brings about unnecessary remobilization of the minimal food stored on the stump. It also results in prevalence of old stumps that are not easily decomposed and allow recycling of nutrients. Harvesting practices that use primitive tools, result in damage to the stands and increase wastage. Cutting position of some bamboo species is recommended to be immediately above the second culm node, i.e. culms should be cut as low as possible leaving one internode aboveground.

Figure 17. Inappropriately harvested culms (green stumps and higher cutting position of highland bamboo, top), lowland bamboo (higher cutting position that does not help to reduce conjection, bottom)

4.2.3. Clear felling, cutting young culms and overharvesting

If harvesting is by clear-felling (Figure 18), recovery will be slow, development of full-sized stems taking 9-10 years (PROTA, 1989). Stems must be full-sized and at least three years old before they can be exploited for structural use and numbers must accumulate to levels making harvesting worthwhile.

Figure 18. Stand growth after clear felling dramatically declines (left); Harvesting young culms (1 and 2 years old) depletes the stand (right)

4.2.4. Interference during and after flowering

Bamboos die after flowering. Regeneration after flowering is from falling seeds and rarely from persisting rhizomes. Thus, unless protected from encroachment, and appropriate soil and plant management practices are applied, it brings the stand at reduced stand value and even at risk of changing to another land use.

4.3. Techniques to maximize productivity of bamboo stands

Application of different management practices, appropriate harvesting techniques and cultural operations help to rehabilitate previously unmanaged bamboo stands and sustainably increase growth, i.e. the number of shoots, culm diameter, height and yield. Cultural operations such as removal of culms of undesirable qualities such as half cut, bent, malformed and dry culms and covering rhizomes with soil gives rise to overall production increase tremendously.

Scientific management is one of the key factors for maximizing productivity of bamboo stands. Different plant and soil management practices (intensive and extensive management) such as soil loosening and deep tilling applied for different natural stands, selective thinning of old and malformed culms, fertilizing, weeding and adopting seedlings after mass flowering of bamboo stands found to increase productivity.

4.3.1. Soil Management

4.3.1. 1. Soil loosening

Ethiopian highland bamboo has diffuse culm spacing hence the appropriate soil management to be applied on mature stands of this species is soil loosening. Soil loosening is done by cultivating the soil, to 15-20 cm depth (Figure 19), with hand tools and mounding the soil around the culm base to cover exposed rhizome parts and create conducive soil conditions. Care should be taken so as not to damage rhizomes and underground shoots by avoiding digging very close to the plant. Hand tools such as Mattock, pick-axe, grab-hoe, and axe can be used for digging the soil. Soil loosening should be conducted during dry season when growth is expected to be minimum because of the relatively long dry spell of the previous months.

Old stumps (degenerated bamboo rhizomes) that are degenerated but still maintained in the forest (Figure 20) might hinder shooting, thus should be removed while loosening the soil. Removing old stamps is applied in intensively managed high-yield model stand of Moso bamboo for pulp-making in China to increase culm production. Removing old stumps can be done using sharp axes so as not to disturb the rhizome system of the bamboo stand.

The soil loosening and removal of old stumps, accompanied by selective thinning of old and malformed culms improves eco-physiological conditions mainly the soil moisture, soil temperature, nutrient availability, and space by relieving aboveground and belowground congestion, thus increases culm yield, reduces shoot mortality and results in bigger plant size. Research reports indicated that the combined application of these soil and plant management techniques increased culm recruitment by 40% more and decrease shoot mortality by 61% less than the stands not received treatment (Yigardu and Masresha, 2013). Application of improved management practices, including protection from human and animal interference, is reported to increase culm yield of previously unmanaged communal bamboo stands by 158-519% more than unmanaged stands. Culm size showed an increment in managed stands

Figure 19. Soil loosening: cultivating the compacted soil to 15-20 cm depth with hand tools and mounding the soil around the culm base, on previously unmanaged communal highland bamboo stands

Figure 20. Removed old rhizomes that hinder underground shoot growth and effective space utilization of bamboo stand

4.3.1.2. Soil mounding around clumps

For sympodial bamboos that have closely space culms in a clump, like Ethiopian lowland bamboo, soil loosening by inter-tiling the soil with in the clump is not possible. Rather, the effective soil management practice applied is soil mounding around the clump. Research showed that the optimum height of the soil mound on bamboo clumps that have closely spaced culms to be 10 cm (Azmy and Hall, 2002). Mounding soil, either by cultivating the soil in the surrounding or by bringing from outside, including composted materials, results significant increase in shoot recruitment.

