

# **Growth and quality of indigenous bamboo species in the mountainous regions of Northern Vietnam**

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**submitted by**

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## 1 Introduction

### 1.1 Overview of bamboo in the world

Bamboo is actually a giant grass belonging to the family *Poaceae* (*Gramineae*) and from the tribe *Bambuseae* of the subfamily *Bambosoideae* (Zhu et al., 1994; Ohrnberger, 1999). It is estimated that about 1250 bamboo species in 75 genera have been identified all over the world (Rao et al., 1998; Nguyen, 2006). Bamboo is recorded to be the fastest-growing land plant on the earth since culms of some species, in just four months, can reach 40 m in height and 30 cm in diameter (Rao et al., 1998). Furthermore, bamboo has an extremely wide range of distribution with a great variety of habitats. In addition, bamboo is an adaptable plant, some species being deciduous, others are evergreen, and especially, some species seem to be able to change their habit when necessary (McNeely, 1995).

The geographical distribution of bamboo generally depends on climate (Gamble, 1978). Most of bamboo species require a warm climate, thus, they mainly grow in the tropical, subtropical and temperate regions except Europe (Dransfield, 1992; Zhu et al., 1994; Nguyen, 2006). In nature, bamboo has a cosmopolitan distribution, ranging from 46°N to 47°S latitude (Dransfield, 1992; McNeely, 1995), reaching elevation as high as 4000 m in the Himalayas and parts of China (McNeely, 1995). Normally, bamboo thrives at temperature range of 8.8 to 36°C and annual precipitation of 1020 to 6350 mm (Huberman, 1959) but some species can event grow in cold climate with temperature of about -20° C (Wang and Shen, 1987).

About 80% of bamboo forest land and species in the world is distributed in Asia and Pacific regions (Fu et al, 2000). According to Dransfield and Widjaja (1995), the largest number of bamboo species is distributed in Asia, this continent has about 590 bamboo species in 44 genera. Australia and the Pacific islands have fewer bamboo species with more scattered distribution (Banik and Rao, 1995). America also has a high biodiversity of bamboos with approximately 400 – 500 species, among them about 300 species in 20 genera are woody (Fu et al, 2000) and the majorities are *Chusquea* Kunth. The island of

Madagascar has 6 genera with about 20 species. Africa has only 3 genera (Fu et al, 2000) with 3 species (Dransfield and Widjaja, 1995) including *Arundinaria alpina* K.Schum. (in Kenyan mountainous area) (Banik and Rao, 1995), *Oreobambos buchwaldii* K.Schum. (in Uganda, Tanzania, Zambia, and Zimbabwe), and *Oxytenanthera abyssinica* Munro (throughout tropical Africa) (Ohrnberger, 1999)

Table 1: Approximate number of woody bamboo genera and species in the world

Region	Genera	Species	
Asia			
Tropical and subtropical	24	270	(the majority is <i>Bambusa</i> )
Temperate	20	320	(the majority is <i>Sasa</i> )
Africa	3	3	(endemic)
Madagascar	6	20	(endemic)
Australia	2	3	
Pacific	2	4	
America			
Tropical	20	410	(the majority is <i>Chusquea</i> )
Total	77	1030	

(Dransfield and Widjaja, 1995)

## 1.2 Bamboo distribution and biodiversity of selected Asian countries

Within its tropical and temperate climates, Asia has many advantages for bamboo growth. Banik and Rao (1995) estimated that about 80% of the bamboos grow in India and in the Asian-Pacific region, including Japan. South and Southeast Asia have most of woody genera (Rao et al., 1998), of which more than 150 species are tall and large, having high economic value (Banik and Rao, 1995). Many Asian countries such

as China, India, Myanmar, Indonesia, Thailand, and Vietnam are very rich in bamboo resources.

China is the big country located from the subtropical zone to the cold temperate zone with a typical monsoon climate (Fu, 1998; Yang and Xue, 1998). The country has the largest number of bamboo species in the world (Bystriakova et al., 2003). Only Yunnan, a Province with total 383000 km<sup>2</sup> area, has more than 200 species belonging to 27 genera (Yang et al., 1998; Pei et al., 1998). Approximately 500 bamboo species of 40 genera have been found in the whole country (Zhu et al., 1994; Fu, 1998; Yang et al., 1998; Pei et al., 1998). In China, bamboo is distributed in the area with coordinates from 85 to 122° E, and from 18 to 35° N (Wang and Shen, 1987). According to Fu (1998), four types of bamboo forest are to be found in this country including temperate bamboo forest (Mountainous bamboo forest), warm bamboo forest (Hilly - mountainous bamboo forest), hot bamboo forest (Hilly - mountainous bamboo forest), and valley (plain bamboo forest). Some important commercial bamboo species are *Phyllostachys pubescens* Mazel ex Lehaie, *Phyllostachys praecox* C.D.Chu & C.S.Chao, *Phyllostachys glauca* McClure, *Phyllostachys bambusoides* Siebold & Zucc., *Phyllostachys viridis* (R.A.Young) McClure, *Bambusa textilis* McClure, *Neosinocalamus affinis* (Rendle) Keng f., *Dendrocalamus latiflorus* Munro, *Dendrocalamus membranaceus* Munro, *Bambusa oldhami* Munro (Fu, 1998)

Gamble (1978) reported that in India, bamboo naturally distributes following the distribution of the rainfall. Based on this concept, the author divided India in to 7 principal regions and showed a list of total 16 genera with 115 species. According to Biswas (2000), the country has about 9.6 million ha of bamboo forest (12.8% of the total area of 75 million ha). Some recent surveys report 128 bamboo species belonging to 18 genera in India (Muktesh, 2001; Upreti and Sundriyal, 2001). Some common bamboo species are *Bambusa multiplex* (Lour.) Raeusch. ex Schult. & Schult.f, *Bambusa polymorpha* Munro, *Bambusa vulgaris* Schrad., *Dendrocalamus brandisii* Kurz, *Dendrocalamus giganteus* Munro, *Dendrocalamus hamiltonii* Nees & Arn. ex

Munro, *Thyrsostachys oliveri* Gamble & Bor, and *Thyrsostachys regia* (Munro) Bennet (Muktesh, 2001).

Myanmar, with coordinates from 92 to 102° E, and from 10 to 30° N, has a total land area of 676577 km<sup>2</sup> and about half of the area is covered by forest (Htun, 1998). There are approximately 100 bamboo species belonging to 17 genera distributed throughout the country. Some common species are *Bambusa polymorpha* Munro, *Bambusa tulda* Roxb., *Cephalostachyum pergracile* Munro, *Melocanna bambusoides* Trin., *Thyrsostachys oliveri* Gamble & Bor, *Dendrocalamus brandisii* Kurz, *Dendrocalamus membranaceus* Munro, *Dendrocalamus strictus* (Roxb.) Nees (Khin, 1995). In Myanmar bamboo naturally grows in the forest but sometimes they are planted for aesthetic reasons only (Htun, 1998).

Malaysia, a tropical country with coordinates from 100 to 119° E and from 1 to 7° N, has approximately 70 known bamboo species, 50 in Peninsular Malaysia, 30 in Sabah and 20 in Sarawak. Of these species, only 12 species are being commercially utilized (FAO, 1997). In this country, bamboo distributes from sea level to 3000 m above. The most common species are *Gigantochloa scortechinii* Gamble, *Gigantochloa levis* (Blanco) Merr., *Gigantochloa ligulata* Gamble, *Dendrocalamus asper* Backer ex K.Heyne, *Bambusa blumeana* Schult.f., *Schizostachyum grande* Ridl., and *Schizostachyum zollingeri* Steud. Some widespread species are *Gigantochloa scortechinii* Gamble, *Dendrocalamus pendulus* Ridl., and *Schizostachyum zollingeri* Steud. in the Southwest coast and *Bambusa farinacea* K.M.Wong, *Gigantochloa ligulata* Gamble, and *Gigantochloa latifolia* Ridl. in the Northern area of Malaysia (Mohamed and Appanah, 1998).

The Kingdom of Thailand is located in the central part of continental Southeast Asia, with longitudes from 97°30' to 105°45' E and latitudes from 5°35' to 20°15' N, and has the total area of 513115 km<sup>2</sup> (FAO, 1998). The climate of this country is greatly influenced by the East and Northeast monsoons (Kamol, 1985). Bamboo in Thailand is

mostly of the sympodial type and commonly appears in mixed deciduous forest areas (Rungnapar, 1998; Vantomme et al., 2002). The country has 60 species of bamboo in 13 genera including *Arundinaria*, *Bambusa*, *Cephalostachyum*, *Dendrocalamus*, *Dinochloa*, *Gigantochloa*, *Melocalamus*, *Melocanna*, *Neohouzeaua*, *Pseudosasa*, *Schizostachyum*, *Teinostachyum*, and *Thyrsostachys* (Sakomsak, 1985; Wanida, 1995; Rungnapar, 1998). Recently, about 17000 ha of bamboo plantations have been established in 25 provinces under the extension program of the Department of Agricultural Extension (Wanida, 1995).

### **1.3 Bamboo in Vietnam**

Vietnam is a tropical country in the East part of the continental Southeast Asia, with coordinates from 102°08' to 109°28' E and from 8°02' to 23°23' N. The country has a multiform topography carved with mountains, hills, highlands and large deltas. Mountain and highland areas dominate the country with about three-fourth of the total land area. Vietnam is also separated by many big rivers running from the West size to the East size.

The climatic conditions of the country bear the monsoon characteristics of Southeast Asia with the prevalence of the Northeast and Southeast winds. However, because of differences in latitude and topography, the climate of Vietnam varies considerably from place to place leading to abundant solar radiation and moisture. Those climatic characteristics are considered to favor condition for biodiversity in general and for bamboo growth in particular.

Vietnam has about 13118773 ha of forest in which 10348591 ha is natural forest and 2770182 ha is planted forest (Department of Forest Protection, 2008). Vu (2005) reported that the country has 767122 ha natural pure bamboo forests and 341273 ha natural bamboo and woody mixed forest (table 2).

In former times, bamboo was mainly harvested from nature since it grows everywhere in Vietnam except in the two delta regions of Red River and Mekong River. Some species with high economic value previously grew in large areas but due to the overexploitation those areas have been reduced gradually (Do, 2000).

Table 2: Bamboo forest areas of Vietnam year 2001

Regions	Natural bamboo forest area (ha)	
	Pure bamboo forest	Wood-bamboo forest
Whole country	767122	341273
1. NE Vietnam	146122	112035
2. NW Vietnam	52556	42256
3. Red River Delta	0	0
4. N Central Coast	138759	75949
5. S Central Coast	29198	2517
6. Central Highland	206538	8812
7. SE Vietnam	193949	20396
8. Mekong River Delta	0	0

(Vu and Le, 2005)

Nowadays, when the demand of the modern industry using bamboo as the raw material is increasing, some projects on large-scale intensive bamboo plantation in large-scale have been established in Vietnam. However, those projects focus only on some commonly used species like *Dendrocalamus barbatus* Hsueh & D.Z.Li in the Northern area or *Dendrocalamus strictus* (Roxb.) Nees in the Southern area.



Bamboo has also been intensively cultivated for shoot products in many areas of the country and it has brought a significant income for farmers. However, some common species that can provide delicious shoot such as *Dendrocalamus asper*, and *Bambusa oldhamii* were exotic and their management techniques were imported.

In conclusion, the use of native bamboo species is now facing a knotty problem as insufficient attention has been paid to the management of those species. Obviously there is also lack of knowledge on bamboo plantation management, processing and utilization of these bamboos. In addition, research activities on bamboo in Vietnam are on the way to be further established and the research results to be better documented. Consequently, bamboo studies are required to support intensive bamboo management activities.

## **2 State of knowledge on bamboo in Vietnam**

### **2.1 Genera and species**

Located in the tropical region of Asia, Vietnam borders the S provinces of China (Yunnan and Guangxi) where many bamboo species are to be found. The flora of the country is also affected by the migration of plants from India, Myanmar and Thailand in the W and from Indonesia and Malaysia in the S (Nguyen, 2006). Those characteristics of Vietnam are advantages for bamboo species diversity. Camus (1923) reported that Vietnam has 57 bamboo species in 12 genera. Some other studies on bamboo taxonomy have been carried out but the results are very controversial. Pham (1999) reported 123 bamboo species of 20 genera whereas Vu and Le (2004) estimated the number of Vietnamese bamboo species of about 200. In a recent study, Nguyen (2006) reported a list of 216 Vietnamese bamboo species within 25 genera.

### **2.2 Growing habit**

Inflorescences and spikelets are two main features to identify bamboo. However, observation of the flowering phenomena of bamboo is very complicated as most of bamboo species seldom flower even if they are hundred years old (Zhu et al., 1994). Nguyen (2006) estimated that the information on flowering of about 60% bamboo species has not been recorded. For this reason vegetative characteristics of bamboo become very important to recognize the differences between species.

The rhizome with well developed root system is a very important part of bamboo structure because it is the basic of the plant helping culms standing stable and produces new bud shoots. The bamboo rhizome is a segmented and complex subterranean system (Holtum, 1958). Gamble (1978) indicated that bamboo has two types of rhizomes, caespitose (growing in dense tufts) and distant rhizomes (growing in spreading culms). Dransfield and Widjaja (1995) also suggested that there are two basic types of bamboo rhizome including sympodial and monopodial.

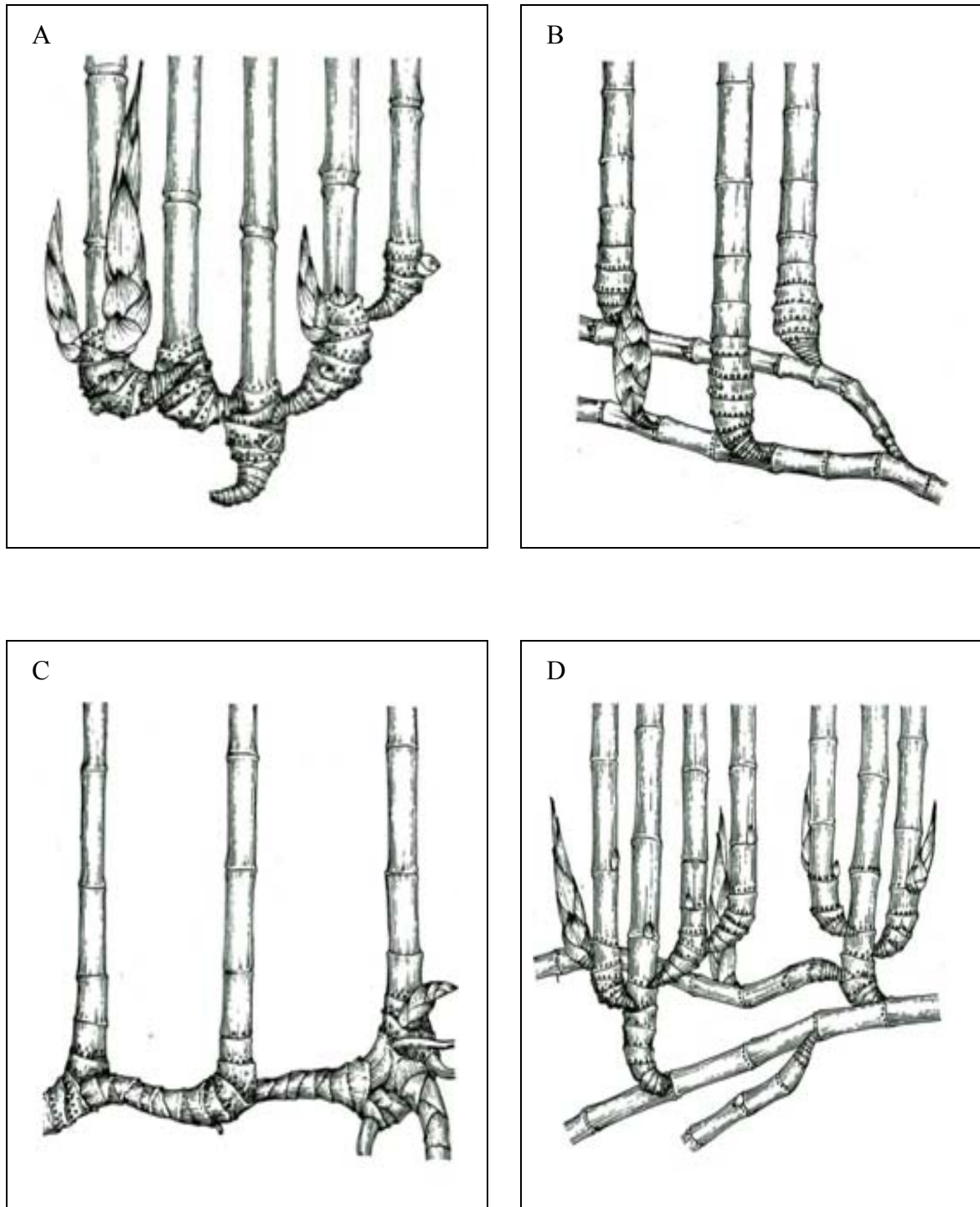


Fig. 1: Rhizome systems of bamboo (after Wang and Shen, 1987)

A - Sympodial rhizome

B - Monopodial rhizome

C - Sympodial rhizome with scattered culms

D - Amphipodial rhizome

Xiao (1991) and Negi and Naithani (1994) divided bamboo into three groups: the sympodial (densely clustered) group, the amphipodial (open clustered) group, and the monopodial (single stemmed) group. For China, Wang and Shen (1987) divided bamboo into four groups: monopodial rhizomes with scattered culms, sympodial rhizomes, sympodial with scattered culms, and amphipodial rhizomes (Fig. 1a-d). Nguyen (2006) shared the opinion of Wang and Shen (1987) and noted that the amphipodial group is the mixture of monopodial and sympodial groups.

The methods used for bamboo identification in previous studies are similar because bamboo belongs to the grass family and thus, the culms arise from the rhizomes. Based on bamboo habit of occurring or not occurring in clumps, in Vietnam bamboo can be divided into three groups as follow:

- a) Sympodial rhizome bamboos, such as *Bambusa vulgaris* Schrad., *Dendrocalamopsis* sp. 2, *Dendrocalamus barbatus* Hsueh & D.Z. Li, etc (Nguyen, 2006), distribute in regions located in below 500 m sea level with mean annual temperatures about 20<sup>0</sup> C and annual rainfall exceeding 1500 mm (Do et al., 2000).
- b) Monopodial rhizome bamboos, some species of the genera *Phyllostachys*, *Indosasa*, etc (Nguyen, 2006), naturally grow in regions above 500 m sea level with mean annual temperatures of around 14<sup>0</sup> C and annual rainfalls above 1000 mm (Do et al., 2000).
- c) Amphipodial rhizome bamboos like *Oligostachyum* sp. and some species of genus *Indocalamus*, etc (Nguyen, 2006). Those species grow wild in regions where climatic conditions have mean annual temperatures about 14 to 22<sup>0</sup> C and annual rainfall from 1000 to 1500 mm (Do et al., 2000).

### **2.3 Bamboo forest formation**

In Vietnam, according to Do et al. (2000), bamboo is only found in secondary forest with two secondary associations. The first association develops after exploitation of timber and the second takes place after shifting cultivation.

In general, the characteristics of bamboo stands are affected by the exploitation intensity. After a tropical forest area is devastated, bamboo species frequently invade the gaps, which results in three following situations including:

- 1) If the forest cover is still high (about 40 - 50 %), the crown cover will close again and bamboo is gradually out competed.
- 2) When the devastation is too serious, the crown cover is reduced to only 20 - 30 %. Under this condition bamboo spreads out quickly and occupies the whole openings and as a consequence the mixed wood-bamboo forests will form.
- 3) In the case of destruction of tropical forest, if its cover is decreased to fewer than 10 %, the pure bamboo stands will be the result.

## **2.4 Usage**

Bamboo is widely used as multipurpose material as its products including culm, shoot, and even leaf can be used not only for home consumption but also for exportation. Recently, with the development of advanced processing technologies, bamboo is considered as a plentiful material resource supporting the modern industry with valuable products such as flooring, pulp, fiber, etc.

Actually, Vietnam has about 88 factories using bamboo as the raw material, among those, six factories produce pulp and paper on the basis of about 150000 – 180000 tons bamboo per year and four factories use bamboo to produce wood based panel with an output capacity ranging from 15000 to 130000 tons of products per year. The other factories have limited output capacity and produce bamboo-curtain, chopstick or toothpick (Vu and Le, 2005).

According to Vu and Le (2005), approximately 400 million bamboo culms are used in Vietnam annually, of which a large amount of culms are used for handicraft making. The whole country has about 1400 handicraft villages with millions of laborers produce exportable commodity on the bases of bamboo and rattan (Phan, 2004). Generally, export of bamboo and rattan handicraft products is important for both economics and society in Vietnam. From the year 2000 to 2005 the annual income of this work was about 100 millions in US dollar (Phan, 2004; Vu and Le, 2005).

Some bamboo species like *Schizostachyum pseudolima* McClure and *Bambusa procera* A.Chev. & A.Camus have been used as a major material in the paper industry of Vietnam since a long time (Ha, 2004). For the whole country, paper industry consumes an amount of approximately 150000 – 180000 tons of bamboo culms per year (Vu and Le, 2005). However, these culms were mainly harvested from natural forest and as a result bamboo forest areas have been reduced significantly (Ha, 2004).

At present, 50% of building materials for housing in rural areas rely on bamboo (Vu et al., 2002; Do, 2006). Some bamboo species with thick walls such as *Dendrocalamus barbatus* Hsueh & D.Z. Li, *Dendrocalamus latiflorus* Munro, *Dendrocalamus membranaceus* Munro, *Bambusa blumeana* Schult.f., and *Bambusa bambos* (L.) Voss are appropriate to housing. Annually, approximately 50 % harvested bamboo culms are used for construction in Vietnam (Do, 2006) and it is certain that bamboo will be used as main building materials for rural housing in Vietnam for a long time.

Bamboo is not only providing trunk for various uses, it is also supplying edible shoot for human life. Shoot of some endemic bamboo species of Vietnam such as *Dendrocalamus giganteu* Munro, *Dendrocalamus barbatus* Hsueh & D. Z. Li, *Dendrocalamopsis* sp. 2, *Bambusa sinospinosa* McClure, etc. is one type of safe and delicious vegetable (Do, 2006) but most have not been planted in specialized forest for shoot productions. Cultivation of exotic bamboo species like *Dendrocalamopsis oldhamii* (Munro) Keng f., and *Dendrocalamus asper* Backer ex K.Heyne for shoot

products became popular in Vietnam in 1997 and by the end of 2003, Vietnam has about 1500 ha exotic bamboos planted to produce shoot products but the area of these species is in fact much larger than the official statistics (Do and Le, 2001).

