For my friend Ranjanan with best regards.
Oscar Hidalgo New Delhi, February 28/2004

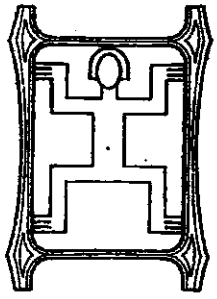
BAMBOO

THE GIFT OF THE GODS

by

Oscar Hidalgo-López

PART-1



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BAMBOO THE MARVELOUS PLANT

Bamboo is the most marvelous plant in nature.

Some giant culms of genus *Phyllostachys pubescens*, grow up to 1.22 meters in 24 hours.

In less than five months, the culms of giant species like *Guadua angustifolia* complete their whole growth of 20 meters which, in many trees of the same diameter takes many years

Bamboo is stronger than wood or timber in tension and compression. The tensile strength of the fibers of a vascular bundle could be up to 12.000 kilograms per square centimeter, almost twice that of the steel.

In spite of the strength and hardness of the giant bamboo culm wall, the culm can be cut very easily in few minutes, even with a stone ax, if we know the exact place of the internode where it should be cut. To cut the trunk of a high density tree with the same diameter using a stone ax would take several days and many stone axes

With bamboo wee can replace wood or timber in all their applications, but we cannot use wood or timber to make all of the things and structures that can only be made with bamboo.

Only a supernatural beign or a superplant can support the radiation of an atomic bomb. In Hiroshima, Japan, the only plant which survived the radiation of the atomic bomb in 1945 was a bamboo plant. The incinerating heat developed by the radiation destroyed all the trees and wooden houses and the whole city was razed except this bamboo plant.

I have been fortunate to have worked and studied bamboo for many years. Now I also agree with the Garrows and other ancient cultures of Asia, that in the world of plants bamboo is the representation of the divinity because it is A GIFT OF THE GODS

Oscar Hidalgo-López

CONTENTS

16 PREFABRICATION OF BAMBOO HOUSES

PART 7- CONSTRUCTION OF BAMBOO STRUCTURES

17 CONSTRUCTION OF BAMBOO SCAFFOLDINGS (KNOT-TYING)

18 BAMBOO SPATIAL STRUCTURES

PART 9 - APPLICATION OF BAMBOO IN DIFFERENT FIELDS OF ENGINEERING

23 BAMBOO IN THE FIELD OF AERONAUTICS

24 BAMBOO IN THE FIELD OF CHEMICAL ENGINEERING

25 BAMBOO IN THE FIELD OF CIVIL ENGINEERING

26 BAMBOO IN THE FIELD OF ELECTRICAL ENGINEERING

Introduction

One afternoon in 1963 at the end of the lecture which I gave to the last semester students at the College of Agricultural Sciences of the National University of Colombia in Palmira, about the traditional uses of "guadua" (the vernacular name of our main giant bamboo species, *Guadua angustifolia* Kunth) in rural construction, one of the students asked me: *What is guadua?, What is its origin?* When he noted the surprise his question caused me, because I am an architect and he was almost an agronomist, he told me, *I have to write a thesis about guadua and so far I have not been able to find any botanical or technical information about this plant in the library.*

I could not believe what he said. I could not believe that there were no scientific or technical studies about the most useful of all our plants, which for centuries has contributed to the social and economic development of Colombia, where about 60% of the total population of the cities and rural areas use this material not only in the construction of their houses, but also in buildings, factories and in the construction of stables, bridges, aqueducts and many other uses.

Based on my belief, I promised my student that I would get some information for his thesis. During several days, I visited the libraries of various universities including that of Natural Sciences in Bogota where I found hundreds of books written by our botanists, even about plants which have no economic value, but I could not find any botanical or technical information about our "guadua". My student was right and I became frustrated because I could not help him with any information. Unfortunately, this student died in an accident two months later, not knowing that his questions were the seeds which created in me a great interest for the study of our marvelous "guadua" in which I have spent many years of my life.

What was the reason for the lack of interest of our botanists, agronomists and forestry universities in the study of this plant? I talked with several forestry engineers who told me that at that time (1963), there were so many large natural plantations of bamboo in our country that this plant was considered to be a weed and the Cinderella of our natural resources since it was only used by poor people in the construction of their houses. Consequently, nobody was interested in the study of this plant since it was considered a waste of time. For this reason, there was no technical or scientific information about this plant. Therefore, students had not received any information about it from their professors at the university, not even about the way it could be cultivated. I became frustrated, because if there was no information about this plant, how could I start studying it?