4.3.1.3. Fertilizing

The types of fertilizer to be applied on bamboo stands can be organic or inorganic fertilizer. Those organic fertilizers such as barnyard manure, weeds and shrubs, cattle manure, pond mud, green manure and compost not only increase nutrient in soil, but also improve the physical quality of soil. Unlike inorganic fertilizers, the response might be slower immediately after application organic fertilizers but it could exert a long lasting effect on growth of the stand after one growing season. As a general practice, for quick response in bamboos, inorganic nitrogen-based fertilizers are preferable before and during the shooting season, whereas organic fertilizers are preferably applied during later growth stages. Moreover, effect of organic fertilizer application may become more pronounced when applied continuously for a long period of time as bamboo has never been negatively affected by high doses of organic fertilizer.

4.3.2. Selective thinning

Thinning is the manipulation of the canopy of a stand that results in an immediate reduction in stand-level leaf area, followed eventually by increase in the leaf area of residual plants, i.e. it results in a trade-off associated with allocating leaf area onto fewer, eventually larger plants that increase the overall value of the stand. In the short-term, it clearly reduces canopy leaf area and thus gross stand growth but leaf area returns to its pre-thinning stand-level within a certain duration of time that depends on the stand age, site quality and the intensity of thinning (Juodvalkis, *et. al.*, 2005).

The management of previously unmanaged bamboo stands by selective thinning, i.e. selectively removing old, malformed and congested culms (Figure 21), accompanied by soil loosening is an important silvicultural measure that helps boosting up of bamboo productivity. Selective thinning is done by removing all plants which are four and more year old culms. So as to make selective thinning easy, bent culms that have intermingled branches with other bamboo plants need to be separated prior to removing the selected plants.

Figure 21. Selective thinning of four and more year old and malformed culms (bottom), bamboo stand after thinning (top)

4.3.3. Removing other competing plants

Bamboos grow either in pure stands or mixed with other trees or bushes. Bushes, trees and other weeds compete with the bamboo clumps for aboveground resources such as light and precipitation and belowground resources such as nutrient, water and growing space. Thus removing such competing plants reduces their effect on stand growth; it also helps to eliminate inter hosts and habitats of pests that bring about disease, insect damage and reduces flammable weeds that cause fire.

4.3.4. Irrigation

A good effect can be seen by irrigating sympodial bamboo stands. Irrigating once every week or every other week in the dry season, and if possible, enables early shooting and yield improvement. When there is no rain for a long time during the shooting time, stands should be watered timely to keep soil moist and secure a vigorous growth. But avoiding water logging on bamboo stands is important.

4.3.5. Stand structure adjustment

Bamboo stand structure is mainly concerned with the number of plants per unit area or density of the stand and the age composition (age structure) of plants. These parameters are important aspects in investigating bamboo stand dynamics and yield. Density of sympodial bamboo timber stands is affected by the density of first planting and the number of culms of retained bamboos.

4.3.5.1. Optimum density at first planting

Stand density within a certain limit and leaf area index has a very significant correlation with the stand yield. Thus, a reasonable density at first planting is an important condition to ensure the output level of bamboo stands. The density of planting is determined by size of culms and soil conditions. Different spacings are recommended for different bamboo species, worldwide. The two Ethiopian indigenous bamboo species can be classified under the medium to large sized bamboos, depending on growing sites. Plantations of lowland bamboo in Pawe area, with a spacing of 4 m X 4 m were found closing canopy at the age of four. Traditionally, farmers plant highland bamboo with a spacing starting from 5 m X 5 m, in Ethiopia. Generally, from the experiences of recommended spacing for other bamboo species and from observations made, planting density of the two indigenous species should not be narrower than 4 m x 4 m.