## 2.5 Research

Despite of the traditional spirit and the widespread usage, there have been only few studies on important bamboo species in Vietnam. Camus E., G. and Camus A. (1923) were the first authors who worked on bamboo taxonomy in Vietnam (Nguyen, 1995). Since then bamboo classification has been published by few other taxonomists such as Nguyen and Tran (1971), Tran (1993), and Pham (1999).

Further research has been published about bamboo species and their conservation status in Vietnam (Do, 2000). Some years later, 18 bamboo species were identified and their names were updated (Vu and Le, 2004). Nguyen and Tran (2006) reported on the six new species of *Melocalamus* genera of Vietnam. 'Bamboos of Vietnam' published by Nguyen (2006) is one of the newest publications in this field. The book does not aim at botanical or taxonomical descriptions, but attempts to show the diverse valuable bamboo resources of the country and presents 194 species with short description, briefly important information and photos.

Studies on bamboo plantations in Vietnam were carried out in the 1960s when Pham (1963) reported on *Dendrocalamus membranaceus* Munro plantation and Nguyen (1964) investigated soil characteristics of *Dendrocalamus membranaceus* Munro plantation areas. Some other studies also focused on plantation methods applying for *Dendrocalamus membranaceus* Munro species such as Tran and Luu (1980), Le (1990), Ngo (1994), and Nguyen (1997). Recently, Nguyen (2000), Le and Nguyen (2000), Do and Le (2001) and Do (2006) worked on some bamboo species being intensively cultivated for shoot products.

There are several research papers on bamboo propagation techniques. Hoang (1977) worked on effects of some growth stimulants on air layering of *Dendrocalamus membranaceus* Munro. The other studies on bamboo propagation applied for *Dendrocalamus membranaceus* Munro as well were conducted by Le (1993 and 2000) when Dinh (1999) worked on propagation and plantation of *Phyllostachys pubescens* Mazel ex Lehaie in Hoa Binh, and Phung (2001) published on vegetative propagation of *Dendrocalamus latiflorus* Munro in the South of Vietnam.

Focusing on pest and disease of bamboo, Le et al. (2007) investigated eight insect species damaging bamboo shoots and the authors introduced a protectively covering method by using plastic bags. Nguyen and Pham (2006) presented techniques to isolate and select entophytes used to protect growing bamboo culms from *Fusarium equiseti*. In previous report, Tran (1972) worked on some diseases harming bamboo; Le (1973) presented some chemical methods to protect bamboo from timber insects. Nguyen (1973) and Doan (1977) focused on some species of the *Curculionidae* family attacking bamboo shoot.

Bamboo utilization seems to be an emerging topic in Vietnam. Ngo (2003) introduced general information on plantation and utilization of bamboos whereas Le (2002) and Do (2004) published on physical and mechanical properties of culms of some commonly used bamboo species in Vietnam. Bui (2002) worked on *Dendrocalamus barbatus* Hsueh & D.Z.Li used to produce wood based panel. Nguyen (2000) worked on the influence of bamboo composition on absorbing capacity of preservation solution and Nguyen (2004) presented some simple methods of bamboo preservation for construction.

It can be summarized that research on bamboo in Vietnam focuses mainly on species identification. However, the scientific names of many bamboo species have not been identified so far. Study on bamboo cultivation including propagation receives a lot of attention but the studies focus only on the common species like *Dendrocalamus membranaceus* Munro. Bamboo utilization has got more attention recently as the demand of usage of bamboos for daily life and industries is increasing.



## 2.6 Objectives

This study was carried out in order to enhance the knowledge on a) site conditions, b) characteristic of stand structure, and c) tissue properties on economically important bamboo species in the mountainous regions of the Northern Vietnam to improve the efficiency of bamboo management activities. The specific objectives of the study are as follow:

- To analyze site requirements of important bamboo species in the mountainous regions of the Northern Vietnam,
- To investigate stand structures of those species,
- To determine the physical and mechanical properties of bamboo culms,
- To study the current management techniques and propose suitable management methods for those stands.

### 3 Materials and Methods

#### 3.1 Study areas

##### 3.1.1 Location

The study was conducted in four different districts in the mountainous regions of Northern Vietnam including Nguyen Binh (Cao Bang Province), Yen Binh (Yen Bai Province), Doan Hung (Phu Tho Province) and Tan Lac (Hoa Binh Province).

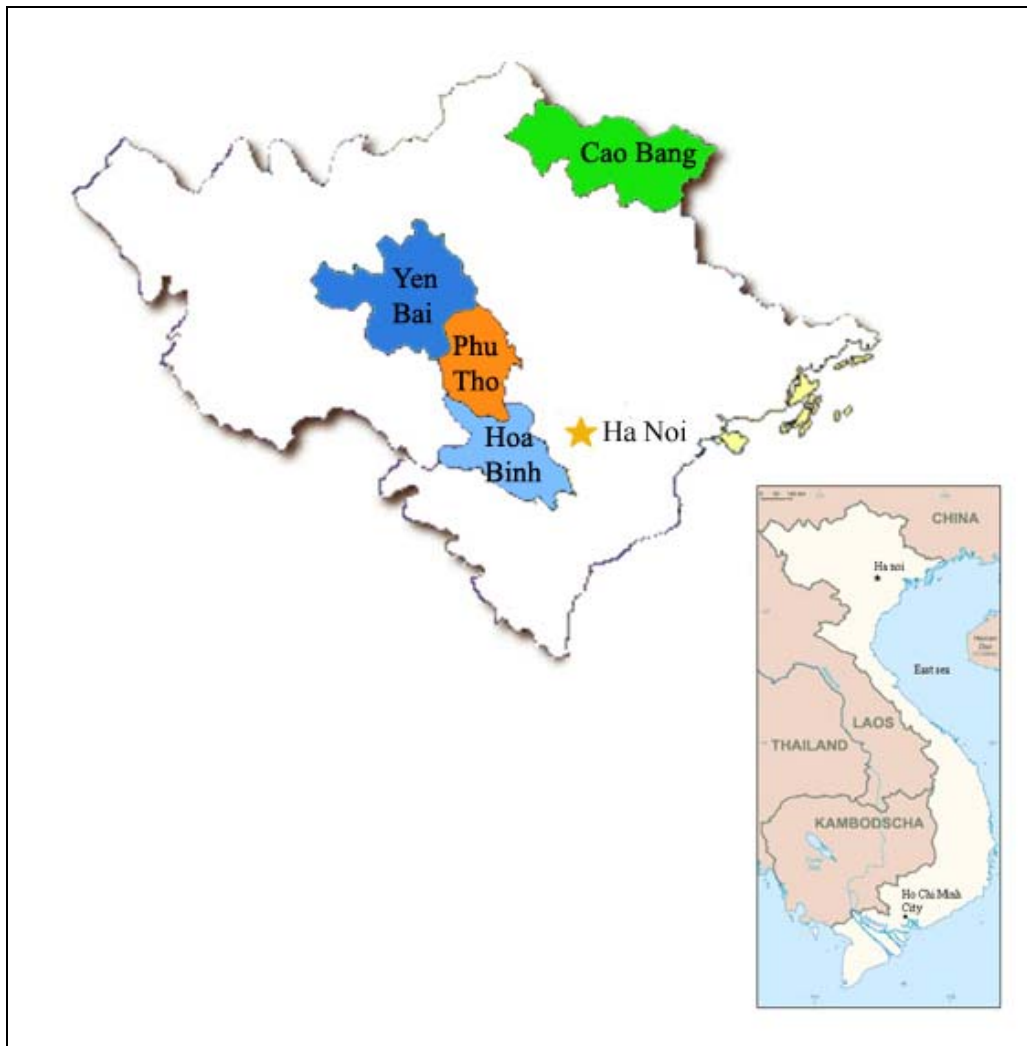


Fig. 2: The location of the study areas in Northern Vietnam

### 3.1.2 Topography and climate

The Nguyen Binh district is located at around 22°40' N and 105°53' E and belongs to Cao Bang, a Northeast Province of Vietnam at the border with China. The Province possesses limestone high land area with altitudes of over 1000 m above sea level. The topography of this region is complex with steep slopes of about 45° or more. Close to the tropic of Cancer and characterized by tropical monsoon, this area has a sub-tropical climate with cold winters. From December to March, it receives winter monsoon with rain, high humidity, and sometimes, even with snow. According to Nguyen (2000), the annual average temperature of this area is 20.3°C, the relative ambient humidity is above 80%, and the mean annual precipitation is about 1763 mm but the main rainfall is observed from April to September.

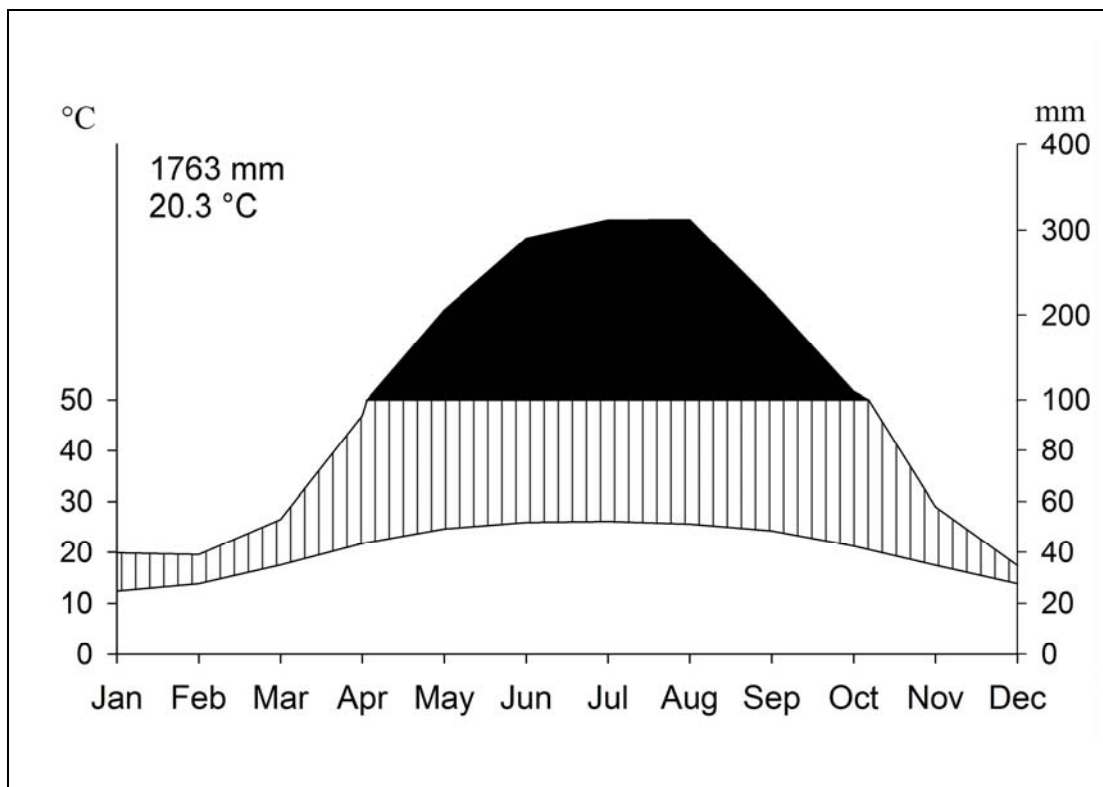


Fig. 3a: Climatic diagram of Nguyen Binh district (drawn according to Nguyen, 2000)

The Yen Binh district covers a mountainous area, 180 km North from Hanoi, at around 21°48' N and 104°58' E. The district belongs to the Hoang-Lien-Son Range, the Southeast ending part of the Himalaya, ranging from Northwest to Southeast. With altitudes of about 80 m above sea level and affected by the Hoang-Lien-Son area, Yen Binh has a characteristic of tropical monsoon climate with cold wet winters and summer rain (Nguyen, 2000). In summer, the area is affected by strong wind coming from the East Sea with high humidity leading to heavy rain. The mean annual precipitation of this area is quite high with about 2107 mm, the relative ambient humidity is about 85 to 90%, and the annual average temperature of this area is 22.7°C.

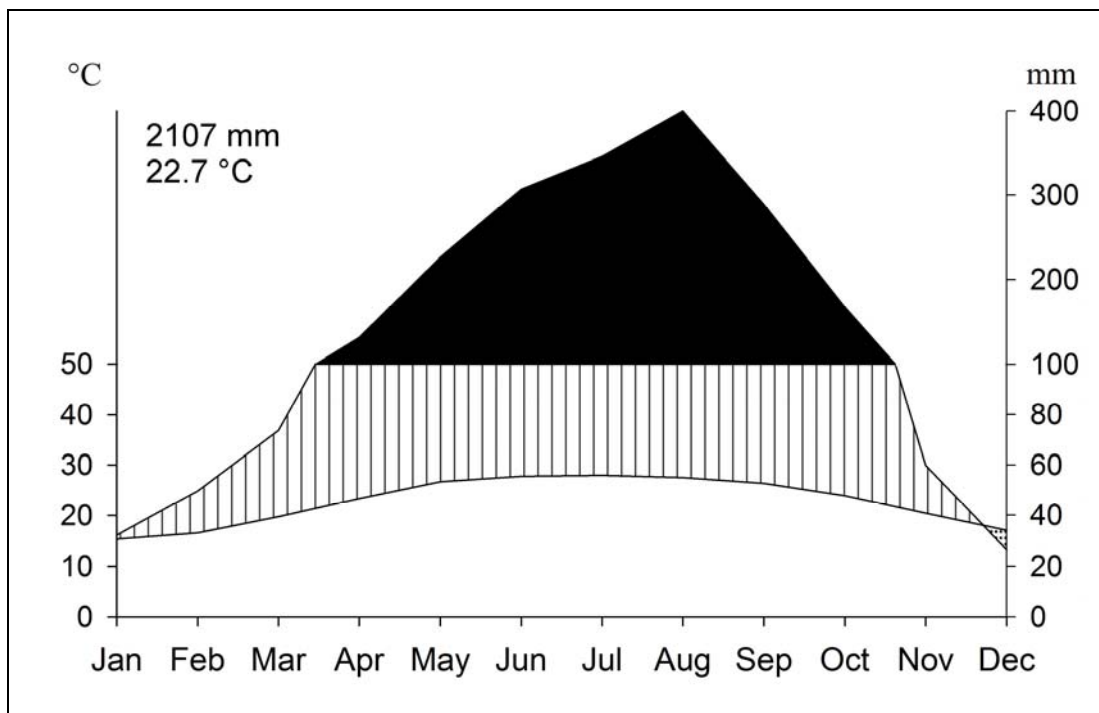


Fig. 3b: Climatic diagram of Yen Binh district (drawn according to Nguyen, 2000)

The Doan Hung district is a midland area with altitudes of about 50 m above sea level. This is a transition area in between the mountainous region and the plains with coordinates of around 21°32' N and 105°11' E. In this area, high limestone mountains are absent, only low hills alternate with small flat regions. Due to the effects of tropical monsoon, the district has four seasons with cold winters and rainy summers. The dry

period lasts 1 to 2 months. The mean annual temperature is 23.1°C, the mean annual precipitation of the area is about 1850 mm, and the relative ambient humidity is about 84%. The monthly average precipitation reaches the maximum of about 383 mm in July and minimum of about 25 mm in December (Nguyen, 2000).

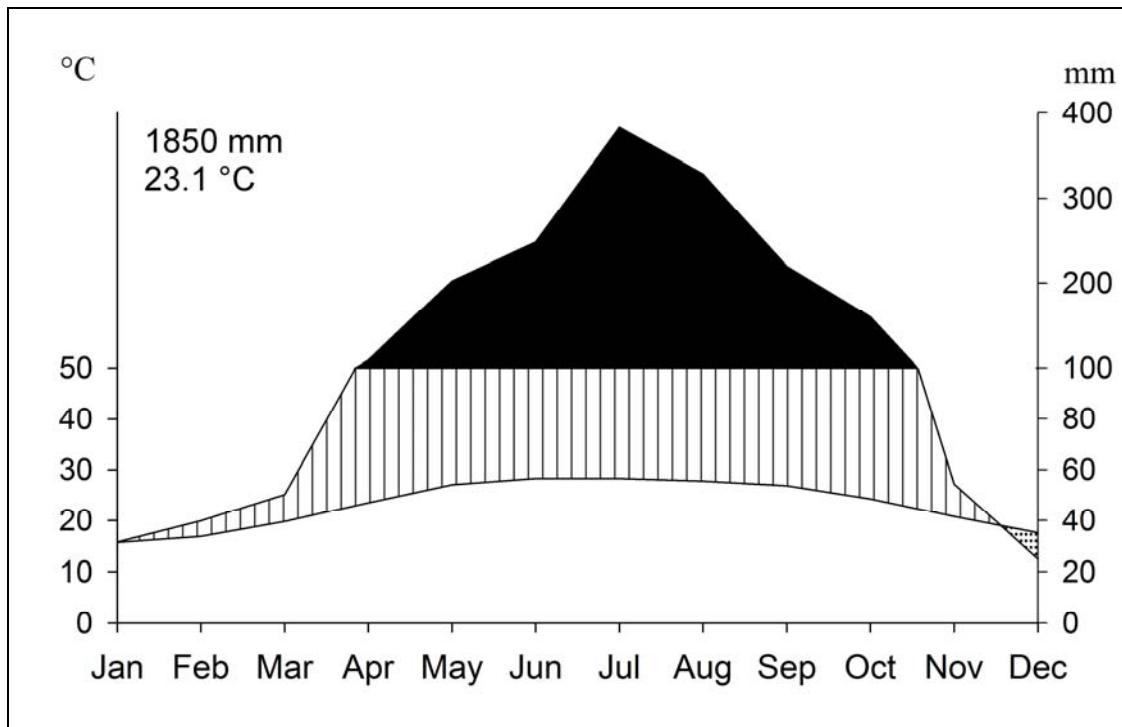


Fig. 3c: Climatic diagram of Doan Hung district (drawn according to Nguyen, 2000)

The Tan Lac district is located at around 20°38' N and 105°12' E, about 150 km Southwest from Hanoi. This is a combination of valleys and high limestone mountains of the Northwest region of Vietnam. As a part of the Truong-Son Range running from Northwest to Southeast, the topography of this region is complex and strongly divided. With the altitude of about 100 m above sea level, this study area has a tropical climate affected by monsoon with cold winter with low rainfall (dry period from 4 to 5 months) and hot summers with abundant rain, (Nguyen, 2000). The mean annual temperature is 23.0°C, the mean annual precipitation is about 1833 mm, and relative ambient humidity is 82% (Nguyen, 2000).

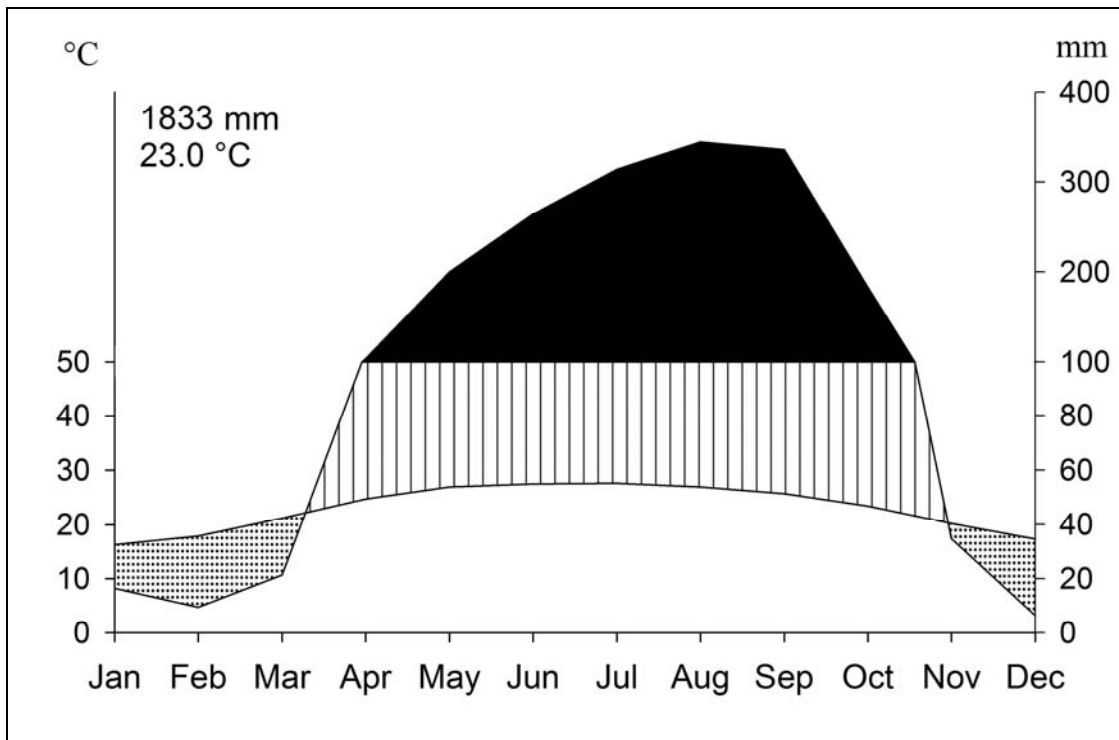


Fig. 3d: Climatic diagram of Tan Lac district (drawn according to Nguyen, 2000)

## 3.2 Study species

In this study, six indigenous bamboo species in the mountainous areas of Northern Vietnam were selected, those species have high economic values or/and satisfy certain requirements of available technologies in Vietnam. Of those, three species are sympodial bamboos; the other two are monopodial and the remaining one is amphipodial. Scientific names, growing habits and correlative areas of the selected bamboo species are presented in table 3.

### 3.2.1 Monopodial bamboo species

*Phyllostachys edulis* Lehaie has some synonyms such as *Bambusa mosoo* Japon ex Sieb, *Bambusa edulis* Carriere, *Phyllostachys mitis* A. et C. Riviere, and *Phyllostachys pubescens* Lehaie. The name *Phyllostachys edulis* Lehaie has been unanimously used

for this species since 2006 (Vu and Le, 2004; Nguyen, 2006). It is a monopodial bamboo (running rhizome) with erect, rounded stems. Each node in the upper part has two branches, one large and one smaller along with two furrows. Culms sheaths are bell shaped with stiff, brown hairs in its outer surface. The auriculars developed with rough margins and the leaves are oblong, with acute apex.