Several weeks later I received from my friend Dr. Guillermo Ramos Nuñez a small publication, "Bamboo as Construction Material" written in 1953 by Dr. Alonzo McClure at the U.S Department of Agriculture, Washington D.C In this publication, I learned that "guadua" was not a tree (as it was believed to be in Colombia) but a giant grass, which was considered to be one of the best bamboos in the world for durability and strength. For me, this information opened the doors of that marvelous world of bamboo in which I have been wandering for many years and which has taken me to visit several countries of Asia such as Japan, China, the Phillipines, Taiwan and Indonesia, where I started my studies on bamboo.

There has been little interest in this plant in Latin America as a result of the lack of technical and scientific information written in Spanish about our native bamboo species, so most Latin American countries have destroyed their native giant species up to the point that in most of them bamboo is on the brink of extinction like in Venezuela, México and Guatemala.

It is very important to point out that Colombia is the only country in Latin America which has still preserved most of its native species, thanks to the Colombian Institute of Natural Resources (INDERENA). In 1960, when our giant native bamboo species were on the brink of extinction due to the intensive destruction of the natural bamboo plantations which began in the nineteen fifties, this institute forbade the cutting of bamboo without its permission and fortunately this norm is still in force.

This book is the result of many years of research that I have carried out at the National University of Colombia at the School of Architecture, where I founded the CIBAM (Bamboo Research Center); as a United Nations consultant in Ecuador and Costa Rica; as a consultant for the Acuerdo de Cartagena PADT -REFORT in Peru and Bolivia, and in the libraries of several universities including Washington University in Canada, the University of Columbia in NewYork, and the University of California in Berkeley, where I received great collaboration.

This book includes some traditional applications of giant bamboos and some of the most important and advanced studies on this plant carried out in recent years by outstanding researchers from-China, India, Japan, Germany and United States in different fields.

The first part of the book include: Anatomy and Physiology of bamboo in which I received the collaboration and guidance of my friend and teacher Professor Dr. Walter Liese of Germany. I think that this is the most important part of the book because the anatomy and physiology of bamboo are the basis for understanding not only the structural behavior of bamboo, but also the thousands of different applications of this marvelous plant that has been considered to be a gift of Gods since ancient times.

The other chapters deal with the use of bamboo in different fields of ancient and modern architecture, in different branches of engineering, and in theconstruction of modern structures. It also considers its use inthe manufacture of new types of composite materials, which will generate new applications of bamboo in the future, and finally its use in the field of medicine and as a biomedical material.

I hope that this book will contribute to the technical and scientific study of our native giant bamboo species, to the development of many industries related to the manufacture of composite materials, and the development of new types of structures, in Colombia and the other countries of the Americas where this marvelous plant can grow.

Finally, I want to dedicate this book with my deepest gratitude to my student, who changed the direction of my life with his questions, to Dr. Walter Liese, to Mrs Ingrid Radkey of the University of California and many other people of other institutions, who taught and helped me in my reseach.

PART ONE

The Bamboo Plant

THE BAMBOO PLANT

WHAT IS

Bamboo is not a tree as it is considered by the majority of people, but a giant arborescent grass, or in other words, a woody giant herbage. As such, it belongs to the family *Gramineae (Poaceae),* subfamily *Bambusoideae,* whose members possess a similar distinctive in the leaf blade anatomy, i.e., fusoid cells and arm cells, which sets the bamboo apart from grasses. All grasses that possess this ty-pe of leaf anatomy are known as "*bambusoid grasses*". They range from a few centimeters in height, such as those of genera *Raddiella* which grow on wet rocks near rapids in the Guianas, South America, to giant species up to 40 meters high, as *Dendrocalamus giganteus,* from India.

PALEOBOTANY

In relation to the origin of the plant, Velenovsky claims that the bamboo plant flourished in the Cretaceous period, when grasses and cereal appeared, just before the beginning of the Terciary period, when the first humans also appeared. (Porterfield 1925).

Fossils of *Chusquea rolloti* of the Tertiary were found in the area of La Virginia near Girardot, Colombia (about 140 kilometers from Bogota). (Berry 1929). According to Taylor & Smoot (1984), the earliest recorded paleobotanical contribution was the description of fossil "bamboo shoots" by the Chinese scholar Shen Kua (1029-1093), published in 1086 in his work entitled "*Dream Pool Essays*".

Although the beginning of paleo-botany may be traced to this work, it was not until the seventeenth century that paleobotanical investigation began in Europe. Shen Kua reported in his work that in the year 1080 there was a landslide in China on the bank of a large river in Yang-Ning Kuang near Yenchow;"*...The bank collapsed, opening a space of many meters, and under the ground a forest of bamboo was thus revealed. It contained several hundreds bamboos with their roots* (rhizomes) *and trunks* (culms) *complete, and all turned to stone. Now bamboos do not grow in Yenchow. Perhaps in very ancient times the climate was different so that the place was low, damp, gloomy, and suitable for bamboos...*" (Deng. 1976; Li. 1981).