4.3.5.2. Reasonable density of retained mother culms

A reasonable standing-culm density is the basis to increase production, both for timber stand and shoot stands. Research conducted on determining the proportion of mature culms, in timber stands, of the two indigenous bamboo species indicated that the number of mature culms, culms of age three and more years old should be kept to the minimum. Hence 1 and 2 years old culms should never be harvested, a great proportion of the mature culms, i.e. about 75% of the mature culms should be harvested by retaining 25% of the mature culms.

4.3.5.3. Adjusted age structure culms

Generally 1 or 2-year-old bamboos culms are in young and mature phase, its tissues being tender and bud-eyes on the handle part having strong germinating power and good development. They are therefore the promise of regeneration of the bamboo stands. For those 3 or 4-year-old bamboos in their mature phase, most bud-eyes on the handle part have shot and developed into bamboos.

Consequently, all the 4-year-old old culms and part of 3-year-old ones are cut down. The age structure of bamboo stands vary depending on the management applied. A relatively rational age structure, i.e. the ratio of 1-year-old: 2-years-old: 3-years-old bamboo culms were found to be 3:4:4 in privately owned bamboo stands in north western Ethiopia. Up on sustainable applying the appropriate management and harvesting techniques, the rational age structure can be achieved.

4.3.6. Harvesting techniques

It is only mature culms, of age three years and more, that are recommended for harvest. Retaining limited fraction of mature culms is required to be, maintain stability of the stands. Besides, bamboo is harvested during the dry season, where moisture content of culms is the lowest and there is no damage of the underground shoot growth that happens when the soil is moist. The lower moisture content of culms at the time of harvesting is important to reduce attack by pest that search for food. Culms are often piled properly, in a slanting position, with a supporting beam, to drain hygroscopic water found within culms.

Labeling the year of recruitment of culms is the most realistic way of determining the age of plants. In conditions where labeling each year's recruitment is difficult, the use of morphological parameters used to identify age can be used.

The type of harvesting technique to be applied heavily depends on the culm spacing and the clumping pattern of the species. Highland bamboo has diffuse culm spacing, hence harvesting is done by selecting mature culms.

Whereas, very closely spaced culms of lowland bamboo do not allow direct entrance into the clumps so as to harvest mature culms. Thus the appropriate harvesting design should be applied.

So far two types of harvesting designs are recommended for closely spaced sympodial bamboos: the horse-shoe harvesting design and the X-shaped harvesting design. The horseshoe harvesting technique enables a harvester to get into the clump easily and work on all three sides and harvest old culms. On the other hand, X-shaped harvesting techniques is applied by making an entrance into the clump in X-shaped fashion (Figure 22). The X-shaped design is often recommended to be applied in the natural stands of bamboo for it produces higher number of new culms per clump and results in higher total above-ground biomass as compared with Horse-shoe shape harvesting technique (Othman, *et. al*., 2012). X-shaped harvesting technique is also recommended for vigorously growing bamboos, like lowland bamboo, that have higher number of culms/clump.