Table 3: Study areas and correlative species in Northern Vietnam

Districts	Species name	Vietnamese name	Growing habit
Tan Lac	<i>Oligostachyum</i> sp.	Lanh anh	Amphipodial
Nguyen Binh	<i>Phyllostachys edulis</i> Lehaie	Truc sao	Sympodial
Yen Binh	<i>Indosasa angustata</i> McClure	Vau dang	Sympodial
Doan Hung	<i>Dendrocalamus latiflorus</i> Munro	Dien trung	Monopodial
	<i>Dendrocalamopsis</i> sp. 2	Tre gay	Monopodial
	<i>Dendrocalamus barbatus</i> Hsueh et D.Z.Li	Luong	Monopodial

*Indosasa angustata* McClure is a member of the genus *Indosasa* and has been known under the name *Indosasa amabilis* McClure. It is a monopodial bamboo (running rhizome) with erect stems. The stems are dark-green, young culms are thickly pruinose. The upper part of stems, with branches, has furrows along the internodes and prominent nodes. Each node has three branches, one developed branch and two smaller at two sides. The outer surface of the culm sheaths is covered by brown hairs, their blade is triangular. The leaf blades are elongated, oblong with acute base. The shoots are edible with bitter taste and are occurring in late winter and spring. In the study sites, *Indosasa angustata* stands develop after the destruction of natural forest, and are managed to produce shoots and culms.

### 3.2.2 Sympodial bamboo species

*Dendrocalamus latiflorus* Munro has two synonyms: *Bambusa atiflora* (Munro) Kurz and *Sinocalamus latiflorus* (Munro) McClure. This sympodial bamboo with scattered clumps has rounded stems with smooth nodes. Young culms are glossy-green and are thickly pruinose, later turn to yellow-green with white spots when mature. Branches develop only in some nodes of the top part; each node has one main and two small branches at two sides. The outer surface of the culm sheath has black hair but the inner surface is glabrous. The sheath blade is lanceolate with an acute long-needle. The auricle is short and small. This species is also called the wide-leaf bamboo because its leaf dimension is about 20 to 50 cm length and 5 to 10 cm width. The leaf blade is elliptical to oblong-lanceolate with smooth hairs.

*Dendrocalamus barbatus* Hsueh et D.Z.Li has a synonym (*Dendrocalamus membranaceus* Munro) and belonged to the genus *Dendrocalamus*. It is a sympodial bamboo with erect cylindrical green stems. The nodes have one main and 2 to 5 small branches. The base of the main branches is always swollen with developed aerial roots. The outer surface of sheaths has dense brown to purple hairs. The sheath blades are lanceolate and recurved with hair on both surfaces. The auricles are developed and covered by brown hair. Leaves are wedge and shaped with 6 to 8 parallel veins. Shoots are edible and densely covered by brown-purple hairs. In Vietnam *Dendrocalamus barbatus* grows naturally in the Thanh Hoa Province but are planted widely in the E of the country. It is mainly used for house construction, pulp, paper, activated charcoal and food.

*Dendrocalamopsis* sp.2, a sympodial bamboo, belongs to genus *Dendrocalamopsis*. Young stems are covered by smooth, reddish hairs. The internodes at the middle culm have larger diameters than others. The nodes are prominent swelling and each upper node has one long straight main branch and 1 to 3 small undeveloped branches. The outer surface of the culm sheaths are covered by reddish-purple hair when young and turning black when mature. The sheath blades have sharp-pointed tips and the auricles



are developed and densely covered by tiny hairs. The leaves are wedge shaped with 8 to 10 parallel veins. The shoots are edible, covered by dark-brown hairs.

### **3.2.3 Amphipodial bamboo species**

The amphipodial bamboo (so-called the running bamboo) is the mixture of sympodial and monopodial groups. In this study, *Oligostachyum* sp. was selected as a representation of this group. This species is a member of the genus *Oligostachyum* that grows scattered in small groups of two or three culms. In the upper part, each node usually has three branches, one main and two smaller in two sides. The culm sheaths are brown and covered by grey-yellow hairs. The leaves have acute apex and wedge shaped bases with four to five pairs of veins. In Hoa Binh Province, *Oligostachyum* sp. stands were developed from nature forest, after forest exploitation or/and shifting cultivation activities. Those stands nowadays become house-timber as forest garden mainly managed to produce shoots and culms.

### **3.3 Data collection**

#### **3.3.1 Management system analysis**

The necessary information of bamboo management systems includes the activities and time schedule of seeding, planting, tending, pruning and harvesting, etc. These data are collected via field surveys in three steps as follow:

- 1) Step 1: Collecting available relevant documents about bamboo management systems and elaborating semi-structure questionnaires.
- 2) Step 2: Usage of the semi-structure questionnaires. Farmers who own the bamboo stands are interviewed to gain the local knowledge of bamboo management systems. The field work process was completed when no new information was obtained further. The number of interviewees was not fixed.
- 3) Step 3: Classifying and revising the collected data.

#### **3.3.2 Stand inventory**

For the analysis of the stand structure, stand inventories were carried out. In the study sites, the sampling stands were selected separately for each bamboo species. The selected stands were pure planted bamboo stands in mature state and visibly unaffected by pests and diseases.

The sample plots were set up in squares of 20 x 20 m. For each species, nine sample plots were randomly selected. For each of sample plots, important information was collected as follow:

For monopodial and amphipodial bamboo species, the total number of culms was counted. For sympodial bamboo species, the total number of culms was counted in each clump, and the total number of clumps was recorded as well.

The age of the culms was identified based on experience of foresters by using a combination of three methods: (1) judging of culm colour, (2) counting twigs scars and (3) determining the position of the culms. Further the diameter at the middle of internodes at breast height of all culms was measured with a caliper. For each study species, one representative sample plot was selected to measure the height of all culms using a meter stick.

### 3.3.3 Cut culm measurement

For each of sample plots, four culms in four different age classes were randomly selected (36 culms per species). After measuring their culm height ( $h$ ) and diameter at breast high ( $d$ ) they were cut to count the total number of internodes per culm ( $I$ ) and measure the total culm length ( $l$ ), culm wall thickness ( $t$ ) of the internode at breast high,

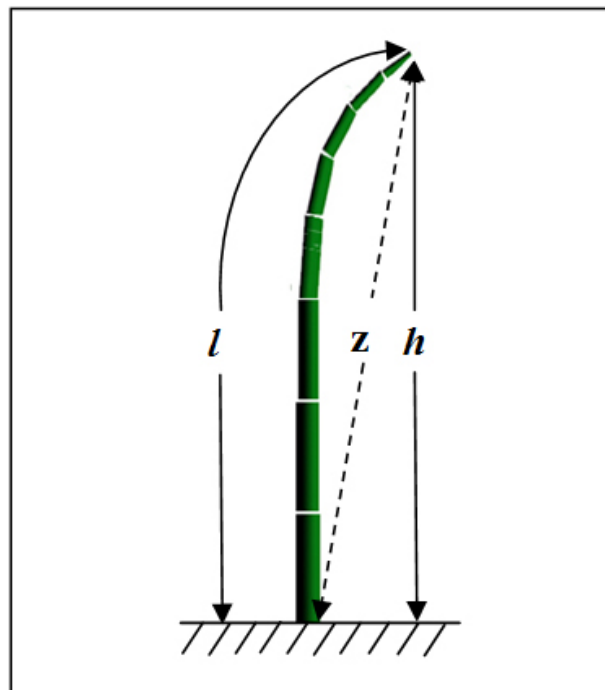


Fig. 4: Measurement of cut culms ( $h$  = the culm height;  $l$  = the total culm length;  $z$  = the linear distant)

The total curvature of bamboo culms has been estimated by Camargo (2006) based on the total culm length ( $l$ ) and the linear distant ( $z$ ) (the distant between the base and the apex) (Fig. 4), and the total curvature was calculated as  $C_v(\%) = 1 - (z/l) \times 100$ . In this study, the culm height ( $h$ ) (the vertical distance from the ground to the top of the culm) is used instead of the linear distant because it is one of the main investigative factors of the standing culms, and the total curvature was calculated following the formula 1.

$$C_v(\%) = 100 \times \left( 1 - \frac{h}{l} \right) \quad (1)$$

Where:  $C_v$  = the curvature (%);  $h$  = the culm height (m);  $l$  = the culm length (m)

### 3.3.4 Determination of physical properties

At the height of 3 meters from the base of each cut culm, a section of six internodes (three above and three under the point of three meters) was cut for analysis of physical and mechanical properties.

The physical properties of bamboo culms including their moisture contents (MC) and basic wood density ( $\rho$ ) were tested in four age classes (from age one to age four) using 30 samples for each age class.

$$\rho(g/cm^3) = \frac{1}{1000} \times \frac{DM}{V} \quad (2)$$

Where:  $\rho$  = basic wood density ( $g/cm^3$ )  
 $V$  = volume in fresh state ( $mm^3$ )

The specimens used for the basic wood density test were 15 mm wide, 15 mm long and as thick as culm wall thickness. The results were calculated according to Le (1998) (the formula 2)

The specimens used to determine moisture content were about 25 mm wide, 25 mm long and as thick as culm wall thickness. The results were calculated according to Le (1998) (the formula 3).

$$MC(\%) = \frac{FM - DM}{DM} \times 100 \quad (3)$$

Where: MC = moisture content (%)  
 FM = the mass of the sample in fresh state (g)  
 DM = the mass of the sample after drying (g)

### 3.3.5 Determination of mechanical properties

The mechanical properties including bending strength ( $f_m$ ) and compression strength ( $\sigma$ ) of bamboo culms were tested and calculated basing on the standard TCVN 356-70 of Vietnam using *Universal Testing Machine* MTS QT/25 (USA) in the wood laboratory of the Forestry University of Vietnam. Mechanical characteristics of bamboo culms were analyzed in the four different age classes (from age one to age four); within each age class 30 samples were tested.

In general, bamboo culm is a thin-walled hollow cylinder separated by nodes. In this study, we used straight internodes which were dried to 12% moisture content, then divided into test pieces. The specimens used for the analysis of the bending strength have dimensions of 12 mm in width (tangential direction), 200 mm in length (longitudinal direction) and their depth (radial direction) was equal to culm wall thickness.

The specimens used for compression test have the prism form taken from internodes which were dried up to 12% moisture content. The dimensions of the test pieces were 15 mm in length (tangential direction), 15 mm in depth (longitudinal direction) and their width as culm wall thickness (radial direction).

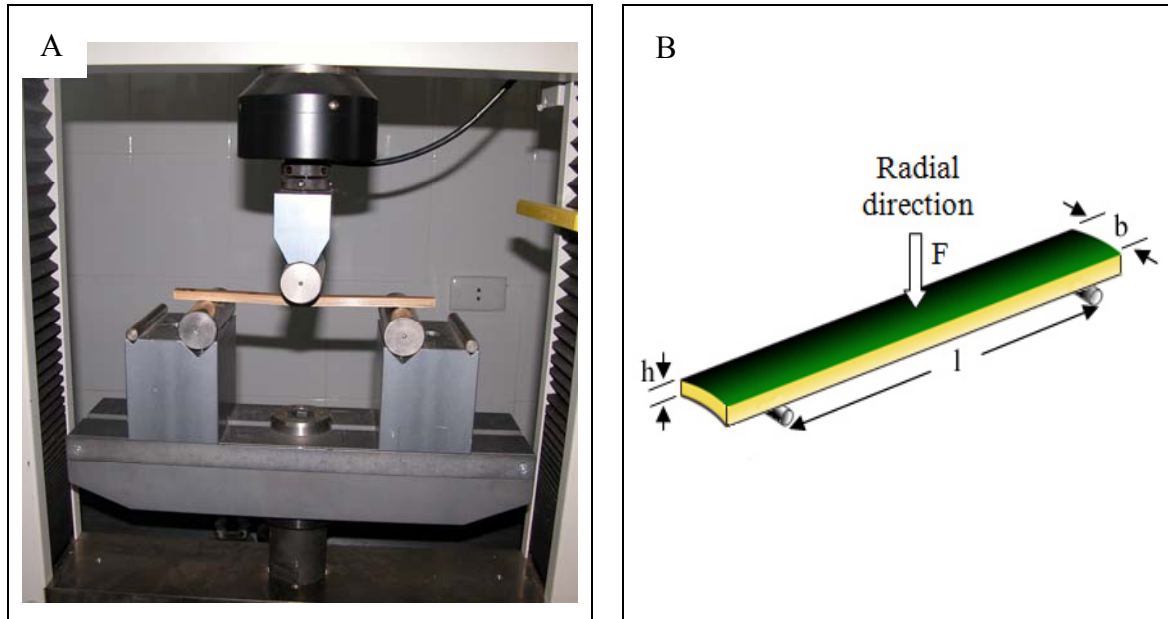


Fig. 5: Bending test

A – *Universal Testing Machine* MTS QT/25 for bending test

B – the bending test piece

F = the direction of the strength; l = the free span; b = the width; h = the depth

A three-point bending test was conducted by applying a cylindrical loading head that attaches to the middle point of the upper surface (outer layer) and two parallel cylindricalities support to the under surface (inner layer) of the test pieces. Therefore, the specimens were radially loaded. The specimens were placed with outer layer upward, inner part laid on the two cylindrical supports. The distance between the centers of the two supports was 150 mm free span and the crosshead speed was 10

mm/min. The results were calculated according to the standard EN 310:1993 and Le (1998) (the formula 4).

$$f_m (N / mm^2) = \frac{3}{2} \times \frac{F_{\max} \times l}{bh^2} \quad (4)$$

Where:  $f_m$  = bending strength (N/mm<sup>2</sup>);

$F_{\max}$  = the maximum load at which the sample fails (N);

$l$  = the free span (mm);  $b$  = the width (mm);  $h$  = the depth (mm)

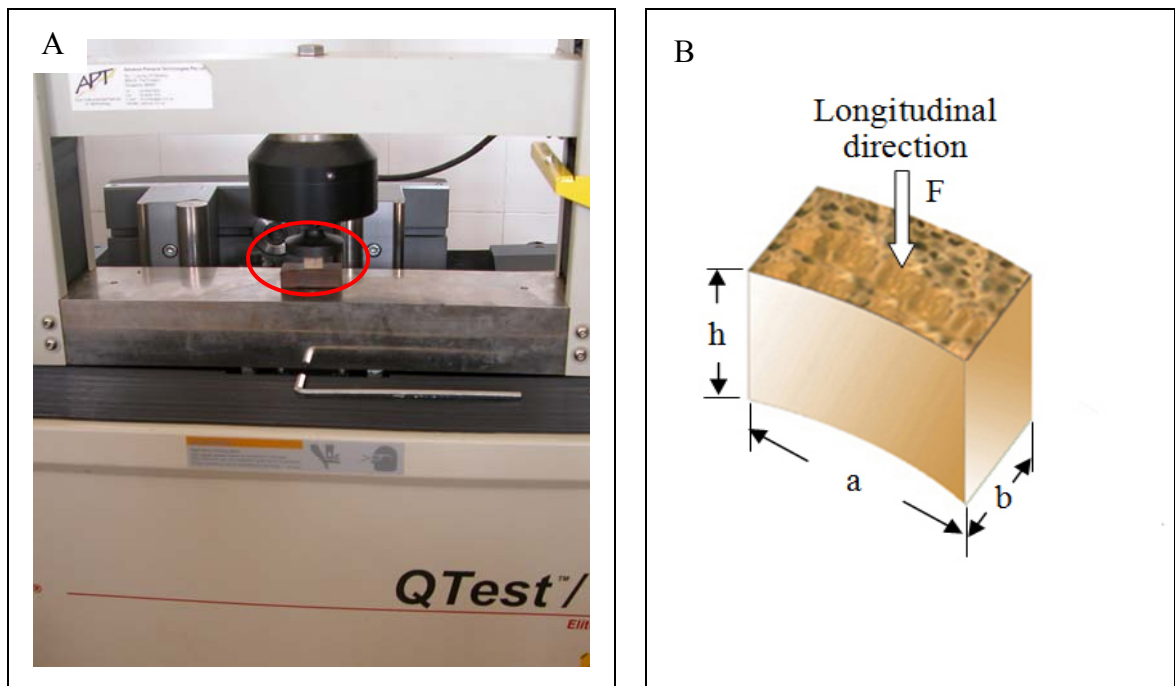


Fig. 6: Compression test

A – *Universal Testing Machine* MTS QT/25 for compression test

B – the compression test piece

$F$  = the direction of the strength;  $a$  = the length;  $b$  = the width;  $h$  = the depth

A longitudinal compression test was organized with two steel platens of the testing machine, one attaching upper surface and the other supporting under surface of the test pieces. The results were calculated according to Le (1998) (the formula 5).

$$\sigma ( N / mm^2 ) = \frac{F_{\max}}{a \times b} \quad (5)$$

Where:  $\sigma$  = compression strength (N/mm<sup>2</sup>);

$F_{\max}$  = the maximum load at which the sample fails (N);

a = the length (mm); b = the width (mm); h = the depth (mm)

### 3.3.6 Soil analysis

To achieve some information about the general soil conditions of the research areas, some physical and chemical characteristics of soil were analyzed. The soil samples were taken at the depth of 35 cm because the soil layer from the ground to 35 cm is obviously important for bamboo growth due to the rhizome systems of all most bamboo species develop at that depth (Xiao, 1991; Fu, 2001). The investigated parameters of soil were:

- Soil texture (sand, silt and clay, presented in %)
- Hydrolysis acidity (Hs ldl/ 100g)
- Organic materials (OM %)
- Soil pH
- Cation exchange capacity (CEO in meq/100g soil)
- Major nutrients (NH<sub>4</sub><sup>+</sup>, K<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub> in mg/100g soil)



For each bamboo species, nine soil samples were taken using soil augers at the center of the 9 field plots, and then all the soil samples were labeled and kept in plastic bags for transportation. Further processing including physical and chemical analysis was carried out at the laboratory of the Forestry University of Vietnam.

### 3.3.7 Plant osmotic potential analysis

Six individual bamboo culms were randomly selected from each of bamboo stands during the dry season (from November to December) to analyze the leaf osmotic potential at midday and in the state of full water re-saturation.

Leaf samples were directly collected at 12h00 to 13h00 and a part of these were full water re-saturated (leaves were taken from branches which were cut and re-saturated with distilled water for 24 hours). Eight to ten grams of fresh leaves were taken from sun exposed branches in the North exposition, at insertion heights of 6 to 8 m. After plucking up, the leaves were weighed in the fresh state immediately then killed off by using a mobile gas stove to avoid enzymatic changes. All samples were labeled and kept in waterproof bags for transportation. Further processing was carried out at the laboratory in Goettingen following the standard processing described by Kreeb (1990) using a semi-micro osmometer (Knauer, Berlin, Germany).

Following Kreeb (1990), the osmotic potential  $\Psi_{\pi}$  in (MPa) in a solution is proportional to the depression of the solution's freezing point  $\Delta_t$  ( $^{\circ}\text{C}$ ) and it was calculated following the formula (6).

$$\Psi_{\pi} = 0.1013 \times [0.021 (\Delta_t)^2 - 12.06 \Delta_t] \quad (6)$$

Where:  $\Psi_{\pi}$  = osmotic potential

$\Delta_t$  = the depression at freezing point that is measured by cryoscopy

Related to the temperature of 0°C, the equation was adapted to the actual air temperature at plant sampling time in the field. According to Kreeb (1990), the osmotic potential at t°C was calculated following the formula (7)

$$\Psi_{\pi, t^{\circ}\text{C}} = \Psi_{\pi, 0^{\circ}\text{C}} \times \frac{1 + t_{\circ}\text{C}}{273} \quad (7)$$

Where:  $\Psi_{\pi, 0^{\circ}\text{C}}$  = osmotic potential at 0°C  
 $\Psi_{\pi, t^{\circ}\text{C}}$  = osmotic potential at t°C

## **4 Results and discussion**

### **4.1 Site requirement**

#### **4.1.1 Plant osmotic potential**

Climate and soil induced salinity can be considered as a natural process. Being more severe as drier the climate, the environment is covered with adapted vegetation that evolved to cope with the site factors of periodical drought and salt excess or high soil solute concentration (Milöhner and Köpp, 2007). An essentially necessary condition for the osmotic transport of water inside plants is that the internal concentration in plants has to correspond with the concentration of the soil solution (Truong et al., 2003). Evidently, the variation of the soil solution has its effects on plant growth and their yields (Dirksen, 2004; Aceves-N, 2006)

As a condition to build up a site-adequate concentration within their cell plants must take up salts from the soil and/or synthesize sugar and organic acid within the cells (Fu, 2001). Hence, the osmotic potential within the plant reflects the water and salt situation of soils (Mitlöhner, 1998; Truong et al., 2003). Therefore, the plant osmotic potential can be supposed to be a measure of the adaptation of plants towards the salt and/or solute concentration of the site (Fu, 2001; Truong et al., 2003). Measuring osmotic potential can also be used to study not only site conditions but also plant characteristics to match plant species to sites or to diagnose the adaptation of plant species in relation to environment (Mitlöhner, 1997; Milöhner and Köpp 2007).

The osmotic potential of a solution is always negative and is thus lower than water potential of pure water, which is zero (Fu, 2001). So, the higher the negative number (the smaller the number, or the more negative) of the osmotic potential of a solution, the more concentrated the solution is (Krug, 2004). This concept also means the higher the negative value, the stronger the osmotic potential or the stronger the capability of the cell's solution to suck water in.

For the plant's life, while the content of dissolved salts, sugars and organic acids, etc. in the cells solution is relatively stable, the water content is a continuous variable, mainly due to the changes of the air temperature. Therefore, the value of osmotic potential within the plants is almost depended on the water content in the cells. Theoretically, the plant osmotic potential attains its relative minimum value (the furthest negative value from zero) at noon due to water loss inside the cells during the daytime causing the increase of the concentration of the cytoplasm solution, whereas it reaches relative maximum value (the closest negative value from zero) at night when the temperature decreases, stomata close and water in the cells is re-saturated (Fu, 2001).

According to Milöhner and Köpp (2007), it is expected that the maximum value of plant osmotic potential in the state of full water re-saturation reflects the actual water and salt situation of the soil. To obtain these data, for each bamboo species, in dry season the branches with leaves of six individual stems were cut and re-saturated with distilled water. To prevent evaporation, the cut branches were covered with black plastic bags. From those branches, leaves samples were collected. In contrast, the minimum value of osmotic potential reflects the water and salt situation of the plant which is measured from the leaves samples collected directly from the six same bamboo stems around midday.

For the six bamboo species, the mean values of midday osmotic potential are all more negative than the mean values of saturated osmotic potential. The results perfectly fit with the general rule as mentioned above, showing the demand on water of bamboos at midday is stronger than in the state of water saturation. This result corresponds with the publication of Jensen (2004) that the variation of transpiration rate has a close relationship with osmotic adjustment which helps plants maintain turgor to withstand drought.

As shown in Fig. 7, *Phyllostachys edulis* has an outstanding osmotic potential presented by not only midday but also saturated values (-2.32 MPa and -2.29 MPa respectively). It

is concluded that this species grows under the site conditions that have the highest soil concentration of osmotically active solutes among the six bamboo species.