ETYMOLOGY

The origin of the word "bamboo" is a puzzle to etymologists. Some believe that this word is Malayan in origin and it is the onomatopoeic for *bam-boom*, the cracking sound made by the culms when they are burned. With the heat, the air in the sealed hollow bamboo internodes expands until they blow apart. Other authors consider that the term "bamboo" had its origin in"*mambu*", the ancient Indian term for bamboo.

Herbaceous and woody bamboos

The subfamily *Bambusoideae* is divided into two broad groups: The *herbaceous bambusoid grasses,* or herbaceous bamboos, that usually have soft culms, and the *woody bambusoid grasses* or woody bamboos, or simply "bamboos". This latter group forms the tribe *Bambuseae* (See Table 3-3) which have woody culms, usually hollow and are divided by septums or diaphragms. They branch at the nodes and usually reproduce from rhizomes that give rise to new long-lived culms. They flower only after many years, at which time most of them produce seeds and then die, in the majority of cases, while grasses only flower annually and most commonly reproduce by seed

Classification of the woody plants

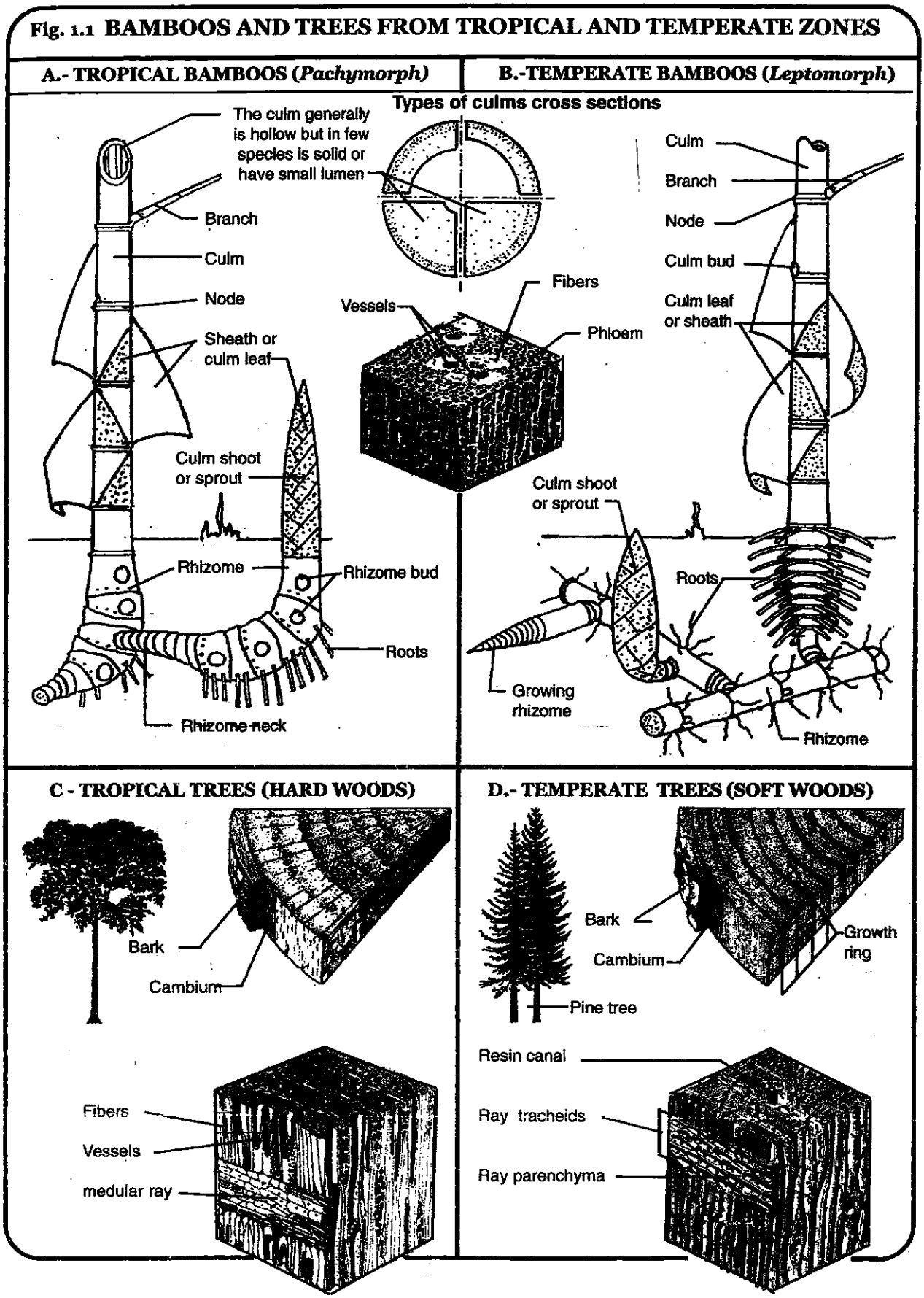
The basic anatomical element of the plant is the cell.. The joining of cells forms the tissue, and the joining of tissues forms the woody body or mass. As a woody grass, bamboo is a member of the woody plants, which also include trees (softwoods and hardwoods) and palms. All of them have differences in their morphology, and also in their anatomical structure and tissue organization.