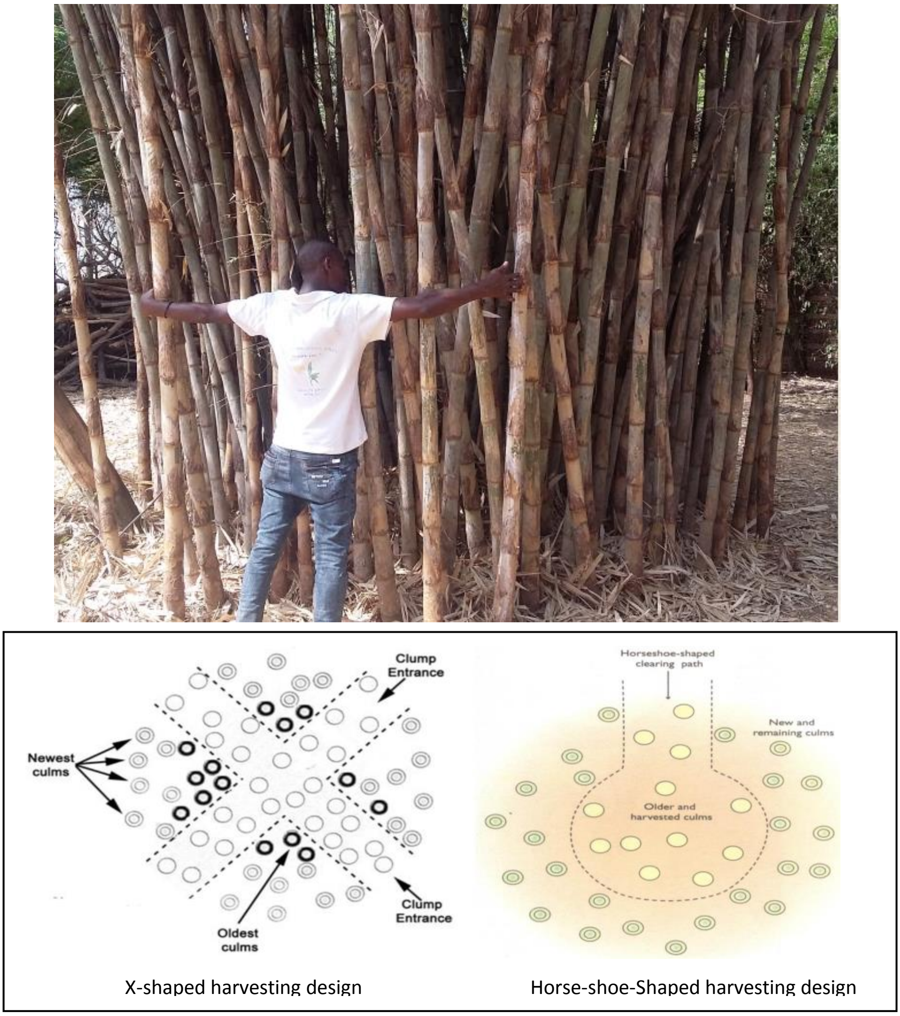

Figure 22. Harvesting designs to be applied while harvesting lowland bamboo culms from clumps: top lowland bamboo clump; photo by Yared Kebede, April, 2016; X-shaped harvesting designs (lower left); Horse shoe -shaped harvesting design (lower right), adapted from INBAR (2012).

4.3.7. Protection from interference

In areas where free browsing by large animals is exercised, fencing may be required to protect young shoots from damage and to avoid soil compaction by trampling. Damage by animals, particularly at shoot tip that harbors the apical meristem, during the shooting season, prohibits the growth of the shoot (Figure 23, left). Frequent fire, both wild and human-induced, is a major problem to a lowland bamboo forests especially in dry areas and during the dry season. Thus, in such fire prone areas, firebreaks preferably 10 – 15 m wide should be constructed.

4.3.8. Disease and Insect Pest Control

Damage caused by insects is a problem that should not be overlooked. Insects attack bamboo culms not only after harvesting but also while growing in the field (Figure 23, right). Insect damage decreases the mechanical and physical qualities of bamboo culms. The following considerations are important to control insect attack of culms while growing in the field.

(1) Bamboo culms should be harvested at the right time. The culm should never be cut during the stage when growth is extensive, since this is the period when the bamboo culm is most susceptible to fungus and insect infestation. Bamboo culms should be cut when insects and fungus are least expected to flourish. Severely damaged bamboo must be separated from the rest of the culm and burned.

Figure 23. Problems that need protection: bamboo shoots browsed by animals, at their tips (left), do not grow further. Bamboo culm borer is a common problem that needs due attention (right).