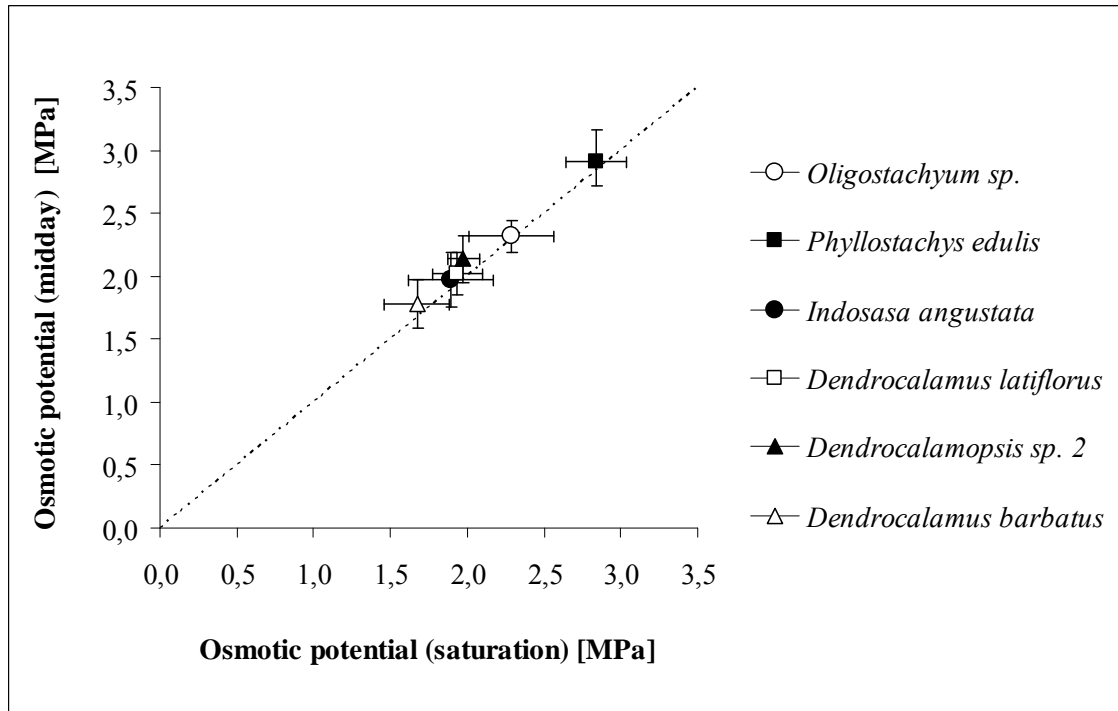


Fig. 7: Mean values and standard deviation of midday and saturated negative osmotic potentials of bamboo species in Northern Vietnam

The mean values of osmotic potential of *Phyllostachys edulis* in this study is 4 times higher than the values of this species (under the name *Phyllostachys pubescens*) recorded in the North of Fujian Province, South China with the values of -0.88 MPa at midday and -0.63 MPa at pre-dawn (Fu, 2001). This significant difference can be expressed by some reasons as following: firstly it is affected by the distinct characteristics of each study site. In dry seasons the minimum precipitation values of Fujian Province are 201, 272 and 407 mm in March, April and May respectively (Fu, 2001) whereas the mean precipitation in Cao Bang Province goes down to 35, 40 and 39 mm in December, January and February respectively (Nguyen, 2000). Secondly, this

difference of the values of osmotic potential in the two study sites may be influenced by the study times (when the leaf samples were taken off) as well.

According to Aceves-N (2006), the variations of the salt concentration of the soil solution cause substantial changes in both morphology and physiology of plants. Therefore, the significant differences in osmotic potential of *Phyllostachys edulis* between the two study areas indicate the reliable difference in its morphological characteristics. The observed data about the stand height of *Phyllostachys edulis* planted in this study show the values 11.0 m whereas Fu (2001) recorded its stand height measured in Fujian Province was 12.6 m. This difference leads to the conclusion that although this was some variations on morphology, the species *Phyllostachys edulis* seem to be able to change its habit to adapt to some different site conditions.

Among the six study species, *Oligostachyum* sp. has lower negative osmotic potential than *Phyllostachys edulis* (both midday and saturated values) but considerably higher than the other four species. It appears that, the site conditions of *Oligostachyum* sp have the noticeable different characteristics in comparison with that of the others. The other three species including *Dendrocalamus latiflorus*, *Indosasa angustata*, and *Dendrocalamopsis* sp. 2 can be arranged in the same group which has low osmotic potential values. The species *Dendrocalamus barbatus* has the smallest negative osmotic potential values (-1.78 MPa at midday and -1.67 MPa in the position of water saturation) among the six study species.

In summary, with different values of osmotic potential, each species adapted itself to different site conditions. Of the six species, *Phyllostachys edulis* grows under the site conditions with the highest soil concentration of osmotically active solutes in comparison with the sites of the other species. The group of *Indosasa angustata*, *Dendrocalamus latiflorus*, *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* can grow under about the same site condition with poorer soil concentration and *Oligostachyum* sp. is in between.

As shown in table 4, the mean values of saturated osmotic potential of the six bamboo species range from -2.84 MPa (*Phyllostachys edulis*) to -1.67 MPa (*Dendrocalamus barbatus*) and their mean values of midday osmotic potentials range from -2.92 MPa (*Phyllostachys edulis*) to -1.78 MPa (*Dendrocalamus barbatus*). These values are more negative than that of five tree species growing in moisture evergreen forest, SE of Vietnam reported by Truong et al. (2003).

Table 4: Mean and standard deviation of midday and saturated plant osmotic potentials ( $\Psi_{\pi}$ ) of bamboo species in comparison to results of previous study in Vietnam

Species	$\Psi_{\pi}$ (MPa)	
	Midday	Saturated
<i>Oligostachyum</i> sp.	-2.32 ± -0.12 (6)	-2.29 ± -0.28 (6)
<i>Phyllostachys edulis</i>	-2.92 ± -0.25 (6)	-2.84 ± -0.20 (6)
<i>Indosasa angustata</i>	-1.97 ± -0.22 (6)	-1.89 ± -0.27 (6)
<i>Dendrocalamus latiflorus</i>	-2.02 ± -0.17 (6)	-1.94 ± -0.16 (6)
<i>Dendrocalamopsis</i> sp. 2	-2.14 ± -0.19 (6)	-1.98 ± -0.10 (6)
<i>Dendrocalamus barbatus</i>	-1.78 ± -0.19 (6)	-1.67 ± -0.21 (6)
Moisture evergreen forest, Southeast Vietnam (10°27'57'' - 10°37'46''N; 107°24'31'' - 107°36'07''E) (Truong et al., 2003)		
<i>Dipterocarpus caudatus</i> Foxw.	-0.80 ± -0.30 (6)	-0.60 ± -2.00 (6)
<i>Shorea roxburghii</i> G.Don	-1.10 ± -0.30 (6)	-0.90 ± -0.10 (6)
<i>Diospyros candolleana</i> Thwaites	-0.60 ± -0.10 (6)	-0.30 ± -0.10 (6)
<i>Dipterocarpus caudatus</i> Foxw.	-0.80 ± -0.30 (6)	-0.60 ± -0.20 (6)
<i>Hopea odorata</i> Roxb.	-0.50 ± -0.30 (6)	-0.30 ± -0.10 (6)

Although the values of plant osmotic potential varies due to species, study time, and growing conditions (the SE Vietnam has a tropical climate with two distinguished

seasons (rainy season from May to October and dry seasons from November to April), the differences between plant osmotic potential of the six bamboo species and the four tree species reported by Truong et al. (2003) lead to a remark that in winter bamboos in Northern Vietnam withstand the harder site conditions with high soil solute concentration in comparison with the sites of the four tree species in the Southeast Vietnam.

In addition, the differences between mean values of midday and saturated osmotic potential of the six bamboo species are not significant ( $p > 0.05$ ). The different values of *Phyllostachys edulis*, *Indosasa angustata*, *Dendrocalamus latiflorus* and *Oligostachyum* sp. range from -0.08 to -0.03 MPa and these of *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* is slightly larger (-0.16 and -0.11 MPa, respectively). This led to the preliminary remarks that at the study time salt concentration of soil and cell solution of the four bamboo species (*Phyllostachys edulis*, *Indosasa angustata*, *Dendrocalamus latiflorus* and *Oligostachyum* sp.) were slightly different. It was also assumed that the water supply from the soil for these four species was relatively favorable, while the water conditions of *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* were slightly harder but the stressful water situation of their sites was not very high. The six bamboo species showed close relatively high adaptation toward their site conditions.

#### **4.1.2 Soil**

Soils in the site of *Oligostachyum* sp. species are Acrisols (FAO – UNESCO classification). The soil is generated from limestone and sandstone, soil texture is silty clay (47% clay, USDA texture triangle). Soils of the site are lightly acidic with pH of about 4.7 and the cation exchange capacity is 5.65 meq/100g soils. This area has been affected by the over-cropped process, so that soils become infertile with light-brown in color and quite low humus content (3.8%).



In case of *Phyllostachys edulis*, soils are mainly humic acrisols generated from limestone or/and gneiss with grey color. The texture of soils in this area is clay (57% clay). With pH of about 4.6, the soils are lightly acidic. Among six sample plots, *Phyllostachys edulis* has the highest hydrolysis acidity value (16.10 ldl/100g soils) and cation exchange capacity value (8.32meq/100g soils). Distributed on high mountains, low temperature and high humidity, the decomposition process of organic substance is strong, so the humus content of the soils is richer than that of the other sites (4.7%). However, because of high slope, the soil erosion process is violent together with the weak weathering process, so the soil layer is normally thin.

Table 5: Soil properties of sample plots in 35 cm depth in Northern Vietnam

Study sites	pH (kcl)	NH <sub>4</sub> <sup>+</sup> (mg/ 100g)	K <sub>2</sub> O (mg/ 100g)	P <sub>2</sub> O <sub>5</sub> (mg/ 100g)	CEC (meq/ 100g)	OM (%)	Hs (ldl/ 100g)
<i>Oligostachyum</i> sp.	4.7	4.46	2.56	0.67	5.65	3.8	9.14
<i>Phyllostachys edulis</i>	4.6	3.35	4.11	1.70	8.32	4.7	16.10
<i>Indosasa angustata</i>	4.1	4.05	5.63	3.71	5.88	3.1	15.23
<i>Dendrocalamus latiflorus</i>	4.9	9.67	7.63	0.72	5.56	3.7	5.39
<i>Dendrocalamopsis</i> sp. 2	4.5	4.63	2.57	0.62	7.32	2.0	11.31
<i>Dendrocalamus barbatus</i>	4.5	2.66	2.04	0.66	4.72	2.3	8.75

Where: CEC = cation exchange capacity; OM = organic material;  
Hs = hydrolysis acidity

The soils in the site of *Indosasa angustata* are mainly acrisols which is poorly generated from gneiss. The soil texture is silty clay (46% silt/45% clay) with grey-brown color. With pH value is 4.1 this site has the weakest acidity in comparison with other sites. The humus content of this site is also low (3.1%) and the cation exchange capacity is only 5.88 meq/100g soils. However, the values of nitrogen (N), phosphorus (P) and

potassium (K) in this site are quite high and equal, especially, the value of P<sub>2</sub>O<sub>5</sub> of this site is highest (3.71 mg/100g soils) in comparison with that of others.

Table 6: Soil particle sizes of soil sample plots in 35 cm depth in Northern Vietnam

Study sites	Soil texture		
	Sand (%)	Silt (%)	Clay (%)
<i>Oligostachyum sp.</i>	9	44	47
<i>Phyllostachys edulis</i>	5	38	57
<i>Indosasa angustata</i>	9	46	45
<i>Dendrocalamus latiflorus</i>	12	45	43
<i>Dendrocalamopsis sp. 2</i>	8	44	48
<i>Dendrocalamus barbatus</i>	15	44	44

Three sample plots of *Dendrocalamus latiflorus*, *Dendrocalamopsis sp. 2* and *Dendrocalamus barbatus* were all obtained from the Doan Hung District. The sites of those species have ferralsols soils generated from gneiss and mica schist. The soil texture is silty clay yellow or yellowish-brown in color. The pH values of *Dendrocalamopsis sp. 2* and *Dendrocalamus barbatus* are the same (4.5) when *Dendrocalamus latiflorus* has the highest pH value (4.9) in comparison with the others. All the three sites have low humus content, of which *Dendrocalamopsis sp. 2* have the lowest humus content value of 2.0%, this value of *Dendrocalamus barbatus* is slightly higher (2.3%).

#### 4.1.3 Climate

*Oligostachyum sp.* grows naturally in secondary forests of Hoa Binh Province with the annual average temperature of 23.0°C; the mean daily temperature is 27.6°C in the

warmest month and 16.3°C in coldest month. This species can withstand drought from 3 to 5 months in a year when mean precipitation goes under 10 mm per month. This species is also distributed in Yen Bai, Phu Tho, and Thanh Hoa Provinces. In woody forests, if the canopy is opened by serious timber exploitations, this species invades very fast and occupies the whole openings. *Oligostachyum* sp. adapts to tropical climate with cold winter and low rainfall, hot summer with heavy rain. The mean annual temperature varies from 14 to 22°C (Do, 2000).

*Phyllostachys edulis* is mainly distributed in the Cao Bang Province where the climate is sub-tropical with two distinct seasons, hot rainy and cold dry seasons. The annual average temperature is about 20°C. The mean annual precipitation is approximately about 1700 mm. This species naturally grows in mountainous areas of the N of Vietnam like Bac Can, and Ha Giang Provinces on the limestone mountainous area at elevations of 400 to 800 m, sometimes up to 1000 m above sea level (Nguyen, 2006) and has been successful planted in Lang Son and Quang Ninh at elevations of 400 to 1400 m above sea level (Do, 2006). *Phyllostachys edulis* can withstand temperature lower than zero, and adapts to the sites with soil generated from limestone, gneiss, and mica schist (Do, 2000).

*Indosasa angustata* grows naturally in the mountain areas of the N of Vietnam. Yen Bai Province is one of the main distribution areas of the species with the mean annual temperature of about 23°C. The species grows well in the tropical climate areas with high moisture, annual average precipitation ranging from 2000 to 4700 mm, soil generated from gneiss or mica schist with pH of about 3.2 to 4.6 (Do, 2000). *Indosasa angustata* has been planted in Son La, Hoa Binh, and Thanh Hoa Provinces at elevations of 700 to 800 m. It is a shade bearer, prefers moist site, and grows better under the canopy of secondary forest on the base of hills or valley areas than in opening forest with more light (Nguyen, 2006).

*Dendrocalamus latiflorus* is widely planted in central areas of the North Vietnam and nearby areas. It grows well in Phu Tho, Tuyen Quang, and Yen Bai Provinces on the

soil generated from gneiss or mica schist (Do, 2006), at elevations of 70 to 80 m above sea level (Do, 2006; Nguyen, 2006). This species adapts to the midland areas with tropical climate, the annual average precipitation varies from 1800 to 2000 mm, the annual average temperature ranging from 16.3 to 27.6 °C.

*Dendrocalamopsis* sp. 2 has been successfully planted to produce bamboo shoot products in the Phu Tho Province in tropical climate with the annual average temperature of approximately 23°C and the mean annual precipitation of about 1800 mm. In this Province, it grows well in low hills with thick soil layer, pH of about 4.5. The species has been also planted in Central North Vietnam like Quang Tri and Hue Provinces, at elevations of 100 to 500 m above sea level (Do, 2006).

*Dendrocalamus barbatus* is naturally grown in Son La (along the Ma River) and Thanh Hoa Provinces (Do, 2000; Nguyen, 2006). It is planted widely in the North Vietnam, within and outside its natural distribution, and develops well on the sites with ferralsols generated from limestone, phyllite, and old sediment, pH of about 3.5 to 7.0 (Le, 2000) at elevations of 800 m above sea level (Do, 2006). The main distribution areas of the species have warm, moist climate with dry winter and rainy summer. Mean annual precipitation is about 1600 to 2000 mm (Do, 2000). *Dendrocalamus barbatus* is a light demander so it can not grow under the canopy of other plants (Le, 2000).

## 4.2 Stand structure

### 4.2.1 Accuracy and error of bamboo culms assessment

In this research, each forest stand was inventoried with 9 plots of 400 m<sup>2</sup> each. To assess if those 9 plots are homogeneous in term of bamboo culm density (total number of culms per hectare), the standard deviation of the mean was estimated. To make sure if the inventory design resembles the whole bamboo stand, the standard error of the mean was calculated as well.

The standard deviation, standard error and standard error in percentage are calculates as following in formulas (8; 9; 10).

$$SD = \sqrt{\frac{\sum_{i=1}^n (y_i - \bar{y})^2}{n - 1}} \quad (8)$$

$$SE = \frac{SD}{\sqrt{n}} \quad (9)$$

$$SE \% = \frac{SE}{\bar{N}} \times 100 \quad (10)$$

Where:

- SD = The standard deviation of the mean
- SE = The standard error of the mean
- SE% = The standard error as a percentage
- n = Number of sample plots (sample size)
- $\bar{N}$  = The mean value

Table 7: Standard deviation (SD) and standard error (SE%) of the mean bamboo culm density of 9 plots of 400 m<sup>2</sup> each of the six different bamboo stands in Northern Vietnam

Species	Sample size (n)	Culm density $\bar{N} \pm \text{SD}$	Standard error (SE%)
<i>Oligostachyum sp.</i>	9	7498 ± 399	1.8
<i>Phyllostachys edulis</i>	9	4408 ± 319	2.4
<i>Indosasa angustata</i>	9	2419 ± 191	2.6
<i>Dendrocalamus latiflorus</i>	9	1739 ± 111	2.1
<i>Dendrocalamopsis sp. 2</i>	9	1781 ± 118	2.2
<i>Dendrocalamus barbatus</i>	9	1733 ± 170	3.3

According to Zöhrer (1980) the inventory design resembles the whole forest stand in a sufficient way if the standard error of the mean (here: bamboo culm density) is below 10%. In this study, the standard error of the mean of 9 sample plots per bamboo stand (presented in table 7) indicates that the high precision of sample plot design representing the whole stand of each bamboo species.

#### 4.2.2 Mean diameter

The mean diameter is a parameter in silvicultural stand investigation and indicates structural characteristics of the forest stands. For a bamboo species, the mean diameter is considered as a stable factor indicating its characteristic. Therefore, it is an important indicator showing the quantitative characteristics of the bamboo stands at a certain time. According to Van Laar and Akca (1997) there are several methods to calculate the mean

diameter of a stand, of which the quadratic mean diameter (calculated as formula 11) and the arithmetic mean diameter (calculated as formula 12) are commonly used.

$$d_g = \sqrt{\frac{\sum_{i=1}^n d_i^2}{n}} \quad (11)$$

$$\bar{d} = \frac{\sum_{i=1}^n d_i}{n} \quad (12)$$

Where:  $d_g$  = quadratic mean diameter  
 $\bar{d}$  = arithmetic mean diameter  
 $d_i$  = diameter of individual tree  
 $n$  = total number of trees of the stand

The observed data of quadratic and arithmetic mean diameters of the six bamboo stands show that the two formulas used to calculate the mean diameters have different results. The quadratic mean diameter of each bamboo stand is slightly higher than its arithmetic mean diameter, whereas their standard deviations are similar (table 8). However, the quadratic mean diameter is generally more favored than the arithmetic mean diameter because it relates directly to the total basal area.

Based on the values of the quadratic mean diameter, the study stands can be divided into three groups: the first group has high quadratic mean diameters including the stands of the three sympodial species (*Dendrocalamus latiflorus*, *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus*) with the mean diameter above 8 cm. The second group has the medium size of quadratic mean diameter including the stands of two monopodial species (*Phyllostachys edulis* and *Indosasa angustata*) with the mean diameter values of 5.6 and 6.1 cm, respectively. The last group bears the stand of the amphipodial species (*Oligostachyum* sp.) with the smallest size of quadratic mean diameter of 5.1 cm. This

leads to a preliminary conclusion that the size of diameter of sympodial species is higher than those of monopodial and amphipodial species.

Table 8: Mean and standard deviation of the quadratic mean diameter ( $d_g$ ) and the arithmetic mean diameter ( $\bar{d}$ ) of bamboo stands (n = 9 sample plots) in Northern Vietnam

Species/stands	$d_g$ (cm)			$\bar{d}$ (cm)		
	Mean	Min	Max	Mean	Min	Max
<i>Oligostachyum</i> sp.	5.1 ± 0.2	4.8	5.4	5.0 ± 0.2	4.7	5.3
<i>Phyllostachys edulis</i>	5.6 ± 0.5	4.7	6.3	5.5 ± 0.4	5.1	6.2
<i>Indosasa angustata</i>	6.1 ± 0.4	5.6	6.7	6.0 ± 0.4	5.5	6.6
<i>Dendrocalamus latiflorus</i>	8.1 ± 0.1	7.9	8.4	8.1 ± 0.1	7.9	8.2
<i>Dendrocalamopsis</i> sp. 2	8.2 ± 0.1	8.0	8.4	8.1 ± 0.1	8.0	8.3
<i>Dendrocalamus barbatus</i>	8.6 ± 0.1	8.4	8.7	8.5 ± 0.1	8.4	8.7

The three sympodial bamboo species have the same standard deviation values and those data mean that the fluctuation of means diameter between their sample plots is not significant. That value of *Oligostachyum* sp. is as twice as that of the sympodial bamboo species; however, the fluctuation of its observed data is relatively low. The two monopodial bamboo species are intermediate with regard to their quadratic mean diameter but they have the highest standard deviations indicating a higher variation in diameter.

#### 4.2.3 Density and basal area

Density is one of the most important parameters of the forest stands. For bamboos, density is generally used to determine the appropriate level of harvesting (Fu, 2001). In the case of monopodial and amphipodial bamboos, growing in single culms, the density



is expressed by the number of culms per hectare. However, every year, a new class of bamboo culms is usually produced from the previous year rhizomes leading to the annual changes of the density of each bamboo stand after planting. Therefore, the density of a bamboo stand is commonly determined by the current density or so-called “standing culm density”, although the establishment of new bamboo stands is based on planting density (Dart, 1999 cited by Kleinhenz and Midmore, 2001).