The woody plants are classified into two groups: *Gymnosperms* and *angiosperms*. The *Gymnosperms* include the coniferous species or "*softwoods*", which have needle like leaves, such as pines or scale- like leaves which, except for a couple of species, remain on the tree throughout the year.

The *Angiosperms*, are subdivided into two groups: *dicotyledons* and *monocotyledons*. *Dicotyledons* include the "*hardwoods*" which have broad leaves. They are often deciduous and shed their leaves in the fall or during the winter, except in warmer regions, depending on the species. Bamboos and palms are the most important members of the *Monocotyledons*. The palms include rattan, which has solid but flexible stems and belongs to the climbing, spiny palms. Once the spines are removed, it is used in the manufacture of furniture. Rattan has certain similarity with some bamboo species, but they are different, bamboos are generally hollow and rattan is solid.

Besides the differences which exist in the anatomical characteristics of the woody plants, they have also differences in their growing process. The growing process of the woody plants is based on the formation of new cells by specialized tissues known as *meristems*. For instance, in trees (softwoods and hardwoods), the initial growth of the plant is due to the primary or apical meristem which is later replaced by a lateral meristem known as *cambium* located between the bark and the wood. In bamboos there are not *cambium* because bamboo does not grow in diameter, as will be explained in this chapter.

Fig. 1.1 BAMBOOS AND TREES FROM TROPICAL AND TEMPERATE ZONES



BAMBOO MORPHOLOGY AND PHYSIOLOGY

PARTS OF THE PLANT

1.- THE RHIZOME

Bamboos are perennial plants consisting of a ramifying system of segmented vegetative axes which form a regular alternation of nodes and internodes. These segmented axes, according to their shape and position on the plant, have the following names:the *culm* or *stem* with the branches, which forms the aerial part of the plant and the *rizome system* with its *roots* which forms the subterranean part of the plant; and its structural foundation. The rhizome performs important functions in the life of the plant; it is the vital organ with which bamboo plants reproduce vegetatively or asexually through the branching of rhizomes. As an organ, it has the function of storage and transportation of nutrients. The culms depend on rhizomes for their growth, vigor and spacing on the ground.

Types of bamboos

As mentioned above, the tree species are commonly divided into two large groups according to their geographical position. They are:"softwoods" which naturally grow in the temperate zones, and "hardwoods" which grow in the tropical zones. These two groups have differences particularly in the anatomy of their trunks and their leaves.

Like trees, bamboos are also classified in two main types on the formation pattern of the subterranean part of the culm which also depends on the geographical position where they grows naturally. These main groups or types are: the *leptomorph or monopodial type* which grows in temperate zones; and the *pachymorph* or *sympodial type* which grows in the tropical zones. There is a subgroup or intermediate known as *metamorph* which is a combination of the two main groups, but has no relation with the geographical position.

The only thing that these two groups have in common is the morphology and anatomy of their culms and their growing process.The aerial part of these two groups is so similar that if the species are not known, it is difficult to recognize visually to which group they belong, unless the rhyzomes can be seen, because there is a great difference in the morphology and in the form of branching of the rhizomes between the two main groups and in the formation of the culm shoot, as can beseen in the Fig 1.1.

On the other hand, the two main groups of bamboos have differences in the number of chromosomes, which in the leptomorph type is 2n=48, and in the pachymorph type is 2n=72. The basic number of chromosomes is assumed to be 2n=18. Bamboos with low multiple chromosomes are considered to be of the advanced type and those with high ones are of primitive type. The basic number for most bamboo species is X=12, except for certain bamboo species (especially paquimorph bamboos). The difference in chromosome number and nucleous type can help to explain the systematic development, and classification of bamboos.