4.4. Management of bamboo forests after flowering

4.4.1. Silvicultural techniques to restock flowered bamboo stands

Once the bamboo population is dead after flowering, it will take a couple of years for new cohort to naturally regenerate again. However, applying different silvicultural management techniques and protecting the stand from encroachment, returns the forest to the previous status within a short period of time. Against plantation cost, restocking of previously flowered bamboo stands by assisting the available regeneration is an efficient management measure. Expenditure in developing bamboo forests by restocking is cheaper and also enables quicker regeneration of the flowered area. This will certainly allow the continued growth of new seedlings brought from fallen seeds and persisting rhizomes.

Research conducted in Ethiopia and a study conducted in India, Jabalpur district by Hakeem (1985) showed that protection from fire and applying plant and soil management practices during and after mass flowering promotes regeneration and growth of flowered bamboo stands dramatically. Different management options such as (3) adopting regenerating seedlings by weeding and maintain optimum spacing (2) strip cultivation of bamboo stands after flowering and (3) sawing with newly collected seeds in areas where seed fall is expected to be minimal due to high fire intensity and frequency occurred during bamboo flowering, (4) minimizing weeds by applying deliberate fire that has limited intensity and coverage were evaluated for their effectiveness in restocking lowland bamboo forests in Ethiopia.

Preliminary research results showed that adopting regenerating seedlings by maintaining spacing of 4 m x 4 m is better for proper growth of bamboo seedlings (Figure 24, top-left). In areas where more regenerated seedlings are available, weeding alone may result in overcrowded plants that may take long time to attain mature size (Figure 24, top-right). When there is no management intervention, competition between grass weeds and bamboo seedlings results in poor performance (Figure 24, bottom) and takes longer time to restock the bamboo area. Experiments on Ethiopian lowland bamboo indicated that regeneration and rejuvenation with assisting regeneration could produce mature bamboo culms within 4-5 years. Research also showed that provided that such silvicultural management techniques are applied on flowered Ethiopian highland bamboo stands, the regeneration potential is considerably high (Figure 25).

Generally the following guideline can be followed to restock flowered areas and reduce associated risks associated with bamboo flowering.

- protecting flowered bamboo stands from fire and grazing by animals soas to assist natural regeneration and to ensure proper survival and growth
- opening canopy of the upper storey vegetation on previously flowered bamboo stands
- In areas where the seedling bank is high, adopting the regenerating new seedlings by maintaining a spacing of 4 x 4 m and applying silvicultural techniques such as weeding, thinning out overcrowded seedlings during the first and second years after seed germination on the ground.
- Intercropping, usually with manure or leguminous plants adequately in order to remedy economic loss resulted from flowering, as well as improve soil condition
- Some bamboo populations may bear fruits and produce seeds with low breeding capacity. In heavily degraded flowered bamboo stands that are affected by animal and human interference and frequent fire, regenerating previously flowered bamboo land through natural regeneration may be difficult. Thus, in such cases, introducing seedlings raised in nurseries or wildlings from overpopulated sites is crucial.
- Introducing different clones, planting materials of different ages of original material (the seed) to decrease possibility of simeltaneous flowering in the future.

Figure 24. Applying silvicultural management techniques on bamboo stands after mass flowering hastens restoration to previous state; adopting regenerated seedlings by weeding and thinning out excess seedlings (top left); effect of applying weeding alone (top right). The pictures are taken from Bambassi trial site, 2.5 years after treatment application.

Figure 25. Highland bamboo regenerates well in areas where previously flowered areas are protected from livestock and human interference. Assisting newly regenerated seedlings will have greater impact on hastening growth of the seedlings. Photos of the regenerated seedlings that started rhizome formation and shooting, taken from Masha zone where highland bamboo had flowered in 2010.

4.4.2. Reduce the risk of bamboo forest fire and other interference

Gregarious flowering followed by mass death of clumps carries as risk of forest fires when the dried culms accumulate in huge quantities. Fire hazard in bamboo stands is common in natural bamboo stands in lowland areas of Ethiopia. *O. abyssinica* is a best example in continual burning, sometimes more than twice a year. The community set fire on natural forests including lowland bamboo stands so as to open up the forest for hunting and also to induce the growth of grass for their livestock.