Table 9: Mean and standard deviation of current density (N) and basal area (G) of monopodial and amphipodial species (n = 9 sample plots) in Northern Vietnam

<b>Species/stands</b>	<b>N (culms/ha)</b>	<b>G (m<sup>2</sup>/ha)</b>
<i>Oligostachyum</i> sp.	7489 ± 399	15.3 ± 1.5
<i>Phyllostachys edulis</i>	4511 ± 329	10.8 ± 2.3
<i>Indosasa angustata</i>	2419 ± 191	7.1 ± 1.0

The data in table 9 show that the *Oligostachyum* sp. stand has the highest standing culm density with 7489 culms/ha in comparison with others and it has also the smallest size of culm diameter (see table 8). In general, the running bamboos including monopodial and amphipodial species develop very fast when their running rhizomes spread quickly everywhere far from the mother culms. Therefore, the standing culm density of a running bamboo stand will become very high after some years if there is a lack of control. Finally, the accelerating standing culms density reduces the diameter of the culms gradually.

For the sympodial bamboo stands that grow in clumps, but not in single culms, the number of clumps per hectare so-called “clump density” is the first factor to be considered. Moreover, each clump of sympodial bamboos consists of many culms which are connected through the rhizome systems creating interdependence between the individual culms (Camargo, 2005). On the other hand, bamboo shoots at the first stage

with insufficient number of roots depend primarily on nutrients provided by their mother rhizomes. Hence, the number of bamboo culms in a clump is an important factor that directly influences the quality of bamboo products. Therefore, the density of sympodial bamboos is also expressed in term of the number of culms per clump.

Table 10: Mean and standard deviation of clump density, the number of culms per clump and basal area (G) of sympodial bamboo species (n = 9 sample plots) in Northern Vietnam

Species/stands	Clumps/ha	Culms/clump	G (m <sup>2</sup> /ha)
<i>Dendrocalamus latiflorus</i>	217 ± 13	8 ± 0.6	9.1 ± 0.7
<i>Dendrocalamopsis</i> sp. 2	192 ± 18	9 ± 0.4	9.3 ± 0.7
<i>Dendrocalamus barbatus</i>	208 ± 18	8 ± 0.8	10.0 ± 1.0

Table 10 shows the clump density and the number of culms per clump of the three sympodial bamboo stands. Of which the *Dendrocalamopsis* sp. 2 stand has the smallest clump density with 192 clumps/ha. However, each clump of this stand contains 9 culms, higher than others. The *Dendrocalamus latiflorus* and the *Dendrocalamus barbatus* stands have the same number of culms per clump but the clump density of the *Dendrocalamus latiflorus* stand is slightly higher than that of the *Dendrocalamus barbatus*. In fact, the three sympodial species were planted with the same pacing of 7 x 7 m (about 200 clumps per ha).

Even though the three sympodial stands have differences both in the clump densities and the number of culms per clump, their total number of culms per hectare is nearly the same. However, the *Dendrocalamus barbatus* stand has the largest basal area (10.0 m<sup>2</sup>) due to the bigger diameter of this species. In contrast, the three monopodial and amphipodial bamboo stands have significantly different standing culm density and basal areas (see table 9). In general, the variation of diameter, density, and basal area of these

stands shows that the higher the culm density, the larger the basal area but the smaller the culm diameter.

The above primary conclusion is consistent with the comment of Fu and Banik (1996) and Kleinhenz and Midmore (2001). These previous studies reported that there is an inverse relationship between yield and diameter of shoots and culms which is determined by the standing culm density. Lower standing culm densities promote diameter but reduce total yield. On the other hand, higher standing culm densities increase total yield but reduce diameter of shoots and culms. Based on this principle and different purposes of uses, the standing culm density can be maintained in a larger amount to promote a high culm yield or in a lower amount to gain greater culm diameter.

A study in Bangladesh (Banik, 1998) showed that due to financial problems, the poor not only harvested mature bamboo culms but also immature culms to sell. This practice ultimately destroyed their bamboo stands by decreasing the rhizome vitality. In other cases, the rich did not annually harvest their bamboo stands, so that the clumps were in a congested condition and the yield was decreasing gradually. Thus the maintenance of a reasonable number of culms per clump is one of the most important silvicultural practices to improve the quality of both shoot and culm productions within sympodial bamboo species.

Obviously the diameter of bamboo culms depends on the species, site conditions and management techniques (Dransfield and Widjaja, 1995). Depending on species, giant, medium or small bamboos should be managed in different density to promote general profitability of the species. The previous study showed that the density of bamboos applied for culm timber, shoot and pulp products is as following:

a) For culm timber stands: the standing culm density applied for monopodial and amphipodial species corresponding with high, medium and low production is about 3000, 2225 and 1500 culms per hectare, respectively. The recommended stand density

for sympodial species like *Dendrocalamus strictus* and *Bambusa bambos* is 700 clumps per hectare, each clump containing 10 to 20 culms at 1 to 3 years of age (Fu and Banik, 1996).

b) For shoot product stands: the standing culm density should be of 2225 culms per hectare for large size monopodial bamboo species like *Phyllostachys edulis* Lehaie. The density can be from 9000 to 12000 culms per hectare for medium and small-sized monopodial bamboos. Sympodial bamboos such as *Dendrocalamus latiflorus* Munro, *Dendrocalamus hamiltonii* Nees & Arn. ex Munro and *Bambusa beecheyana* Munro can be planted at the spacing of 4 x 5 m or 5 x 5 m, each clump contents 6 to 8 culms of 1 to 2 years of age (Fu and Banik, 1996; Jiang, 2007).

c) For pulp and paper stands: the standing culm density applied for large size running bamboos such as *Bambusa* and *Phyllostachys* families would be kept from 3000 to 4500 culms per hectare. Sympodial species can be planted with spacing of 3 x 4 m, 4 x 4 m, and 4 x 5 m (Fu and Banik, 1996).

d) For multi-purpose stands: some species can be managed for both culm timber and shoot productions like *Phyllostachys pubescens* (a synonym of *Phyllostachys edulis*), a large size monopodial bamboo species in China, with a standing culm density of 2225 culms per hectare (Fu and Banik, 1996). According to Kleinhenz and Midmore (2001), the average 9100 standing culms per hectare can be applied for the multi-purpose stands but those stands require an intensive management.

In this study, the stands of *Oligostachyum* sp. and *Phyllostachys edulis* have been kept under a very high standing culm density when they were managed for multi-purposes. The current densities of those stands may have negative impacts on the sizes of the product, so that it should be intensively reduced to promote higher shoot and culm diameters.

The *Indosasa angustata* stand has a suitable standing culm density but its mean diameter is smaller. The reason is that the stand was not tended sufficiently and maybe

the bamboo culms were not provided with enough nutrients. Hence, the most important silvicultural treatment needed for this stand are clearing climber and weeds as well as loosening soil around clumps and fertilizing.

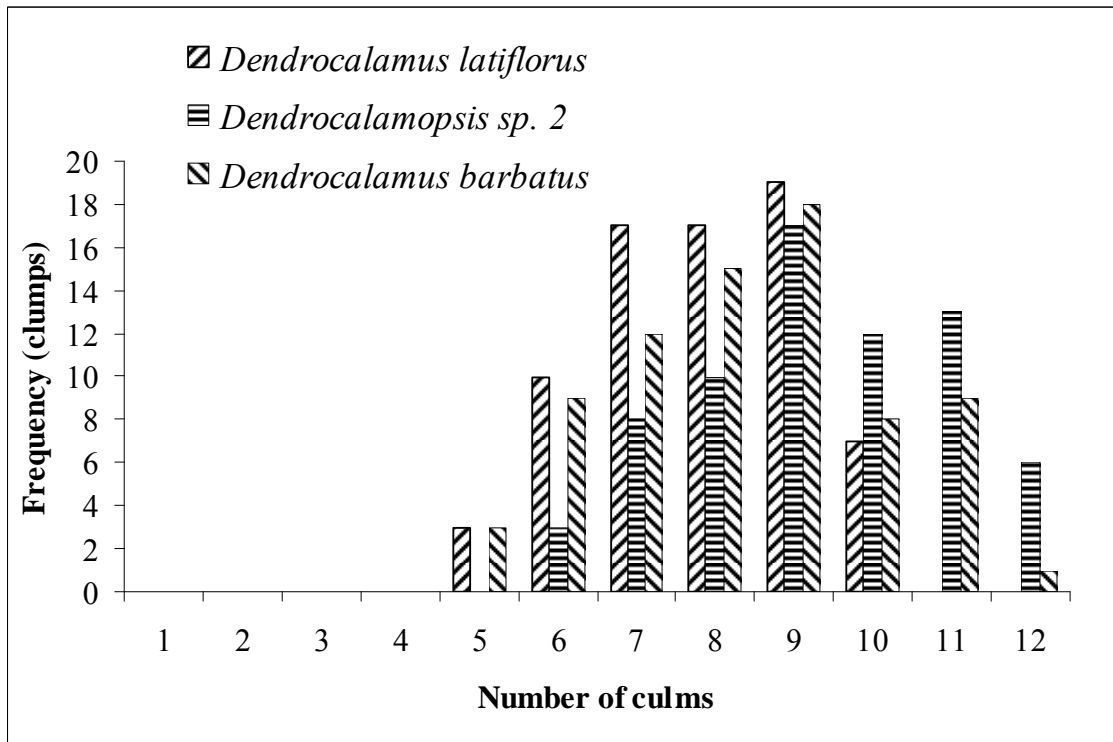


Fig. 8: The frequency of clumps with different number of culms in 9 sample plots of three sympodial bamboo stands in Northern Vietnam

Both clump density and the number of culms per clump of the three sympodial bamboo stands in this study were lower than those suggested by Fu and Banik (1996). The observation data from nine sample plots of each sympodial bamboo stand shows the difference in the stem density between those species but most clumps of those stands consist of 7 to 11 culms. However, some clumps contain only five culms and some others comprise 12 culms (Fig. 8). Therefore, the clump density of the sympodial bamboo stands in this study can be kept in the current status but the number of culms per clump should be maintained in a stable situation with higher density.

#### 4.2.4 Bamboo age and age distribution

In difference to trees, bamboo lacks the vascular cambium layer (Nguyen, 2006; Xiaobing, 2007), so that it has no secondary growth in diameter and consequently no year rings. Therefore, other methods have to be used to determine the age of bamboo culms. Three methods suggested by Fu (2001) are: 1) marking the new culm with a special painting ink, 2) judging of culm color and 3) counting twig scars. In this study, the age of bamboo culms was determined based on experience of foresters by using a combination of three methods as following: 1) Judging of culm color, 2) Counting twig scars and 3) Determining the position of culms.

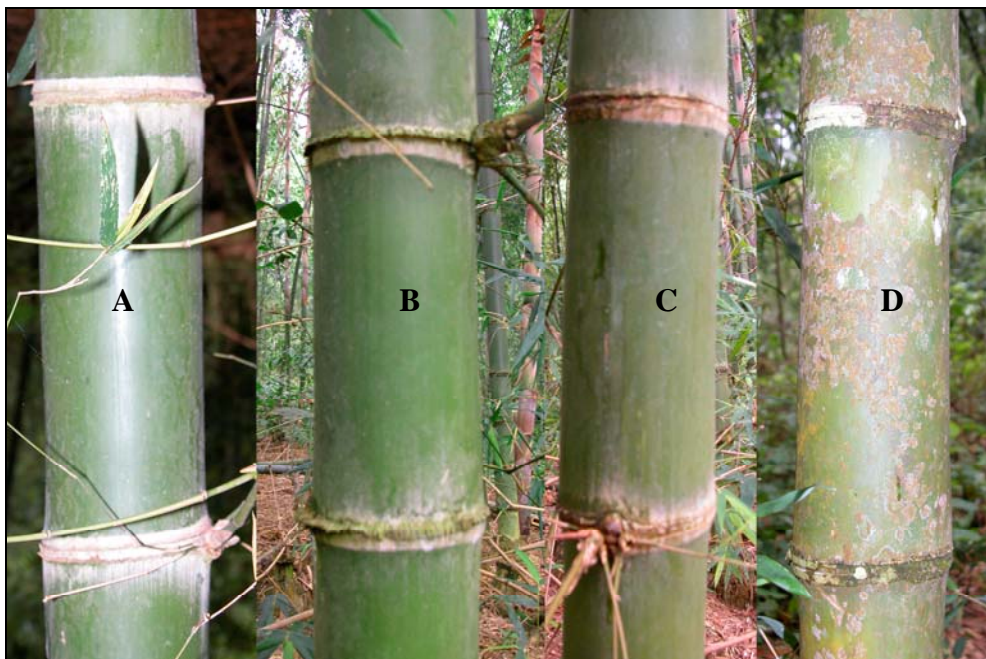


Fig. 9: Culm color in different ages (A - the one year old culm; B - two year; C - three year; and D - four year)

**Judging of culm color:** In general, the color of bamboo culms relates to their age. The color of one year old culms is normally bright green and the surface of the culms is thinly pruinose. As the culms age to two and three, their color becomes more yellowish.

From age four onwards, the color of the culms virtually turns to grey and fungi and mosses appear on the culm surface.

**Counting twig scars:** In general, culms of some bamboo species change their leaves every year and some others change their leaves every two years but twig scars remain. Based on this phenomenon the age of bamboo culms can be determined. To calculate the age of bamboo culms, the equation 13 can be applied for the bamboo species changing their leaves every two years like *Phyllostachys edulis* and in case of other species changing their leaves yearly like *Dendrocalamus barbatus* the equation 14 is used.

$$\text{Age} = 2n + 1 \quad (13)$$

$$\text{Age} = n + 1 \quad (14)$$

Where:  $n$  = the number of twig scars

**Determining the position of culms:** For sympodial bamboos, the position on the ground of a culm relates to its age. There are two principles for this determination. First, the buds of one or two year old culms are vigorous and could produce shoots while the buds of three years or older culms almost lose this capacity (Fu et al, 2000). Therefore, the culms connected with shoots are normally one or two years old. Second, sympodial bamboos usually grow in clump and new culms have the tendency to enlarge outwards of the existing clump to get enough living space. Thus, within clumps as more distant to the clump center as younger the culms are.

The distributions of the number of bamboo culms following age classes of the *Oligostachyum* sp. stand and the *Phyllostachys edulis* stand have the same tendency. For those two stands, the number of culms slightly increases from age class 1 to age class 2, negligible decreases from age class 2 to age class 3, and strongly decreases from age class 3 to age class 4 (Fig. 10). Relatively, the age composition of those stands can be expressed by the ratio 3: 3: 3: 1 for the four age classes.

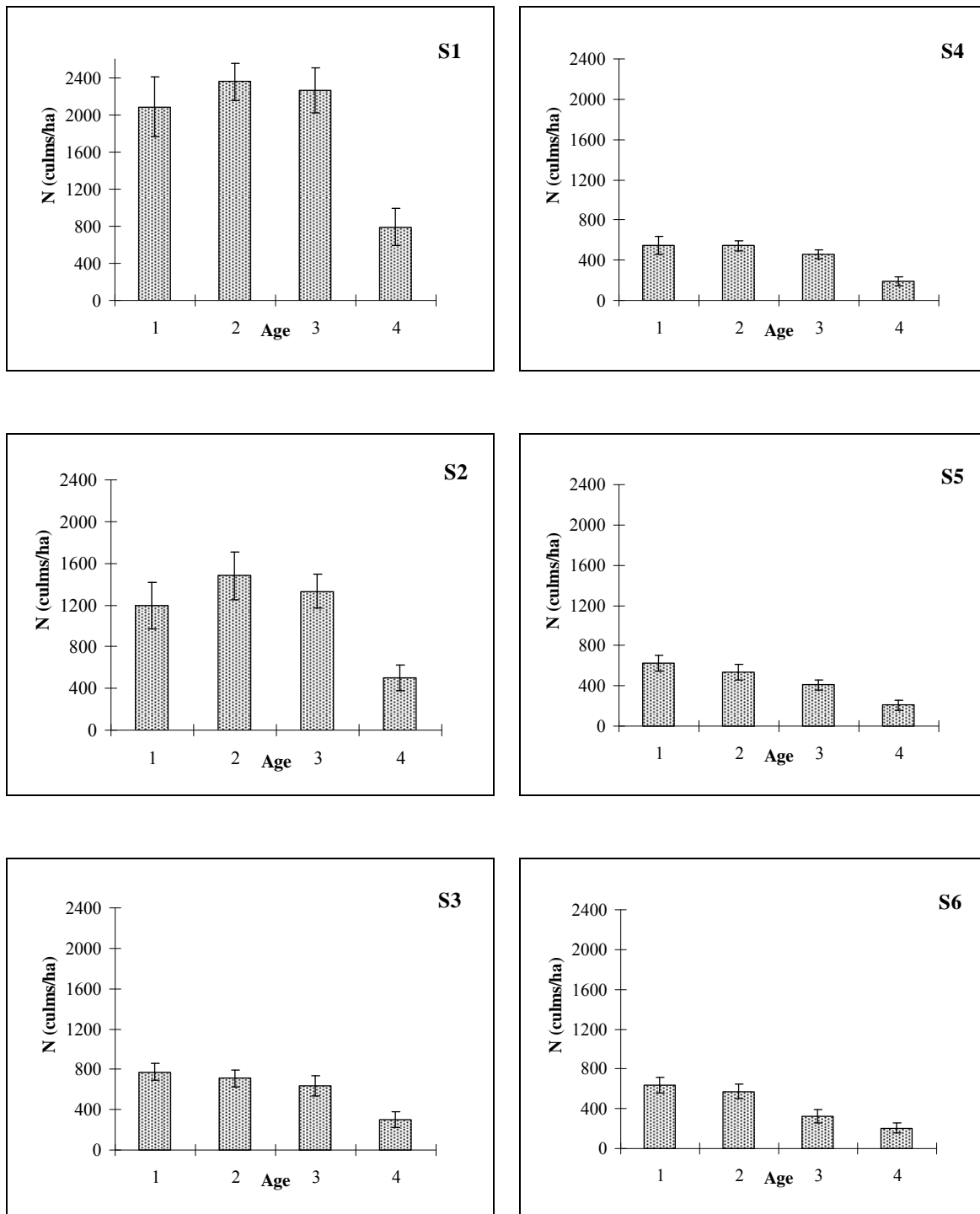


Fig. 10: Age distribution of culm number for the bamboo stands in Northern Vietnam

S1 - *Oligostachyum* sp., S2 - *Phyllostachys edulis*,

S3 - *Indosasa angustata*, S4 - *Dendrocalamus latiflorus*,

S5 - *Dendrocalamopsis* sp. 2, S6 - *Dendrocalamus barbatus*



For the other four bamboo stands, the number of bamboo culms steadily decreases from age class 1 to age class 2 and 3 but from age class 3 to age class 4 it decreases significantly. However, the ratio 3: 3: 3: 1 can also be used to roughly imitate the age composition of those stands of the three bamboo species including *Indosasa angustata*, *Dendrocalamus latiflorus* and *Dendrocalamopsis* sp.2 whereas the age composition of the stand of *Dendrocalamus barbatus* should be expressed by the ratio 4: 3: 2: 1.

In fact, except the two stands of *Oligostachyum* sp. and *Phyllostachys edulis*, the number of culms in age class 3 of all the others is significantly smaller than that of age class 1 and 2. Thus, a large amount of their culms were cut when they reach the age three. However, the smallest number of bamboo culms existing in age class 4 leads to a conclusion that the main cutting age currently applied for all the six bamboo stands is at four years.

#### **4.2.5 Diameter distribution**

##### **4.2.5.1 Diameter distribution of stands**

Diameter distribution is one of the most important stand characteristics in forestry and is also a useful tool for describing the forest structure (Loetsch *et al.*, 1973). There are several mathematical models to describe diameter distribution of woody stands, of which Weibull function has been used for the bamboo species *Phyllostachys edulis* in China (under the name *Phyllostachys pubescens*) (Fu, 2001) and *Guadua angustifolia* in Colombia (Camargo, 2005). The Weibull function is a probability density function that can be applied in a wide variety of shapes, depending on the values assigned to each of three or two constants (Pham, 2008). In this study, the Weibull function with both two and three constants is used to express the form of diameter distribution of the six bamboo stands as well.

The Chi-square test is normally used to indicate whether the difference between the distribution of the observed data and the predicted distribution is significant. If the p-

value is less than 0.05 (5% significance level), the two distributions are significantly different at 95% confidence level. In this case the observed data do not match the predicted distribution. In contrast, if the p-value is bigger than 0.05, the two distributions are relatively similar, so that the distribution of observed data fits with predicted distribution at 95% confidence level.

The data in table 11 show that the diameter distributions of the six bamboo stands do not fit with the Weibull (2) distributions at 95% confidence level while the p-values of those stands are all 0.01. With Weibull (3), only the *Phyllostachys edulis* stand has the p-value higher than 0.05, therefore, it is possible to conclude here that the Weibull (3) distribution can be used to describe the diameter distribution of only the *Phyllostachys edulis* stand at the 95% confidence level.

Table 11: p-value of Chi-square test for the diameter distribution of bamboo stands (Weibull distributions with 5% significance level) in Northern Vietnam

Species	n	p-value	
		Weibull (2)*	Weibull (3)**
<i>Oligostachyum</i> sp.	2695	0.01	0.01
<i>Phyllostachys edulis</i>	1623	0.01	0.21
<i>Indosasa angustata</i>	870	0.01	0.03
<i>Dendrocalamus latiflorus</i>	625	0.01	0.01
<i>Dendrocalamopsis</i> sp. 2	640	0.01	0.01
<i>Dendrocalamus barbatus</i>	623	0.01	0.01

Note: (\*) Weibull function with two constants;  
 (\*\*) Weibull function with three constants

Although Weibull is a flexible function widely used to describe the size distribution of trees (Fu, 2001), the diameter distribution of five bamboo stands (excepting *Phyllostachys edulis*) can not be described by using this function at the 95% confidence

level in this study. In fact, it can be explained that the exploitation activities applied for those stands are uncontrolled. Surely, the size and the number of cut culms depend on the market demand, so that the human interventions significantly disorder the close-to-nature diameter distribution of those stands.

#### 4.2.5.2 Diameter distribution following age classes

Usually each year the edge buds of mature rhizomes differentiate into shoot buds which will then develop into new culms (Fu, 1996; Fu, 2001; Nguyen, 2006). Therefore, for bamboo stands, a new class of culms generates each year. In other words, each bamboo stand consists of consecutive culm classes and the age gap between these culm classes is one year.