In 1879, the Rivieres were the first to publish a clear distinction between the two basic forms of the bamboo rhizomes. They used the terms "*caespitose*", or "clumping " for pachymorph, and 'traçant" or "running" for leptomorph. In 1925 McClure introduced the terms "monopodial" and "sympodial" when he was living in China, and later, at the Smithsonian Institution, in Washington, he developed the concept of "leptomorph" and "pachymorph" respectively. Today the terms "leptomorph" and "paquimorph" are used in the Americas by the botanists and taxonomists, and the terms "monopodial" and "sympodial" in Asia.

a).-LEPTOMORPH RHIZOME

The leptomorph rhyzome is also known by the names of monopodial, traçant, indeterminate, and running bamboos. Bamboos with leptomorph rhizomes are usually distributed in temperate regions, such as Japan, Korea and China, where winters are severe. They are characterized by relatively strong frost-resistance, and consequently they can be cultivated at high elevations in the tropics.

Bamboos with this type of rhizome are represented in Asia by the genera *Arundinaria*, and *Phyllostachys*. The most cold-resistant are: *Phyllostachys praecox*, *Ph. propinqua*, *Ph. dulcis*, *Ph. iridenscens*, *Ph. nuda*, *Ph. angusta*, *Ph. aureosulcata*, and *Indocalamus*. In the Americas there are only three native species of leptomorph type which belong to the asiatic genus *Arundinaria*, and grow in the temperate zones of the southeastern of the United States up to 46° north latitud.

The subterranean part of the plant consists of two major parts, the *culm-base* with its root system and the *rhizome* system (See Fig. 1.1). The *culm-base* corresponds to the subterranean prolongation of the aerial culm and is conected to the rhizome by the *culm neck*. The internodes at the lower part of the culm-base are the shortest and there are usually 13-16.

The leptomorph rhizome has the creeping habit. It is long and slender, with a cylindrical or subcylindrical form, and a diameter usually less than that of the culm originating from it. The internodes are longer than broad, and they are generally shorter than those of the culm. They are typically solid with narrow lumen. Every node bears a solitary lateral bud and an encircling belt of roots at each node. Beyond the bud there is a longitudinal groove.

Most of the lateral buds are temporarily or permanently dormant. The majority of those that germinate generate single culms, directly, or rhizomes. But it is very difficult to

determine whether a lateral bud of the rhizome is going to form a rhizome or a culm shoot when it is still dormant. The meristem generated in the lateral bud forms a culm neck which turns its apex upward forming the *culm base* and the culm shoot, and finally the culm proper. The buds on the *culm-base* can only grow into rhizomes and cannot grow into new culms.

The culms and the rhizomes grow in alternation all through the year. According to Ueda (1960), in temperate zones the rhizome grows during summer and autum when the temperature is relatively high, and the culms grow through winter to spring when the temperature is relatively low. The rhizome begins to develop after the new culm shoots have attained their full growth and the new branches and leaves have developed. This usually starts in March after the soil temperature rises up to about + 5° C. The rhyzome grows fastest in August and September, and ceases to grow gradually from November onwards.