The effect of fire is expected to be high especially after flowering, mainly because of the fuel load associated with the accumulated dried culms and branches of flowed bamboo culms. Besides the accumulated dried grass within the bamboo stands a trigger burning of bamboo stands. At this end, seedling establishment is unlikely on burned sites, as the fire may also affect the seed bank and surely the regenerated seedlings.

However, sources indicate that bamboo spreads rapidly from rhizomes following disturbances. If established bamboo clones occur in or near burned areas, increased clone size or rhizome spread should be expected. Besided, controlled burning, with regulated intensity and frequency, applied after seedling germination, may help to reduce competing grass weed, but this information should be further investigated. Therefore precautions against occurrence of fire should be taken once the culms start drying. Fire could be protected by establishing fire breaks.

4.4.3. Awareness creation to local community

Perhaps connected to the rareness of bamboo flowering, it is considered as indicator of bad fortune in some cases and also regarded as a disease in many communities in Ethiopia. As a result, the local communities are not aware that bamboo provides seed after flowering; they do not try to collect and conserve seeds. Therefore, awareness creation needs to be considered as one of the actions in the process of avoiding the risks of mass flowering and enhancing regeneration.

4.4.4. Seed collection

Once bamboo flowering has occurred in an area, measures should be taken to collect sufficient seed, as there is always a surplus of seed production of which only a certain proportion regenerate when left to fall.

4.4.5. How to use flowered materials

The seed: We could collect seed, raise seedling and make plantation from bamboo flowering. We can use the seed as the research material to carry out researches on bamboo embryology, taxonomy, genetics and breeding, etc. and for large scale plantation establishment. Bamboo seeds, are a little sweet and rich in starch contents. Seeds of some species are edible and some even have exceptional effects of fever and poison.

The dried bamboo culms: Bamboo culms collected after flowering could be used for many applications. They could be used for shade, fence, fuel, and pulping materials without any negative influence on quality. For some industrial products, some quality limitations may be seen.

Bamboo flower: Bamboo flowering makes its sexual reproduction (Cross breeding) possible and sexual hybridization has the advantages of combining parents' characters, shaking genetic homeostasis and producing many individuals with abundant vitality and variation. As a result, sometimes the offspring possess evident hybrid advantage of fast growing, good resistance, wide adaptability and high yielding.

Harvesting standing culms before flowering starts

Usually most gregarious flowering events occur over a period of three or more years with the peak in the second or third years. When several clumps in the plantations show widespread signs of flowering and emergence of new culms ceases or reduces drastically, it is safe to assume that flowering is gregarious and will continue into the coming years with death of the clumps. To minimize the loss it would be desirable to begin harvesting of the bulk of the remaining clumps at the earliest.

4.5. Management guidelines for Ethiopian highland bamboo

The following management guidelines can be followed to obtain high productivity with the desired culm quality out of the previously unmanaged bamboo stands:

1. Soil loosening by cultivating or inter-tilling the compacted soil to a depth of 15-20 cm using hand tools such as mattock, pick axe, grab hoe and mounding the soil around the culm base and cover exposed rhizome parts;
2. Removal of old stumps comprising degenerated rhizomes maintained in the forest using sharp tools;
3. Removal of other impeding physical bodies (boulders) that may hinder emergence and development of new shoots;
4. Selective thinning of four and more years old and malformed culms should be done after uncurving the bent culms in the stand so as to make thinning easier;
5. Protection of the forest from livestock and human interference is a prerequisite for improving productivity unmanaged communal bamboo stands;
6. After the forest is rehabilitated, probably within 3 to 4 years, a rational harvesting intensity that maintains sustainable yield and productivity of the stand should be in place;
7. Harvesting 75% of mature culms i.e. culms of age three and more is found to be optimum intensity;
8. Retaining old culms that are meant to stabilize productivity should be limited to a small fraction (25% of the excising mature culms);
9. One to two year old culms are required to maintain productivity for bamboo stands hence must not be harvested while older culms could be harvested in a certain ratio;
10.
11. No clump should be clear felled except after flowering and when seeding has been completed; culms should be cut as low as possible

leaving one internode above ground; cutting should begin from the side opposite to where new sprouts are emerging.