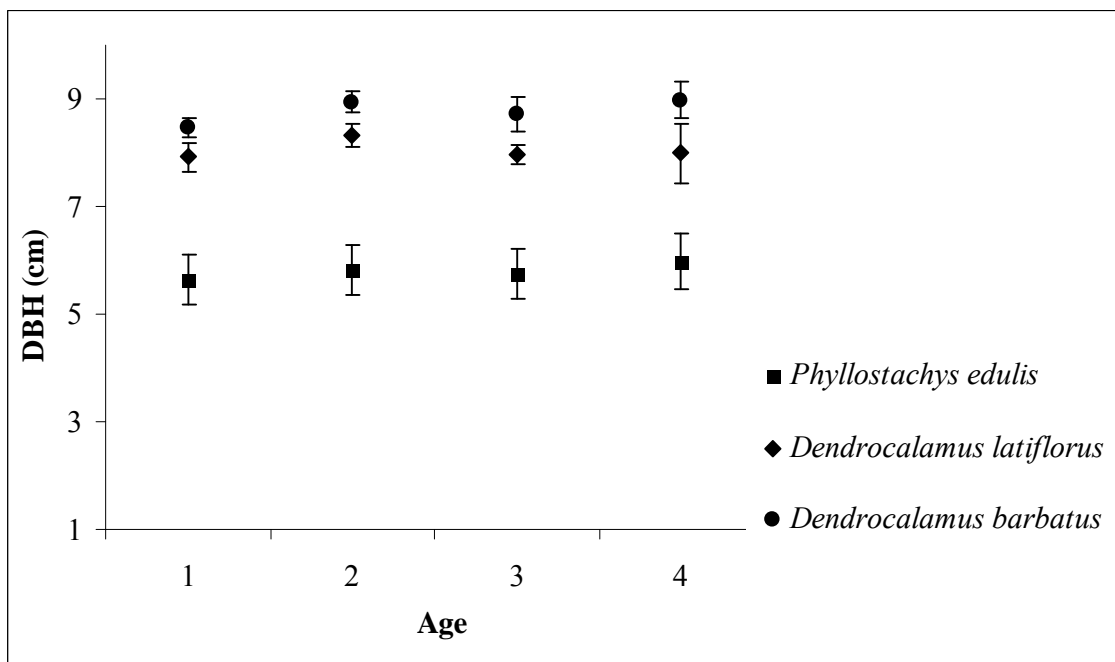


Fig. 11a: Diameter distribution based age classes ( $n = 9$ ) of the *Phyllostachys edulis*, *Dendrocalamus latiflorus* and *Dendrocalamus barbatus* stands in Northern Vietnam

As mentioned above, bamboo has no secondary growth, so that after a culm fully develops, its diameter does not change in dimension anymore (McClure, 1957; Fu, 2001; Nguyen, 2006; Xiaobing, 2007). As a result the diameter parameter of bamboo culm remains stable and is fixed at the end of the culm-development stage. Therefore, the mean diameter of bamboo culms within each age class is constant.

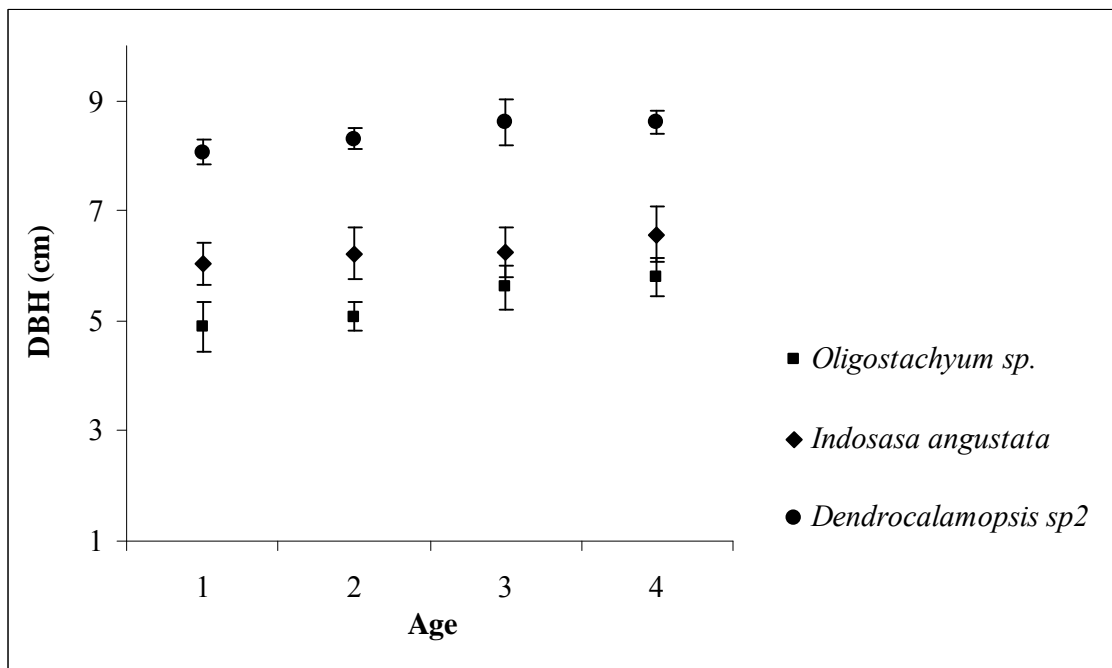


Fig. 11b: Diameter distribution based age classes (n = 9) of the *Oligostachyum sp.*, *Indosasa angustata*, and *Dendrocalamopsis sp. 2* stands in Northern Vietnam

The quality of shoots and young culms within a bamboo stand not only depends on the climate and management but also the situation of the stand (Fu, 1996) like the possibility of nutrient accessibility and reproduction capability. This follows the fact that the site conditions affect the plant, and in-turn the plant reflects the site condition. Hence in a certain period of time, the variation of the quality of bamboo culms which is

here illustrated by the mean diameter of different age classes is used to obtain the situation of the stand (Fig. 11a and b).

The observed data in Fig. 11a show that the variation of diameter values of the stand of *Phyllostachys edulis*, *Dendrocalamus latiflorus* and *Dendrocalamus barbatus* has the same tendency. The mean diameter values of those stands all increase from age class 1 to age class 2, afterward, decrease to age class 3, and finally negligible increase to age 4. Although the mean diameter values of those stands are different in each age class, the variation of their diameter is not noticeable in the four age classes showing the relatively stable status of those bamboo stands.

From age class 1 to age class 3, the variations of diameters in four age classes of the stands of *Oligostachyum* sp., *Dendrocalamopsis* sp. 2 and *Indosasa angustata* are the same, and they all increase from age class 1 to age class 3. From age class 3 to age class 4, the diameter value of the *Dendrocalamopsis* sp. 2 stand changes very little whereas the diameter values of the *Oligostachyum* sp. and *Indosasa angustata* stands continuously increase (Fig. 11b). In conclusion, the three bamboo stands here have the same growing tendency that the diameter of the bamboo culms belonging to youngest age class is smaller than that of the bamboo culms of older age classes. This leads to the primary conclusion that the current situation of those bamboo stands is not stable and they may be at over mature stage and/or in the lack of nutrition status.

## **4.2.6 Stand height**

### **4.2.6.1 Mean height**

In forestry, the stand height is one of the most important parameter used to calculate the volume, assess the site condition and describe the growth performance (Fu, 2001). For the even-aged woody stands, according to Pham (2008), the arithmetic mean height of all trees is a useful measure for the stand height because the variation of their height is small.

For the bamboo stands, in even-aged or uneven-aged, the height of bamboo culms is the stable parameter and is not affected by aging because the young bamboo culms are formed by the elongation of their internodes and reach their full height within a period of only few months, from then on the height of the culms does not change any more (Liese and Weiner, 1996; Fu 2001) and thus, bamboo culms have no annual growth in height (Fu, 2001; Nguyen 2006; Xiaobing, 2007). Therefore, the arithmetic mean of height can also be applied for the stand height bamboo.

Table 12: Mean and standard deviation of the arithmetic mean height (h) of 9 sample plots (400 m<sup>2</sup>) of bamboo stands in Northern Vietnam

<b>Species/stands</b>	<b>Mean (m)</b>	<b>Min (m)</b>	<b>Max (m)</b>
<i>Oligostachyum</i> sp.	9.1 ± 0.3	8.7	9.5
<i>Phyllostachys edulis</i>	11.0 ± 1.1	8.5	12.2
<i>Indosasa angustata</i>	9.4 ± 0.5	8.3	10.2
<i>Dendrocalamus latiflorus</i>	11.9 ± 0.2	11.7	12.1
<i>Dendrocalamopsis</i> sp. 2	12.5 ± 0.2	12.3	12.8
<i>Dendrocalamus barbatus</i>	12.9 ± 0.1	12.7	13.1

Fu (2001) presented a term of commercial height of bamboo culms used for *Phyllostachys pubescens* (a synonym of *Phyllostachys edulis*) which is determined by the height measured from the ground up to the base of the crown. However, different bamboo species have different characteristics of branch spreading. For example, the height from the ground up to the base of the crown of *Dendrocalamopsis* sp. 2, or *Dendrocalamus barbatus* is very short while their utilization height is much longer. Thus the commercial height can not be applied in this study but the total height measured from the ground to the top of the crown is used instead.

The data of the arithmetic mean height of the six bamboo stands in table 12 show that *Oligostachyum* sp. has the smallest value of stand height with 9.1 m while that of *Indosasa angustata* is slightly higher with 9.4 m and those two species can be disposed in a group with the smallest values of culm height. In contrast, *Dendrocalamus barbatus* has the biggest stand height with 12.9 m in comparison with others. Three bamboo stands, *Phyllostachys edulis*, *Dendrocalamus latiflorus* and *Dendrocalamopsis* sp. 2 with the mean diameter values of 11.0 m, 11.9 m and 12.5 m, respectively, can be classified into a medium group.

The fluctuations of stand height of three monopodial and amphipodial bamboo stands including *Oligostachyum* sp., *Phyllostachys edulis*, and *Indosasa angustata*, are larger than those of three other sympodial bamboo stands, among which the *Phyllostachys edulis* stand has the largest variation of culm height since its standard deviation value is 1.1. The standard deviation values of mean height of the three sympodial stands are 0.1 and 0.2; therefore, the variation between their culm heights is less than that of monopodial and amphipodial stands.

#### **4.2.6.2 Height curve**

According to Pham (2008), a stand height curve is the curve of best fitting to the cloud of points representing plot of height against diameter of all trees in the stand which can be used to predict the height of a tree when only its diameter is measured. The height curve is very useful in forest inventory because diameter parameter recording is normally easier than height measurement.

Fu (2001) used six models including the 2nd degree parabola, Prodan, Petterson, Korsun, Logarithmic, and Freese to estimate the height of *Phyllostachys pubescens* (a synonym of *Phyllostachys edulis*). The author reported that those equations are more suitable for pure bamboo stands than for mixed bamboo stands. Camargo (2006) used both linear and non-linear functions to estimate the culm length of *Guadua angustifolia*

and concluded that within *Guadua angustifolia* stands different values of culm length in the same diameter classes were obtained.

Table 13: Height curve equations and coefficient of determination ( $R^2$ ) of bamboo stands in Northern Vietnam

Species	Equation	$R^2$
<i>Oligostachyum</i> sp.	$h = 6.0184\ln(d) - 0.5293$	0.69
	$h = -0.0125d^2 + 1.3654d + 2.5757$	0.70
<i>Phyllostachys edulis</i>	$h = 7.6353\ln(d) - 1.4749$	0.75
	$h = -0.2288d^2 + 3.9001d - 2.9149$	0.76
<i>Indosasa angustata</i>	$h = 7.3019\ln(d) - 3.4952$	0.63
	$h = 0.0704d^2 + 0.3488d + 4.7335$	0.66
<i>Dendrocalamus latiflorus</i>	$h = 11.324\ln(d) - 11.614$	0.70
	$h = -0.1148d^2 + 3.3118d - 7.1603$	0.71
<i>Dendrocalamopsis</i> sp. 2	$h = 11.209\ln(d) - 10.762$	0.57
	$h = 0.0776d^2 + 0.197d + 5.7565$	0.59
<i>Dendrocalamus barbatus</i>	$h = 10.285\ln(d) - 9.0593$	0.65
	$h = 0.0345d^2 + 0.602d + 5.2273$	0.65

In this study, in each bamboo stand, one sample plot was randomly selected to measure the diameter and height of all culms. From those data, the relationship between diameter and height was described by using some common functions. Among those functions, two height curve equations including logarithmic and polynomial with the highest value of coefficient of determination were chosen to be presented in table 13.



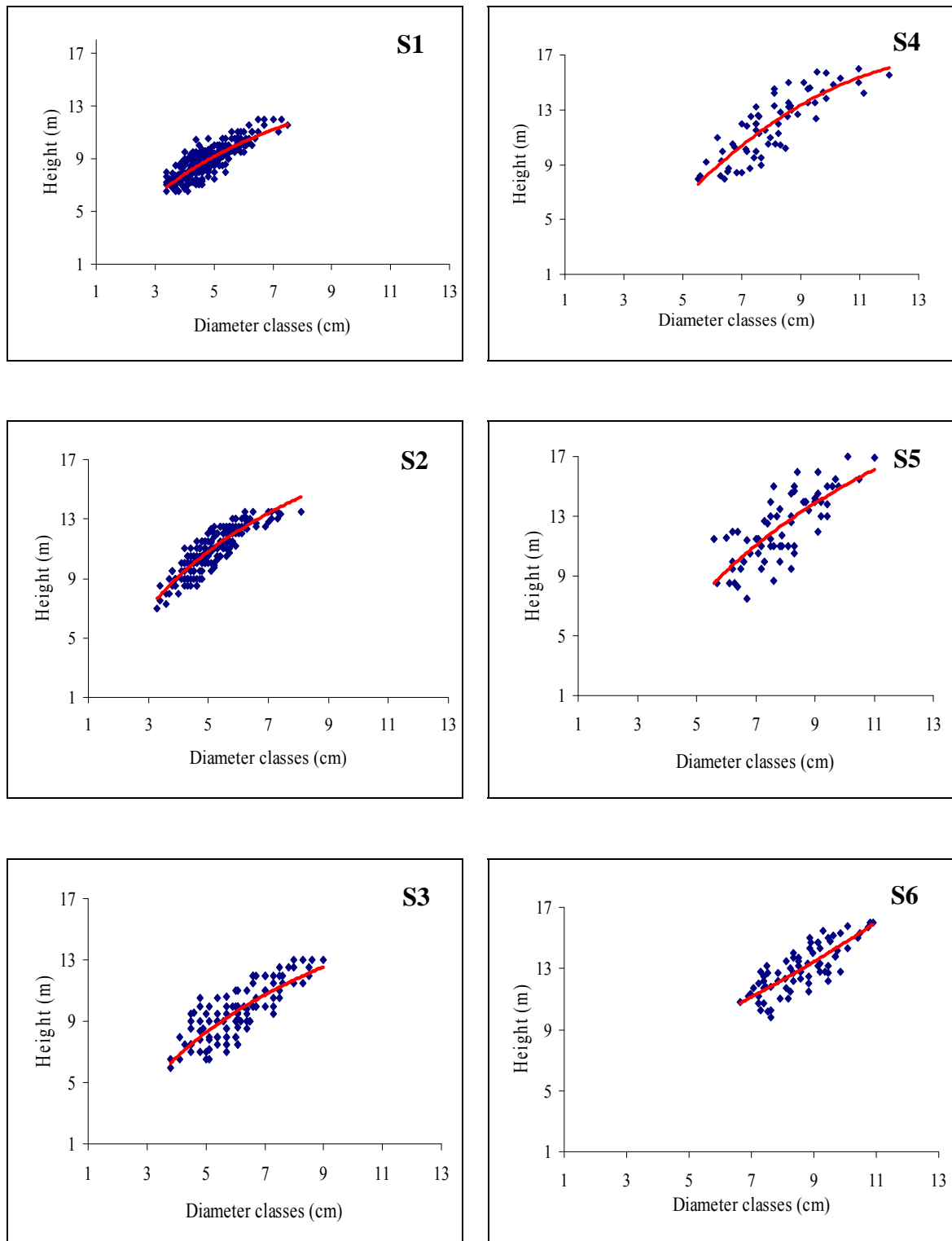


Fig. 12: Height curve fitting with polynomial model

S1 - *Oligostachyum* sp., S2 - *Phyllostachys edulis*,

S3 - *Indosasa angustata*, S4 - *Dendrocalamus latiflorus*,

S5 - *Dendrocalamopsis* sp. 2, S6 - *Dendrocalamus barbatus*

The observed data show that only *Dendrocalamus barbatus* stand has the same value of coefficient of determination ( $R^2$ ) of both polynomial equation and logarithmic equation. All values of ( $R^2$ ) of polynomial equation of other stands are bigger than those of logarithmic equation. Therefore, among the two presented equations, polynomial is more suitable for those bamboo stands than logarithmic.

The small and medium diameter classes of all study bamboo stands consist of many culms with different height values. It is consistent with the comments of Fu (2001) and Camargo (2006) that in case of bamboo, the height of culm is always different within diameter class. In addition, the small classes in both height and diameter variables were not observed (Fig. 12) because all of the study bamboo stands are at mature stages while the bamboo culms with small sizes may only be found in the young bamboo plantation stands (Camargo, 2006).

### 4.3 Dendrometric characteristics and properties

#### 4.3.1 Dendrometric characteristics

##### 4.3.1.1 Diameter

The data of diameter at breast height of each study species were observed from 36 cut culms showed in table 14. Statistical data on mean diameter indicate that monopodial and amphipodial bamboo species are all smaller than the sympodial bamboos. Of the six study species, *Oligostachyum* sp. (the amphipodial species) has the smallest diameter value with 4.7 cm, the other two monopodial bamboos have medium size of diameter with 5.9 and 6.7 cm and the remaining three sympodial bamboos including *Dendrocalamus latiflorus* with 8.1 cm, *Dendrocalamopsis* sp. 2 with 8.7 cm and *Dendrocalamus barbatus* with 9.5 cm have the highest diameters.

Table 14: Mean and standard deviation of the diameter at breast height (d) of bamboo species (n = 36 cut culms) in Northern Vietnam

Species	Mean (cm)	Min (cm)	Max (cm)
<i>Oligostachyum</i> sp.	4.7 ± 1.0	3.5	7.3
<i>Phyllostachys edulis</i>	5.9 ± 1.3	4.0	8.3
<i>Indosasa angustata</i>	6.7 ± 1.0	4.7	8.5
<i>Dendrocalamus latiflorus</i>	8.1 ± 1.1	6.2	10.5
<i>Dendrocalamopsis</i> sp. 2	8.7 ± 1.5	6.5	11.5
<i>Dendrocalamus barbatus</i>	9.5 ± 1.7	6.6	13.4

The values of the mean diameter at breast height of the six study species are within the range recorded by Nguyen (2006) for the same species in Northern Vietnam. However, standard deviation values of all study species are quite high ranging from 1.0 (*Indosasa angustata*) to 1.7 (*Dendrocalamus barbatus*) that means the fluctuation of diameter between culms of those species is apparent.

#### 4.3.1.2 Culm height and the total culm length

Observed data show that *Oligostachyum* sp. is the smallest species with 8.7 m in height and 9.1 m in length. The three sympodial bamboos can be disposed in the highest group, their mean height ranging from 12.9 to 13.9 m and their mean length ranging from 13.7 to 15.4 m. The two monopodial species including *Phyllostachys edulis* with 10.8 m in height and 11.2 m in length and *Indosasa angustata* with 10.0 m in height and 10.3 m in length are in between.

Table 15: Mean and standard deviation of the culm height (h) of bamboo species (n = 36 cut culms) in Northern Vietnam

Species	Mean (m)	Min (m)	Max (m)
<i>Oligostachyum</i> sp.	8.7 ± 1.4	6.8	12.3
<i>Phyllostachys edulis</i>	10.8 ± 2.6	6.9	15.3
<i>Indosasa angustata</i>	10.0 ± 2.1	6.6	14.3
<i>Dendrocalamus latiflorus</i>	12.9 ± 1.4	9.8	15.6
<i>Dendrocalamopsis</i> sp. 2	13.9 ± 2.0	9.0	16.9
<i>Dendrocalamus barbatus</i>	13.1 ± 1.5	9.5	15.9

In comparison with the data presented by Do et al. (2000), the mean height value of *Indosasa angustata* observed in Ha Giang Province (104°E and 22°N) is 17.0 m much higher than the value of this species measured in this study. The mean height of *Oligostachyum* sp. is smaller and that of *Dendrocalamopsis* sp. 2 and is bigger than the values recorded by Nguyen (2006). For the other species, their height values are accordance with the previous recordings of these authors.

The high values of standard deviations of both culm height and culm length of all study species shown in table 15 and 16 indicate that the fluctuations of both their culm height and culm length are quite remarkable. Based on the values of standard deviation, the six

study bamboos can be divided into two groups. The first group includes *Phyllostachys edulis*, *Indosasa angustata*, and *Dendrocalamopsis* sp. 2 and the second group consists of the three species. Of which the culm height and culm length of the three species in the first group vary stronger than the others.

Table 16: Mean and standard deviation of the total culm length (l) of bamboo species (n = 36 cut culms) in Northern Vietnam

Species	Mean (m)	Min (m)	Max (m)
<i>Oligostachyum</i> sp.	9.1 ± 1.4	7.2	12.6
<i>Phyllostachys edulis</i>	11.2 ± 2.6	7.2	15.6
<i>Indosasa angustata</i>	10.3 ± 2.1	7.0	14.5
<i>Dendrocalamus latiflorus</i>	13.7 ± 1.3	10.9	16.1
<i>Dendrocalamopsis</i> sp. 2	15.4 ± 2.1	10.3	18.4
<i>Dendrocalamus barbatus</i>	14.5 ± 1.6	11.5	17.8

#### 4.3.1.3 The culm curvature

The total curvature of bamboo culms has been estimated by Camargo (2006) based on the total length (l) and the linear distant (z) (the distance between the base and the apex) of cut culms. Following this method, the total curvature value of a bamboo culm can only be measured after the culm was cut off because of that measuring the linear distant of the standing culms is impracticable. Therefore, the observed data of the total curvature cannot be applied again in the further studies if we want to estimate the culm length of standing culms via the total curvature of the culms.

In this study, the culm height (h) (the vertical distance from the ground to the top of the culm) is measured instead of the linear distant (z) with the aim to further use the total curvature of bamboo culms to estimate the total culm length from the culm height.