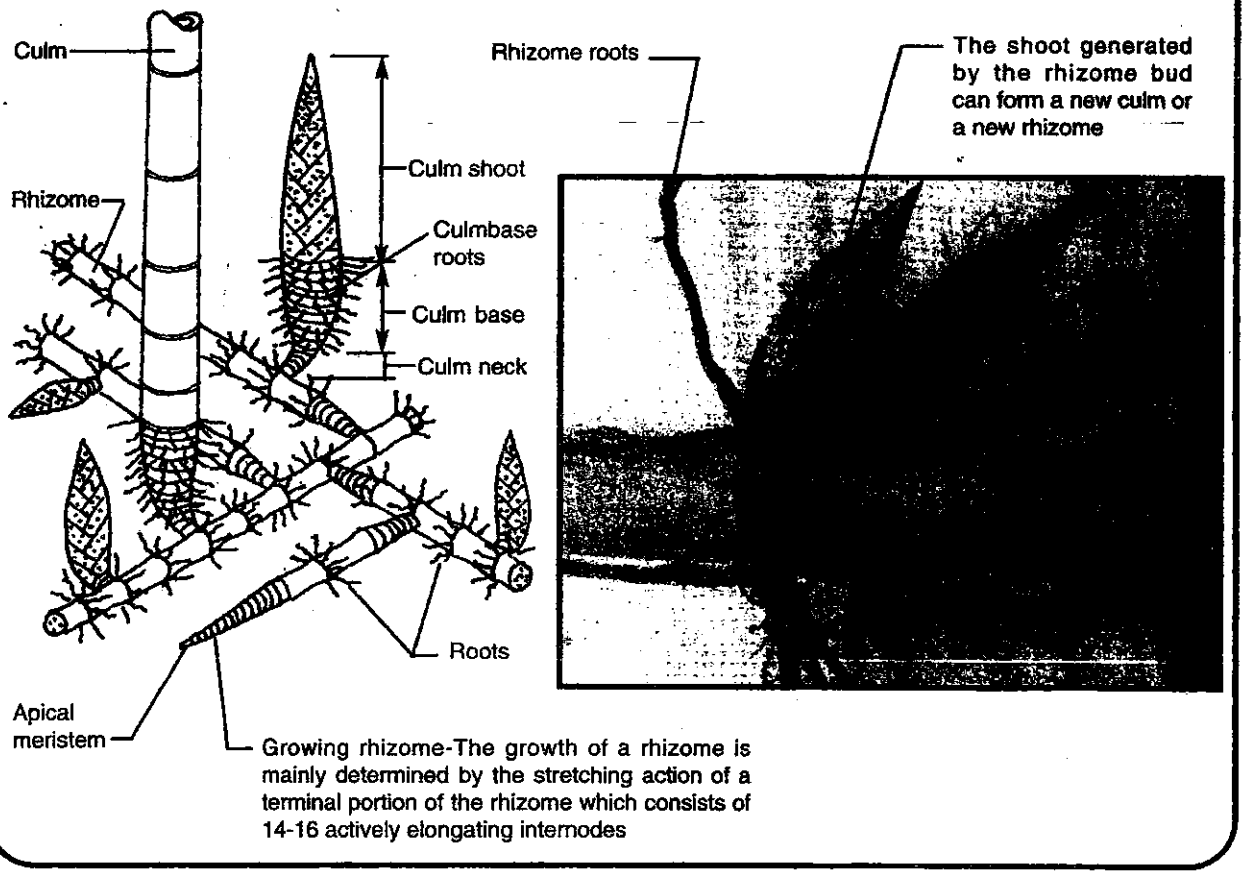
The rhizome shoot is slender and runs its apical meristem forward, parallel to the ground surface. The elongation of a leptomorph rhizome shoot depends on the activity of two meristems: the *apical meristem* at the terminal end of the rhizome, and the *intercalary or intermediate meristems* located between the internodes of the rhizome. The apical meristem consists of tunica-corpus and its derived meristem. The cells of a derived meristem differenciate into sheaths, buds, primordial roots and vascular bundles. The original slanted bundles and enlarged parenchyma cells form a new node at the young sheath position, and divide the derived meristem into several intercalary meristems.

The growth of a rhizome is mainly determined by the stretching action of a terminal portion of the rhizome which consists of 14-16 actively elongating internodes. The internodes of the streching portion elongate according to the rhythm of "slow-fast-slow" from back to front. The latter sections of the stretching portion mature and stop stretching. As the growing season proceeds, the apical meristem produces new nodes and internodes continnuously. The new internodes formed by the meristem at the terminal end, act in succession replacing the former part of the stretching portion. The rhizome tip continues to grow.

The apical meristem of the rhizome shoot is tightly embraced layer by layer by hard thick sheaths and is sharply pointed like a borer which can penetrate through the hard-textured soils or the gravel gaps with driven force generated from the internodal elongation. The rhizome shoot does not necessarily maintain a horizontal position nor does it fallows in a fixed direction but it may twist, bed, shrink, elongate or wind with the topograraphical and soil conditions. It grows in all directions, and forms a complex interwined network. It may run to considerables distances and send out many single culms that appear on the ground scattered at certain distances every year.

Ueda (1960) made extensive excavations of the leptomorph rhizomes of several species of Japanese bamboos,

Fig. 1.2 RHIZOME SYSTEM OF THE LEPTOMORPH TYPE



Growing rhizome-The growth of a rhizome is mainly determined by the stretching action of a terminal portion of the rhizome which consists of 14-16 actively elongating internodes

Fig.1.3 *The soil has been removed by Ueda in order to show the intrincate system of rhizomes which form a network just below the surface and conect most of the standing culms. This means that the whole grove is one plant.*

plotting the pattern and rate of their extension. He found that the total length of living rhizomes per 0.1 ha. in bamboo groves of *Phyllostachis reticulata* was from 6,300 to 18.740 meters; in groves of *Pleioblastus pubescens* from 47,000 to 57,920 meters.

The rhizome neth under the ground prevents landslide and collapse of river bank and hill sides where there are an erosion problems. Bamboo cultivation for the protection of river banks was recommended in Japan in the sixteen century. This is also the reason why a bamboo plantation is considered a safe refuge when an earthquake takes place.

The depth that the rhizome travels on the ground also varies with the type of bamboo. The horizontal growth mostly take place in the upper soil layer between 10 -30 cm in depth, where water, heat, and air are easily available. Very few rhizomes grow deeper than 50 cm.