4.6. Management guidelines for Ethiopian lowland bamboo

The following management guidelines can be followed to obtain high productivity with the desired culm quality out of the previously unmanaged lowland bamboo stands:

1. Loosen the soil at the periphery of clumps and mound the soil around the clumps to a height of 10 cm. Additional soil can also be obtained by bringing soil or composted material from outside;
2. Apply X-shaped and Horse-shoe harvesting design while harvesting, as prescribed in this book;
3. Protect the forest from livestock and human interference;
4. After the forest is rehabilitated, probably within 3 to 4 years, a rational harvesting intensity that maintains sustainable yield and productivity of the stand should be in place. Harvesting 75% of mature culms i.e. culms of age three and more is found to be optimum intensity for plantation stands;
5. Retaining old culms that are meant to stabilize productivity should be limited to a small fraction (25 percent of the existing mature culms);
6. One to two year old culms are required to maintain productivity for bamboo stands hence must not be harvested while older culms could be harvested in a certain ratio;
7. No clump should be clear felled except after flowering and when seeding has been completed;
8. Culms should be cut as low as possible leaving one internode above ground.

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Glossary

Bamboo shoot, culm shoot: a young culm in any stage of its development short of maturity in height. The ascending axis when segmented into internodes it becomes a stem.

Bamboos: are a subfamily (Bambusoideae) of flowering perennial evergreen plants in the grass family Poaceae.

Caespitose: Growing in tufts, like grass; describes the normal clump habit of bamboos with pachymorphrhyzomes, except where the rhizome neck is elongated as in *A. alpina*.

Clump: A cluster or group of stems of bamboo growing from a common underground rhizome system

Clump congestion: A major causes or conditions that adversely affect clump yields or productivity as a result of non-harvesting and improper harvesting.

Culm sheath: the sheath of the culm leaf, borne singly at each node of the culm proper, below the level at which the sheath of foliage leaves originate**.**

Culm: A segmented aerial axis that emerges from a rhizome and forms a part of a gramineous plant; It is the above ground stem. The term is used most commonly with special reference to bamboos.

Cutting: A vegetative portion removed (cut) from plant for the purpose of propagation.

Diffuse: spread out; growing in open array; characterizes the normal mature clump habit typical of most bamboos with leptomorph rhizomes, and those whose pachymorph rhizomes have a greatly elongated neck, as in *A. alpina*.

Flower: The reproductive structure of angiosperms, characteristically having either specialized male or female organs or both male and female organs, such as stamens and a pistil, enclosed in an outer envelope of petals and sepals.

Fruiting: To bear or cause to bear fruit:

Gregarious Flowering: all plants of a particular species flower at the same time, regardless of differences in geographic locations or climate conditions, and then die a few years later.

Grove: bamboo stand covering continuous and considerable area.

Leptomorphs rhizome: Are rhizomes and also known by the names of monopodial, tracant, indeterminate, and running bam-boos and are extended and fine rhizomes with long and spaced internodes

Monopodial: Having the form of a monopodium, "a stem of a single and continuous axis. The rhizome is one piece of the modified branch of a monopodial bamboo plant.

Neck: The constricted basal part, characteristic of all or most of the segmented vegetative axes of a bamboo plant.

Offset: a short, lateral shoot or branch which develops from the main stem producing a means of vegetative propagation.

Pachymorph rhizome: are rhizomes with bulb form and have short and compact internodes.

Rhizome: An individual component branch of the subterranean system of segmented axes that constitute the "chassis" (popularly referred to as the "rootstock") of a bamboo plant. A rhizome consists of two parts: the rhizome proper and the rhizome neck. Two distinct types of rhizome are differentiated: leptomorph and pachymorph.

Sporadic: widely dispersed or scattered; irregular in time, flowering at regular intervals

Sympodial: Having the form of a sympodium (syn=together; podos=foot); a term used to designate the branching habit of the type of rhizome described as pachymorph. In sympodial bamboo the rhizomes cannot run for a long distance, the culm base is the main part of the rhizome.