Table 17: Mean and standard deviation of the total curvature of culm (Cv) of bamboo species (n = 36 cut culms) in Northern Vietnam

Species	Mean (%)	Min (%)	Max (%)
<i>Oligostachyum</i> sp.	3.9 ± 0.8	2.4	6.1
<i>Phyllostachys edulis</i>	3.0 ± 0.7	1.7	6.6
<i>Indosasa angustata</i>	3.0 ± 0.8	1.4	5.0
<i>Dendrocalamus latiflorus</i>	5.9 ± 2.5	2.9	12.4
<i>Dendrocalamopsis</i> sp. 2	9.6 ± 2.1	6.3	17.4
<i>Dendrocalamus barbatus</i>	10.0 ± 2.9	5.3	17.4

The data in table 17 show that the values of curvature of the three running bamboo species including *Oligostachyum* sp., *Phyllostachys edulis*, and *Indosasa angustata* are appropriate 3 to 4%. Those values point out that the culms of those species grow in a straight form and the difference between their culm height and culm length is not much with appropriately 0.3 m. The values of curvature of the three sympodial bamboo species are evidently higher than that of running bamboo species, and the differences between culm height and culm length of sympodial bamboos are also higher with 0.8, 1.4, and 1.4 m for *Dendrocalamus latiflorus*, *Dendrocalamus barbatus*, and *Dendrocalamopsis* sp. 2, respectively.

#### 4.3.1.4 Internode length

Bamboo culms are separated by nodes and the part in between two nodes is the internode. The internode length refers to the characteristics of each species and affects its utilization values. Generally the structures of nodes and internodes are different. At nodes the parallel cell structures of the internodes become diverted, whereby bamboo species with long internodes are preferred for furniture, splitting and weaving (Liese, 2003).

As shown in table 18, the internode length differs considerably between species. Among six bamboo species, *Oligostachyum* sp. has the longest internodes with 47.1 cm whereas *Phyllostachys edulis* and *Dendrocalamus barbatus* have the shortest internodes with 33.5 and 33.0 cm, respectively and the values of internode length of the three other species, ranging from 38.9 to 43.6 cm, are in between.

Table 18: Mean and standard deviation of the internode length (*Lint*) of bamboo species (n = 36 cut culms) in Northern Vietnam

Species	Mean (cm)	Min (cm)	Max (cm)
<i>Oligostachyum</i> sp.	47.1 ± 6.4	28.8	63.8
<i>Phyllostachys edulis</i>	33.5 ± 2.5	29.2	39.9
<i>Indosasa angustata</i>	43.6 ± 2.8	38.3	49.3
<i>Dendrocalamus latiflorus</i>	38.9 ± 3.8	28.0	44.5
<i>Dendrocalamopsis</i> sp. 2	39.2 ± 3.2	30.3	45.4
<i>Dendrocalamus barbatus</i>	33.0 ± 3.2	25.1	39.8

The fluctuations of internode length of all study species are very high since the values of standard deviations of those species range from 2.5 (*Phyllostachys edulis*) to 6.4 (*Oligostachyum* sp.). This phenomenon is also stated by Liese (2003) who reported that the length of internodes in the portions of bamboo culms is different as it is longest in the middle of each culm and remarkably reduced at its base and top parts.

#### 4.3.1.5 Culm wall thickness

The culm wall thickness is one of the most important parameters used to assess the utilization capability of bamboo. Differing from tree species, bamboo culms are hollow.

Therefore, it is obvious that the true value of culm volume depends on the wall thickness that is directly correlated to shrinkage (Liese, 2003) as well as other properties of bamboo culms. In this study, the culm wall thickness of internodes at breast height of 36 cut culms within each bamboo species was measured.

Table 19: Mean and standard deviation of the culm wall thickness (t) of bamboo species (n = 36 cut culms) in Northern Vietnam

Species	Mean (mm)	Min (mm)	Max (mm)
<i>Oligostachyum</i> sp.	6.9 ± 0.6	5.9	8.3
<i>Phyllostachys edulis</i>	7.2 ± 1.0	5.8	9.6
<i>Indosasa angustata</i>	7.1 ± 0.6	5.8	8.2
<i>Dendrocalamus latiflorus</i>	10.5 ± 0.9	8.9	12.9
<i>Dendrocalamopsis</i> sp. 2	13.6 ± 1.2	11.0	16.2
<i>Dendrocalamus barbatus</i>	12.5 ± 1.3	10.0	15.0

In general, the six study species have different values of wall thickness. However, the culm wall of all sympodial bamboos is thicker than that of other monopodial and amphipodial bamboos is. Among six bamboo species, *Dendrocalamopsis* sp. 2 has the highest value of culm wall thickness with 13.6 mm which is as double as the wall thickness of *Oligostachyum* sp.

According to Liese (2003), in each bamboo species, the diameter of the culm tapers from bottom to top and the reduction in diameter is accompanied by a reduced wall thickness. In this study, for each species, the relationship between diameter and wall thickness of internodes at breast height of 36 cut culms was described by using some common functions such as linear, logarithmic, and polynomial but the values of coefficient of determination ( $R^2$ ) are small ranging from 0.41 to 0.55.



## **4.3.2 Physical properties**

### **4.3.2.1 Moisture content**

Similar to wood, the physical properties of bamboo are related to moisture content, wood density, shrinkage, etc. The previous studies showed that the variation of both moisture content and wood density of bamboo is due to species, age of culm, position in the culm, site condition, season, etc. (Liese, 1985; Ahmad; 2003; Xiaobing, 2007). However, this variation is one of the primary factors affecting the weight, strength and other properties of bamboo products (Le, 1998). In this study moisture content and basic wood density in 4 age classes (from age class 1 to age class 4) of the six bamboo species were analyzed.

Being a part of the intracellular fluid, water contributes the most to the weight of the bamboo culm. Furthermore, water also exists in extra cellular fluid, between the hemi-celluloses of the cell wall and in the slits between cells. Water in wood or bamboo culm is normally expressed by moisture content which can affect the mechanical properties of wood or bamboo culms (Dransfield and Widjaja, 1995), thereby it influences the usage of bamboo (Xiaobing, 2007).

There are two types of moisture content, the relative and the absolute. The absolute moisture content is more stable than the relative one (Le, 1998). Therefore, the absolute moisture content (so-called moisture content) is commonly used. According to Simpson and TenWolde (1999), the moisture content (MC) is determined by the weight of water in wood and expressed as a percentage of the oven dry weight of wood. The similar definition was used by Dransfield and Widjaja (1995) for moisture content of bamboo culms.

The data on moisture content of the six bamboo species show that the moisture content values were evidently different among the species even in the same age classes, this difference relates to the amount of parenchyma cells which correlate to the water holding capacity of each bamboo species (Liese, 1985). Of the six study species,

*Indosasa angustata* and *Dendrocalamopsis* sp. 2 usually have the highest values of moisture content in all of the four age classes whereas *Oligostachyum* sp. and *Dendrocalamus barbatus* have the lowest values. *Phyllostachys edulis* is a special case since its moisture content is very high in age class 1 but in the older age classes its moisture content can be ranked among the same group with *Oligostachyum* sp. and *Dendrocalamus barbatus* (see appendix 7.4)

#### 4.3.2.2 Basic wood density

The basic wood density is an important parameter which is used to evaluate the quality of wood or bamboo due to direct correlation with mechanical properties. The higher the density value, the better the mechanical properties (Wang et al., 2003). Based on the basic wood density, the intensity and technological values of bamboo products can be evaluated (Le, 1998).

According to Le (1998), fresh wood density, dry wood density, and basic wood density are used to imply the density of wood or bamboo. Fresh wood density is expressed as the ratio between weight and volume of wood in fresh status while dry wood density is calculated in the same way, but both weight and volume of wood are in oven dry state. The basic wood density ( $\text{g/cm}^3$ ) is more commonly used than others because it is expressed by the substantial mass of wood per unit volume and defined as following: “basic wood density is determined as the ratio between the dry weight of bamboo culms and its fresh volume” (Le, 1998).

Like moisture content, the density value was variable among species (see appendix 7.5), this difference relates to the ratio between the number of sclerenchyma cells and parenchyma cells of bamboo culms. Each bamboo species shows its own ratio leading to the difference of the density value (Le, 1998). Among the six bamboo species, *Phyllostachys edulis* has the highest basic wood density values, reaching  $0.89 \text{ g/cm}^3$  in age class 3 and  $0.97 \text{ g/cm}^3$  in age class 4. In contrast, *Dendrocalamopsis* sp. 2 has the smallest basic wood density value with  $0.63 \text{ g/cm}^3$  in age class 4 in comparison. This

value is even smaller than that of age class 1 of some other species such as *Dendrocalamus latiflorus* or *Oligostachyum* sp.

#### 4.3.2.3 Effect of aging on physical properties

The moisture contents depends appreciably on the aging that when class 1 has the highest moisture content and class 4 shows the lowest (Fig. 13). This observation is in accordance with previous studies (Le, 1998; Xiaobing, 2007). The authors reported that the moisture content of bamboo culms is an age-dependent parameter when the young culms have larger moisture content values than the old ones. The decrease of moisture content in older culms is caused by the timber improvement process as the older bamboo culms have thicker wall fibers and higher concentration of vascular bundles (Ahmad, 2003).

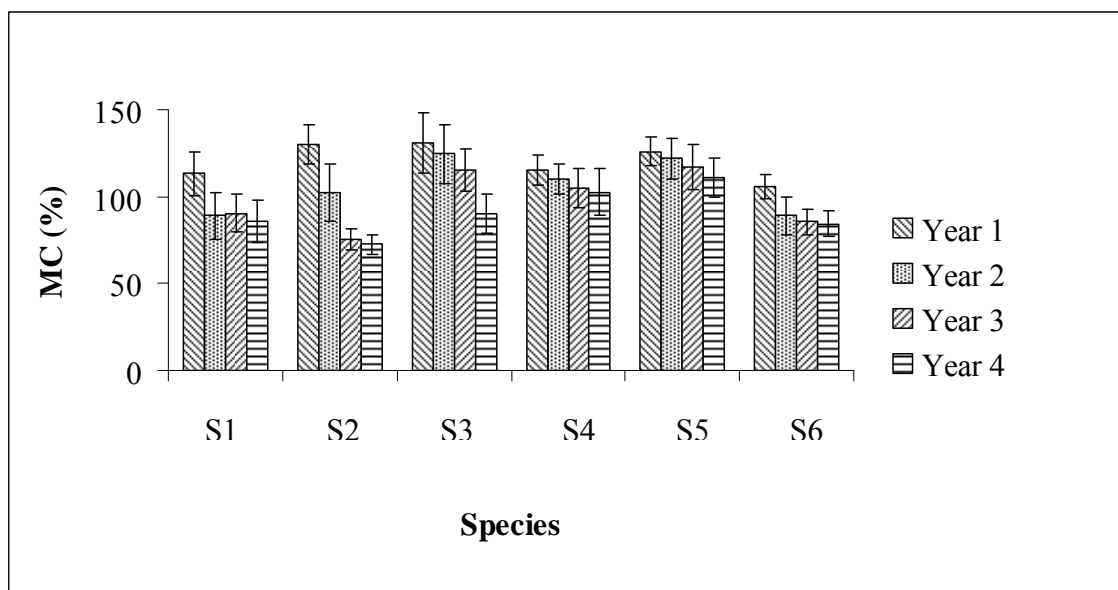


Fig. 13: Moisture content of bamboo culms in four age classes  
(n = 30 test pieces per age class within each of bamboo species)  
S1 - *Oligostachyum* sp., S2 - *Phyllostachys edulis*,  
S3 - *Indosasa angustata*, S4 - *Dendrocalamus latiflorus*,  
S5 - *Dendrocalamopsis* sp. 2, S6 - *Dendrocalamus barbatus*

The moisture content of bamboo culms is found to be very high within age class 1. At this age, moisture content values of some species like *Phyllostachys edulis*, *Dendrocalamopsis* sp. 2, and *Indosasa angustata* are over 100% related to dry weight. However, in the older age classes, the moisture content decreases significantly.

For most study species, a slightly difference in moisture content between age class 3 and 4 was obtained except *Indosasa angustata* which has a remarkable difference in moisture content of those age classes. Therefore, the changing speed of the timber improvement process slows down after the culms reach the three years of age in most study species. Based on this natural phenomenon, the stable stage of bamboo culms can be identified and this stage may occur at the age 3 or 4 in most study species except *Indosasa angustata* that reaches the stable stage at later age.

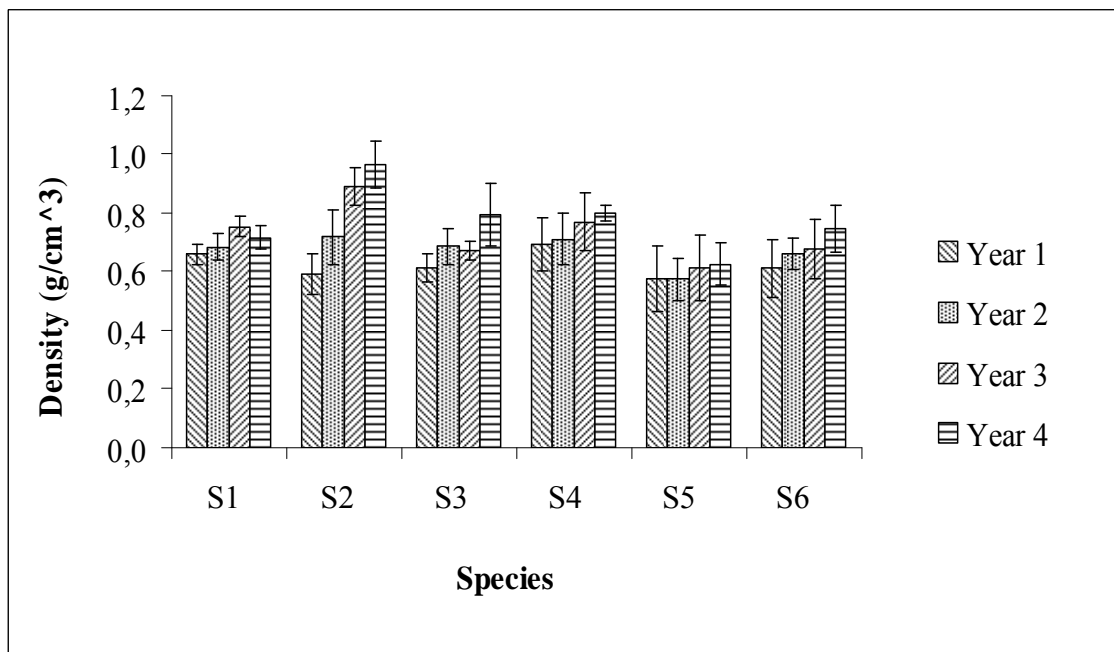


Fig. 14: Basic wood density of bamboo culms in four age classes  
(n = 30 test pieces per age class within each of bamboo species)

S1 - *Oligostachyum* sp., S2 - *Phyllostachys edulis*,

S3 - *Indosasa angustata*, S4 - *Dendrocalamus latiflorus*,

S5 - *Dendrocalamopsis* sp. 2, S6 - *Dendrocalamus barbatus*

The basic wood density depends on the aging although the difference of its values between different age classes is not very high. The observed data show that the values of the basic wood density increase from age class 1 to the older age classes except only *Oligostachyum* sp. which has maximum value in age class 3 and then decreases at age class 4 (Fig. 14). It can be assumed that *Oligostachyum* sp. reaches its mature stage at the age of 3 or 4 and then achieves maximum basic wood density values while the other species may also be mature at those ages but then reach their maximum basic wood density later.

The variation of the basic wood density and moisture content along with ageing of the six study bamboo species corresponds to conclusions of Le (1998) and Wang et al. (2003) who assumed that basic wood density generally increases with the decrease of moisture content. This variation indicates that bamboo culms are mature at a certain age (here: at age 3 or 4) and switch to the stable stage in which physical properties change very little and from then on, those culms should be cut to give space for the new shoots and culms.

#### **4.3.3 Mechanical properties**

Being an anisotropic material, mechanical properties of bamboo are different depending on directions of culms including longitudinal, radial, and tangential. Especially, in a given direction such as radial, the strength of bamboo differentiates from the central part forwards the peripheral part of the culms.

In general the fiber density increases from the inner layers to the outer layers following radial direction of the bamboo culms (Fig. 15) (Liese, 1985; Dransfield and Widjaja, 1995), This variation, therefore, affects the bending strength which is much higher in the outer parts than in the inner parts of the bamboo culms (Liese, 1985, Xiaobo, 2004)

and the outer layers resist a hard tensile stress while the inner layers undergo a larger compressive deformation (Eiichi et al., 2007).

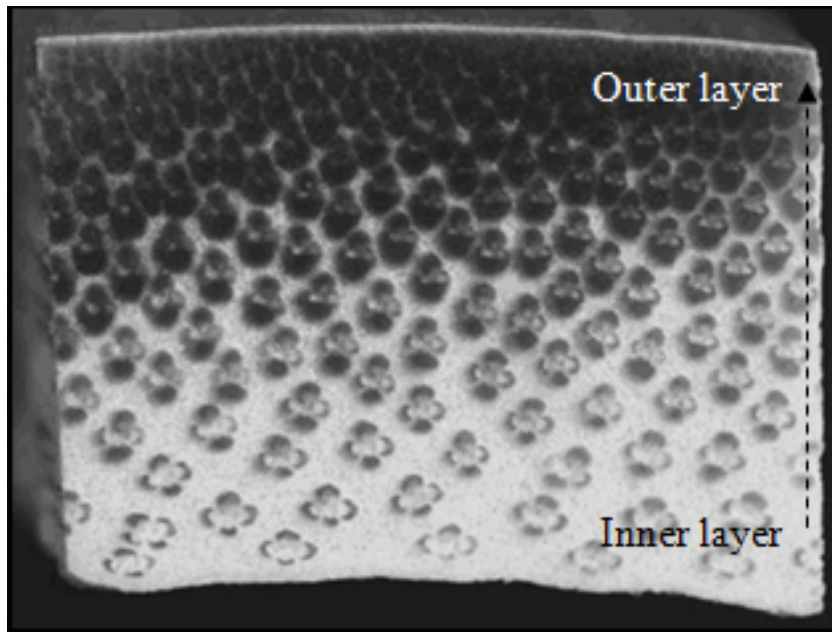


Fig. 15: Macroscopic structure of a cross section of *Phyllostachys pubescens* (a synonym of *Phyllostachys edulis*) (after Eiichi et al., 2007)

#### 4.3.3.1 Bending strength

In this study, the radial bending strength of the six bamboo species was assessed following four different age classes (from class 1 to class 4). The observed data show that the different bamboo species have different bending strength values even within the same age class. In age class 4 for example, *Dendrocalamus barbatus* has the highest bending value with  $179.2 \text{ N/mm}^2$  in comparison with the other species. *Indosasa angustata* with  $155.7 \text{ N/mm}^2$  and *Dendrocalamopsis* sp. 2 with  $157.7 \text{ N/mm}^2$  are two species in the group having the smallest bending values; and the group of *Phyllostachys edulis* with  $172.1 \text{ N/mm}^2$ , *Oligostachyum* sp. with  $170.9 \text{ N/mm}^2$ , and *Dendrocalamus latiflorus* with  $164.3 \text{ N/mm}^2$  is in between.

The bending strength values of bamboo culms of all six study species in this study are very high (see appendix 7.6). The values of bending strength of one year old culms of all bamboo species here are higher than that of *Parashorea chinensis* Wang Hsie with 83.70 N/mm<sup>2</sup> which as a tree species belongs to the woody group III with the high mechanical corresponding properties known in Vietnam (Le, 1998). The bending strength of age class 2 of the study bamboo species can be equally compared with that of *Erythrophleum fordii* Oliv. with 148.10 N/mm<sup>2</sup> which is a tree species in the woody group II with the highest values of mechanical properties commonly used for construction proposes in Vietnam (table 20)

#### 4.3.3.1 Compression strength

For the compression strength, its values vary with different bamboo species (see appendix 7.7). Of the six bamboo species, *Oligostachyum* sp. has outstanding compression strength in its four age classes in comparison with that of the other species. Furthermore, the strength of this species in age class 1 is even higher than that of age class 4 of the others. Therefore, *Oligostachyum* sp. as a special case shows that one species may have the normal value of bending strength whereas its compression strength may reaches very high values.

In comparison with the data presented by Le (1998), the bending strength values of one year old culms of *Dendrocalamus barbatus* and *Oligostachyum* sp. are even higher than those of *Dialium cochinchinense* Pierre with 70.4 N/mm<sup>2</sup> which is one of the tree species having highest mechanical strength belonging to the woody group II in Vietnam. The bending strength values of age class 1 of *Indosasa angustata*, *Dendrocalamus latiflorus*, and *Dendrocalamopsis* sp. 2 including *Phyllostachys edulis* in age class 2 can be equally compared with the bending strength of some tree species commonly used for construction proposes in Vietnam like *Erythrophleum fordii* Oliv. with 66.1 N/mm<sup>2</sup> and *Bassia pasquieri* Lecomte with 62.1 N/mm<sup>2</sup> presented in table 20.

The observed data of mechanical properties including bending strength and compression strength of the six study bamboo species lead to a conclusion that after year two, bamboo culms have sufficient strengths for construction use. Especially, culms of some bamboo species like *Oligostachyum* sp. and *Dendrocalamus barbatus* are ready for use after year one.

Table 20: The bending strength ( $f_m$ ) and compression strengths ( $\sigma$ ) given at 18% moisture content of some common woody species in Vietnam

Species	Vietnamese name	$f_m$ (N/mm <sup>2</sup> )	$\sigma$ (N/mm <sup>2</sup> )
<i>Parashorea chinensis</i> Wang Hsie	Cho chi <sup>(1)</sup>	83.70	47.50
<i>Erythrophleum fordii</i> Oliv.	Lim xanh <sup>(2)</sup>	148.10	66.10
<i>Bassia pasquieri</i> Lecomte	Sen mat <sup>(2)</sup>	176.70	62.10
<i>Dialium cochinchinense</i> Pierre	Xoay <sup>(2)</sup>	205.10	70.40

(after Le, 1998)

Where: (1) wood of group III - the group has high values of mechanical properties;  
 (2) wood of group II - the group has highest values of mechanical properties

#### 4.3.3.1 Effect of aging on mechanical properties

Bamboo is a biological material with complicated mechanical properties which positively differ from that of other materials such as steel, cement or glass. In nature, the mechanical properties of bamboo culms vary due to different species, its growing conditions, age, harvesting time, harvesting techniques, positions in the culm, etc. (Le, 1998).



However, the variation of mechanical properties of bamboo culms in different age classes is one of the most important factors that can be used as an index to manage the cutting time of bamboo culms to meet the certain requirements of the available technologies.