The annual extention of the rhizomes ranges from 0.30 to 0.70 meters in small bamboos and about 4- 6meters in large culm bamboos such as *Phyllostachys bambusoides* (Madake). Their length varies according to species and habitat. The growth period is shorter in areas of high latitud and high elevations than in low latitudes and low elevations. The same is the case on shaded slopes compared to sunny slopes.

According to Takenouchi (1932), in special conditions, the rhizome top goes out of the earth or soil and some continue to grow upwards to become bamboo shoots. Some, however, enter the earth again after stretching a bit on earth, forming the socalled "*jumping rhizome*" like a bow. Jumping rhizomes tend to appear where the upper layer of forest soil is hardened and impervious. The same author points out that when the rhizome is injured or cut off, the nearest bud behind the injured part develops into a new rhizome, which continues to grow in the same direction of the parent rhizome.

The longevity of the rhizome also varies with the specie of bamboo. According to Takenouchi (1932), the rhizome of *Pleioblastus simoni* (Madake) and *Phyllostachys nigra henonis* (Hachicu) continue to function actively to the third year, after which they gradually decline in vigor and from about the fifth year they slowly go into decay and die in the seventh or eighth year. In *P. edulis* (Mosochicu) the period of highest activity of the rhizome is from the third to the sixth year. In the eighth or ninth year decay sets in, and kills it in the twelfth or thirteenth year (Takenouchi 1939, Wen et all. 1981. ;Xiao 1991).

Direction which the leptomorph rhizome takes when it starts its growth

The following information was found in the Chinese book "Treatise on Husbandry" *(Chi min yaoshu*), written by Chia Suniu in the 5th century: "*Owing to the nature of the bamboo it has a tendency to spread its rhizome growth in a southwesterly direction. Therefore they are usually planted in the northeastern part of the garden or grove. After several years they will spread in their growth until the culms fill the whole garden. There is a tradidition that if the bamboos are planted on the western side of the house their roots will spread, covering the ground until they reach a neighbor's house on* the west."

Taking into account that China is located in the northern hemisphere, I think that it is very important to experiment this interesting theory south of the Ecuador, (in the southern hemisphere), in order to see if there is any change in the direction the rhizome takes when it starts its growing process.

b).-PACHYMORPH RHIZOME

This type of rhizome is also known as *clump type*. sympodial, caespitose and determinate. It is typical of tropical zones of the Americas, Asia, Africa and Oceania. It can not withstand freezing temperatures. Bamboos with this type of rhizome are represented in the Americas by genus *Guadua*, and in tropical Asia by the genera *Dendrocalamus* and *Bambusa*.

The morfology and growing process of pachymorph rhizomes is different from that of the leptomorph rhizomes and has the following characteristics: The culm-base does not exist in the subterranean part of the culm and the aerial culm is generated directly by the rhizome, which, in this case could be considered as the culm-base.

The rhizome is solid, with roots on the lower side, the shape is usually more or less curved, and the internodes are broader than long. The maximum thickness of this rhizome is somewhat greater than that of the culm that generates. The lateral buds of the rhizome are dome-shaped and generate only rhizomes. The rhizome is narrow at the neck where it is attached to the mother rhizome, and thick and broad at the other end whose apex protudes out of the ground and grows into a new culm shoot which generates the culm. In the following year a new rhizome grows, which is is generated by the meristematic zone of one of the lateral buds of the mother bamboo.

The bud protrudes forming first the new rhizome neck, and then the shoot of the rhizome itself, which is covered with sheaths. In the rhizome, the sheaths have the function of protecting the tender apical meristem by forming a

sharp-pointed resistant shield around it to protect it when the rhizome is pushed through the soil by the elongation of the rhizome internodes during its growing process. Once developed, (in two or three months, depending on the species),the new rhizome turns its distal end or apical meristem turns upward and forms the culm shoot.

In the tropics new culm shoots or sprouts begin to appear after the beginning of the rainy season. They protrude from the ground as scaly cones covered with sheaths. In warm regions with precipitation at frequent intervals throughout the year, the growth is often more or less continuous.Once the culm-shoot is formed, the apical meristem stops its function and the intercalary meristems located between the nodes start the growing process of each one of the internodes starting from the lowest one.

In pachymorph species, the distance between the culms depends on the length of the rhizome neck and on the position of the rhizome. When the rhizome neck is short, and the position of the rhizome is almost vertical, densely caespitose clumps of bamboo are formed, as in the genera *Bambusa* (*Bambusa vulgaris*), *Dendrocalamus* and some species of genus *Guadua* such as "Guadua brasilera", which is cultivated in Costa Rica .Fig 1.6 B. When the neck of the rhizome is long and the rhizome has an almost horizontal position, as in genera *Melocana*, *Fargesia*, and *Guadua angustifolia*, the culms grow separatelly and open clumps are formed. According to Arbelaez (1996) the minimum and maximum separation beetwen the mother bamboo and the new culm shoot in a clump of *Guadua angustifolia* was 0.85 to 1.70 meters. In Asia there are species of *Melocanna*

Fig. 1.5 *Rhizomes of Guadua angustifolia in which the length of the neck, the separation of the culms, and the short necks developed by the rhizomes for providing a colective foot to support the heavy culms can be seen.*

(pachymorph) in which the culms are separated by more than 3 meters.In some species the neck and the rhizome grows almost vertically and looks like part of the culm (Fig. 1.6).

In general, the pachymorph rhizome system is superficial and does not penetrate more than 0.60 meters below ground level. The longevity of the pachymorph rhizome varies with the specie of bamboo.

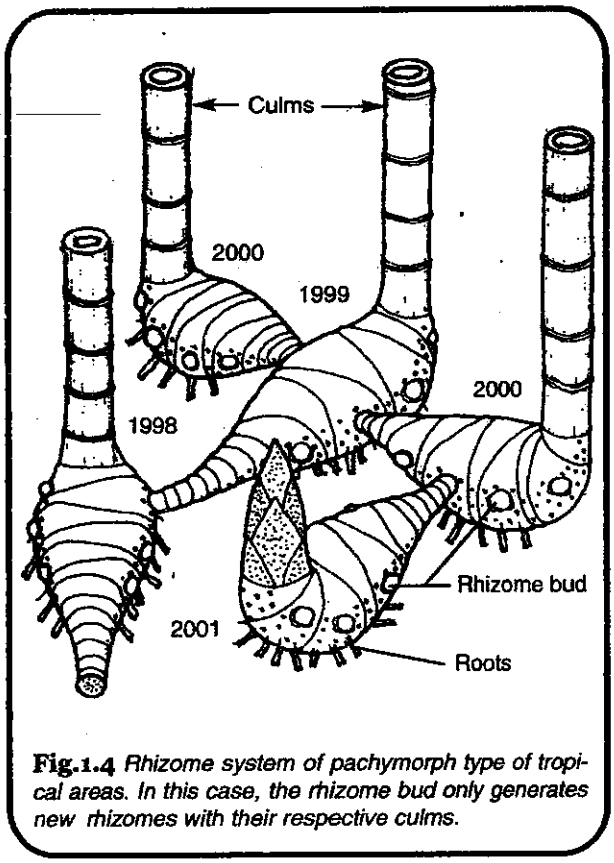


Fig.1.4 *Rhizome system of pachymorph type of tropical areas. In this case, the rhizome bud only generates new rhizomes with their respective culms.*

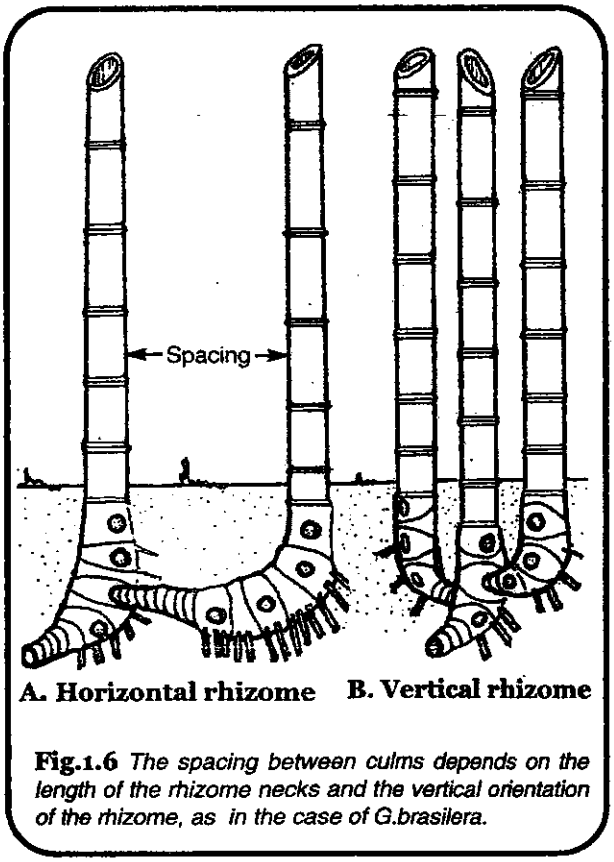


Fig.1.6 *The spacing between culms depends on the length of the rhizome necks and the vertical orientation of the rhizome, as in the case of G.brasilera.*