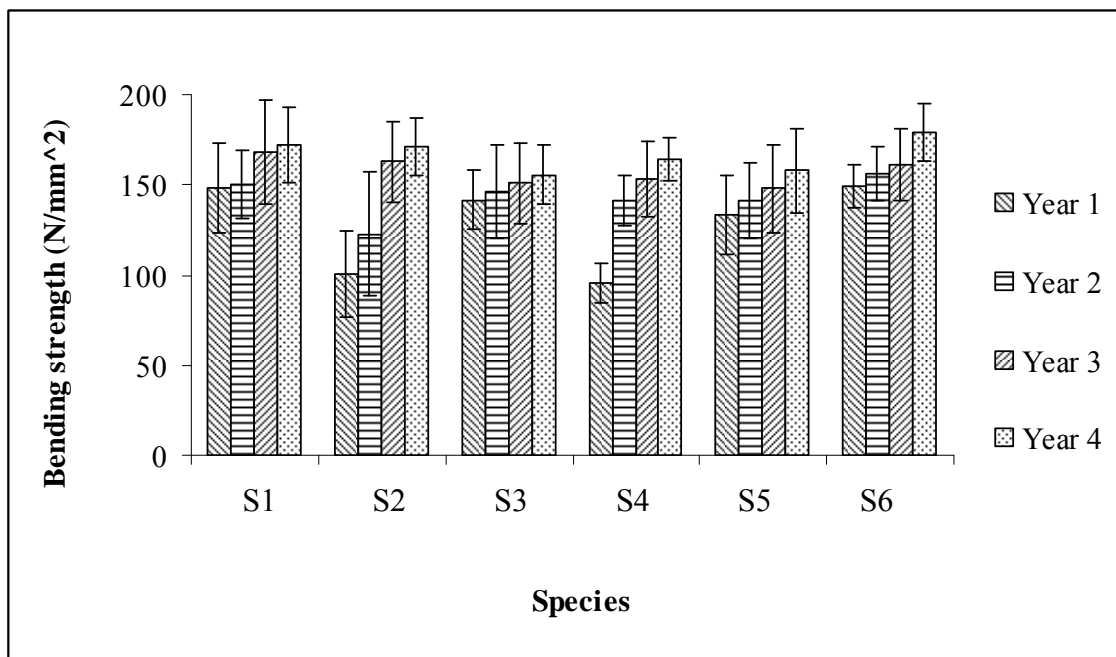


Fig. 16: Bending strength of bamboo culms in four age classes  
(n = 30 test pieces per age class within each of bamboo species)  
S1 - *Oligostachyum* sp., S2 - *Phyllostachys edulis*,  
S3 - *Indosasa angustata*, S4 - *Dendrocalamus latiflorus*,  
S5 - *Dendrocalamopsis* sp. 2, S6 - *Dendrocalamus barbatus*

Like basic wood density and moisture content, bending strength and compression strength of the six species are also influenced by aging. In this study, bending strength and compression strength of most bamboo species have the same tendency increasing from age class 1 to the next age classes, whereas only the compression strength of

*Oligostachyum* sp. reaches its maximum value in age class 3 and then goes down in age class 4

In general, strengths of bamboo get higher when the density of fiber increases (Dransfield and Widjaja, 1995; Eiichi et al., 2007). Therefore, the variation of mechanical properties in four age classes leads to an assumption that the time intervals from age class 1 to age class 4 is the stage of timber improvement of the five bamboo species except *Oligostachyum* sp. which may finish this stage at the age of three because its compression strength reaches maximum in age three and from age class 3 to age class 4 its bending strength increases very little (4.1 N/mm<sup>2</sup>).

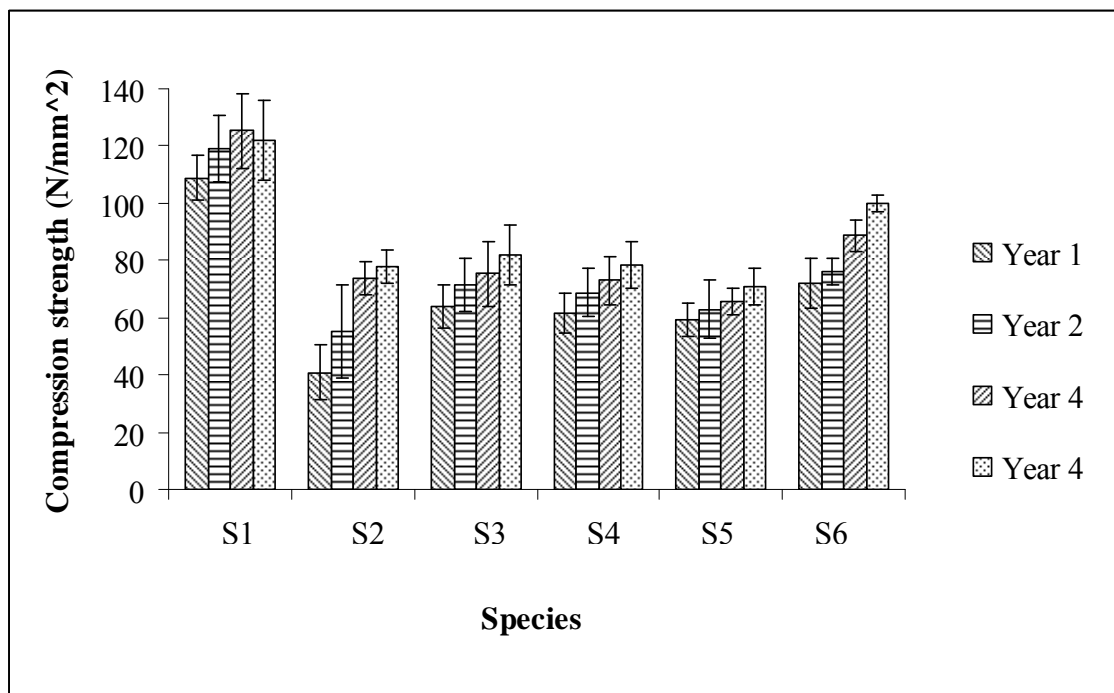


Fig. 17: Compression strength of bamboo culms in four age classes  
(n = 30 test pieces per age class within each of bamboo species)  
S1 - *Oligostachyum* sp., S2 - *Phyllostachys edulis*,  
S3 - *Indosasa angustata*, S4 - *Dendrocalamus latiflorus*,  
S5 - *Dendrocalamopsis* sp. 2, S6 - *Dendrocalamus barbatus*

According to Liese (1985) and Liese and Weiner (1996), bamboo culms become mature at about two or three years of age and then reach their maximum strengths. Fu (2001) announced that the stage of timber quality improvement of bamboo is five years and then the culms move to their stable stage and declining stage in successions. Therefore, it is admitted that the strength properties of bamboo culms reach the maximum values in a specific period of time in coherence with the increase of fiber density and then go down but depending on their own characteristics.

In this study, the bending and compression strengths of the six bamboo species were only observed from age class 1 to age class 4 whereas the older age classes were not included, thus, the maximum values of all bamboo strength properties are unknown. However, the cutting age of bamboo culms should not be latter than age 4 because after this age culms of most bamboo species maybe turn in to over-mature stage.

In addition, the values of bending and compression strength of some species such as *Oligostachyum* sp., *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* are high even in age one (in comparison with the strengths of some woody species presented in table 20), however, at this age the culms are mainly in the reproductive stage (Fu, 1996; Nguyen, 2006), so they should be kept for next generations.

## 4.4 Silvicultural approach

### 4.4.1 Propagation

The six bamboo species can be differentiated into three groups: 1) sympodial (*Dendrocalamus latiflorus*, *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus*), 2) monopodial (*Phyllostachys edulis* and *Indosasa angutata*), and 3) amphipodial (*Oligostachyum* sp), of which the amphipodial is a mixed type of the previous. In general, the bamboo species of the amphipodial group not only have spreading rhizome systems but also have adventitious buds in their stumps (Fu, 1998b); therefore, their growth characteristics are intermediate between the monopodial and the sympodial, but closer to those of monopodial bamboo species. Hence the methods suitable for the monopodial species can be applied for the amphipodial species as well (Fu, 1998b; Nguyen, 2006).

Bamboo can naturally reproduce both generatively and vegetatively. Many propagation methods have been used to produce new bamboo plantlets such as seed sowing, rhizome cutting, stump digging, culm cutting, branch cutting, air layering and tissue culture (Dransfield and Widjaja, 1995; Fu and Banik, 1996; Rao and Zamora, 1996; Kumar, 1996; Lin, 1996; Pattanavibool, 1998; Nguyen, 2006).

The *Oligostachyum* sp. and *Indosasa angutata* stands in this study sites were derived from natural forest areas, after over-exploitation or/and shifting cultivation. At the present, these two species are managed to satisfy the requirements of bamboo shoots and culms as final productions. However, the extension of the areas of those stands is primarily based on the development of running rhizomes.

All of the three sympodial bamboos including *Dendrocalamus latiflorus*, *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* were planted in the study sites. The stump digging method (stump with whole rhizome part) is used for all three species whereas the air layering method was applied to produce *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* plantlets.

For *Phyllostachys edulis*, segments of running rhizomes have been planted. Other methods like culm cutting and branch cutting were not successfully applied for this species (Nguyen, 2006).

#### 4.4.1.1 Rhizome cutting

The rhizome cutting method is commonly used by local people to produce the planting material for monopodial bamboo species. This method has been widely used for species of the genera *Phyllostachys* (Nguyen, 2006). With *Phyllostachys edulis* in the Cao Bang Province for example, running rhizomes of the length of 50 to 60 cm are cut from two or three year old culms (Fig. 18) to used for plantation without raising in the nursery.



Fig. 18: The running rhizome with a shoot bud of *Phyllostachys edulis* in Cao Bang Province, Northern Vietnam

According to the experience of the Dao people, the running rhizomes of *Phyllostachys edulis* at about two or three years of age are used to be planted along streams or at the base of hills showing high rates of success. The experiences can also be applied for

*Oligostachyum* sp. and *Indosasa angutata* when the running rhizome is used as planting material.

#### 4.4.1.2 Stump digging

The stump digging is a very simple method normally used to produce the planting material for most of all bamboo species in rural areas of Northern Vietnam. For so many sympodial bamboo species with limited branches this method is quite the sole choice of local people in Northern Vietnam at present.

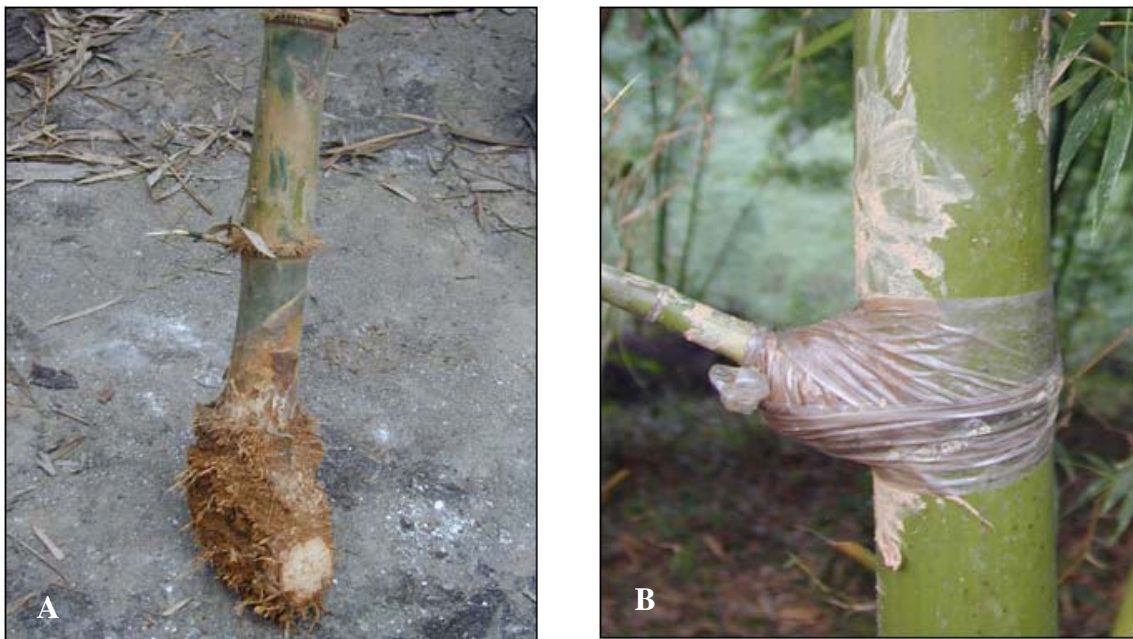


Fig. 19: Vegetative propagation of *Dendrocalamus barbatus* in Phu Tho Province, Northern Vietnam (A - Stump digging, B - Air layering)

In cases of *Dendrocalamopsis* sp. 2, *Dendrocalamus barbatus*, and *Dendrocalamus latiflorus* in the Phu Tho Province, stumps of one or two year old culms are normally used. The stumps with one or two internodes is separated from the mother culms at the culm neck to keep the whole rhizome part which can be directly planted or germinated in

the nursery before planting. With this method a high expenditure of labor and transportation is required because those sympodial bamboo species normally have the big, deep and complex rhizome system.

#### 4.4.1.3 Air layering

The air layering method can be widely applied for bamboo species with a developed branch system because it allows branches to propagate new plantlets without aerial rooting system. Furthermore, by using branches, this method can provide a large amount of planting materials with lower price for bamboo reforestation or/and afforestation in a large scale. Normally, three to ten month old branches can be used.

Table 21: Success rate of air layering of *Dendrocalamopsis* sp. 2 in different dates

Date	The number of layers	Success rate (%)	Layering time (day)
15 <sup>th</sup> July	300	100	20 - 30
15 <sup>th</sup> August	400	100	20 - 25
15 <sup>th</sup> September	200	52	30 - 35
15 <sup>th</sup> October	400	15	40
15 <sup>th</sup> November	100	0	

(after Le and Nguyen, 2000)

Spring (January to March) and in autumn (June to August) are appropriate seasons of the air layering method application. The method shows the high percentage of rooting branches in these two seasons (table 21). Normally, branches are notched about two thirds of their basal area, surrounded by suitable propagating medium, and covered by plastic ribbons and after 20 days over 95 % of the notched branches produce new roots (Le, 1990; Le and Nguyen, 2000; Nguyen, 2006). However, air layering trials for some other species like *Bambusa vulgaris* and *Dendrocalamus giganteus* showed only 10 %

success, for *Dendrocalamus asper*, the successful rate increased up to 50 %, whereas for *Melocanna baccifera*, no branches produce any new roots when this method is applied (Dransfield and Widjaja, 1995).

The air layering method can be appropriately applied for only two sympodial species including *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* out of the six study species because those two species have a larger number of branches which strongly spread out from their nodes and which are located in low positions of the culms. The propagating technique and process applied for the two species were published by Le and Nguyen (2000). However, the air layering method can not be used for the other four species because they possess a limited number of branches that develop only in some nodes on the top part of their culms. Thus, rhizome cutting is the feasible method for those species in Vietnam so far.

#### **4.4.1.4 Further prospective propagation methods**

The branch cutting is an effective method to satisfy the demands of bamboo reforestation or/and afforestation in a large-scale. This method has been successfully applied in Vietnam for the species with developed aerial rooting system like *Dendrocalamus barbatus* Hsueh & D.Z.Li (Nguyen, 2006) or *Dendrocalamus asper* Backer ex K. Heyne and *Bambusa vulgaris* Ness in Thailand (Dransfield and Widjaja, 1995; Rungnapar, 1998).

Two or three year old branch segments of 50 cm length of *Gigantochloa levis* (Blanco) Merr. were used as starting material to investigate the benefits of poly-bags in branch cutting in Malaysia. Othman and Noor (1995) concluded that using poly-bags gave a better percentage of survival and rooting than laying directly cut branches on nursery beds, whereas nursery beds can produce more vigorous plantlets than poly-bags do. The author also indicated that the growth of the cutting can be further enhanced by using



IBA 2000 hormone powder with the concentration of 400 ppm that was applied by the contact method.

Rios (1996) introduced the '*Basal branch method*' applied for *Guadua angustifolia*. The idea based on a natural particularity of the species that branches of the basal part of a culm grow plagiotropous and then reach down towards the soil and plantlets are formed from nodal buds. This method was successfully used for branches which were removed from the culm below the 18<sup>th</sup> node and divided into segments of 4 to 5 cm length and disinfected by Benomyl solution.

Culm cutting is an effective method for sympodial species like *Bambusa* or *Dendrocalamus* (Rungnapar, 1998; Nguyen, 2006) of which one year old culms are most suitable. Either the whole selected culms or their segments with at least one node can be used. The appropriate seasons are spring and autumn (Le, 2000). Those materials should be horizontally ground laid in soil a depth of 5 to 10 cm. It is more successful when the propagation materials are treated by growth stimulant solutions before planting (Dransfield and Widjaja, 1995; Nguyen, 2006). A disadvantage of this method is higher expense in comparison with some others because it requires culms (the most useful part of bamboo) as materials.

In India, production of somatic embryos has been applied for some species such as *Dendrocalamus strictus*, and *Bambusa bambos* (Dransfield and Widjaja, 1995). Plantlet production has also been applied in Thailand, India and America that showed successful results by using seeds and stem pieces (Nguyen, 2006).

The application of tissue culture methods for bamboo propagation has not been reported in Vietnam but through literature micro-propagation, somatic embryogenesis, and in vitro flowering have been introduced by European and American researchers (Nguyen, 2006). However, most of those methods cannot be applied in some developing countries

at present because those methods require advanced of infrastructural facilities (Saxena and Dhawan, 1995).

#### **4.4.2 Density and spacing**

The planting density of the three sympodial bamboo stands planted for culm-timber in the Phu Tho Province was 200 clumps per hectare with spacing of 7 x 7 m. According to MARD (2000) the suitable planting density for *Dendrocalamus barbatus* in pure culm-timber stands is 200 clumps per hectare and the spacing is 5 x 10 m. Le (2000) suggested that there should be two planting densities for this species (200 clumps/ha, 5 x 10 m) and (250 clumps/ha, 4 x 10 m). In general, the dendrometric characteristics and the growing habit of *Dendrocalamus latiflorus* and *Dendrocalamopsis* sp. 2 are similar to those of *Dendrocalamus barbatus*, so that those densities might be suitable for all three sympodial species.

For three monopodial and amphipodial bamboo stands including *Oligostachyum* sp., *Phyllostachys edulis*, and *Indosasa angustata* planted for culm-timber and shoot products, the current densities are 7488, 4511, and 2419 culms per ha, respectively. The *Oligostachyum* sp. and *Phyllostachys edulis* have very high standing culm densities causing negative impacts on the product sizes. This result corresponds to the previous report of Fu and Banik (1996). The authors suggested that the planting density of 2500 culms per hectare (2 x 2 m in spacing) for those species should be applied.

#### **4.4.3 Planting**

##### **4.4.3.1 Planting time**

For the sympodial species, the growth of a bamboo culm begins when the lateral buds of the rhizome differentiate into shoot buds from March to April. Before the shoots emerge from the soil, the number of their nodes is definite. Shoots emerge upward the ground

from June to October by the internodes elongating from cell division of the intermediate tissues (Fu, 2001). Therefore, from late winter to early spring is believed to be the best planting time for those species because after planting, the new shoots will have more favorable conditions of the spring to grow.

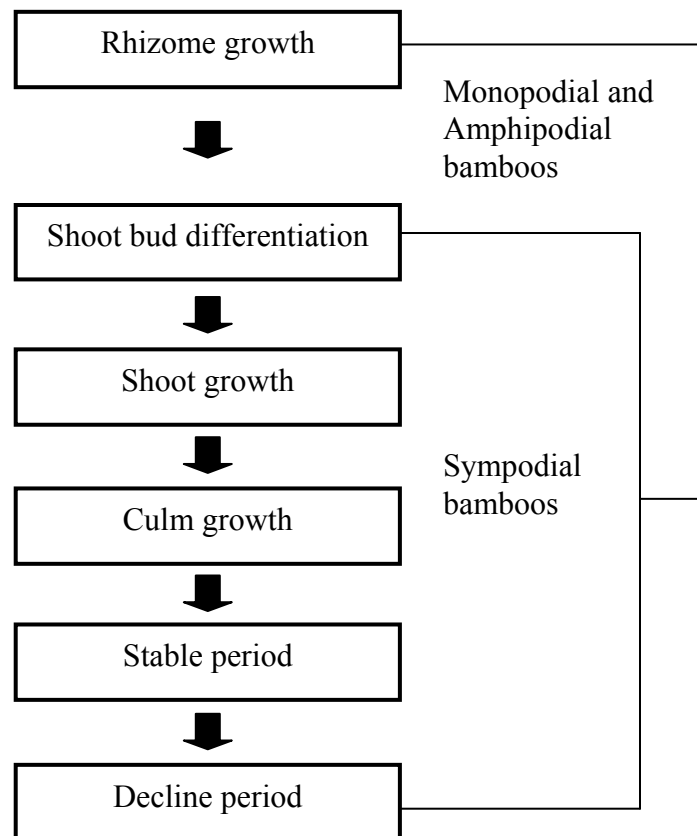


Fig. 20: Growth stages of bamboos (drawn according to data from field survey)

According to MARD (2000) and Le (2000), in the Northern Vietnam sympodial bamboos like *Dendrocalamus barbatus* can be planted twice a year, in spring (January to March) and in autumn (June to August). The previous studies indicated that the sympodial bamboo species can be planted throughout the year time. However, the best time is from January to March when the mother rhizome is still in dormancy period with comparatively lower physiological activity and higher nutrient accumulation (Lin, 1996; Fu, 1998b).

Unlike sympodial bamboos, the first development stage of monopodial and amphipodial species is rhizome growth that takes place from May to July. Following this stage, lateral buds of the rhizome differentiate in to shoot buds from August to September (Fig. 20), and shoots emerge from the soil from January to April. Therefore, monopodial and amphipodial bamboo species can be planted throughout the year. However, the best planting time with favorable conditions is from late winter to early spring or in the rainy season.

In the Cao Bang Province, the indigenous knowledge of the Dao people indicated that the best planting time for *Phyllostachys edulis* is the dry season just before and after the Lunar New Year. It is in accordance with Fu (1998) that the survival rates of *Phyllostachys praecox* C.D.Chu & C.S.Chao planted in winter, spring, and in the rainy season are 96.4, 99.5, and 91.3%, respectively. Therefore, large scale planting is better in late winter or/and early spring.

#### **4.4.3.2 Site preparation**

Before digging planting holes, shrubs and weeds are to be cleared. Several techniques can be used such as overall, strip and lump land clearing. The overall land clearing can change the land environment negatively so it is favorable to establish pure bamboo stands with strip land and lump land clearing. Those techniques are frequently used in the steep hillsides to prevent soil erosion and water loss (Fu Maoyi, 1998; Le, 2000; MARD, 2000).

The planting space should be carefully calculated before digging planting holes. After digging, holes should be filled in two third of the depth using a combination of soil and organic fertilizer (dung of cattle) and this work must be conducted at least one month before planting (Le, 2000; MARD, 2000). The hole-size depends on the species. For big and middle size bamboo species the hole-sizes should be 100 x 60 x 50 cm (in length, width, and depth, respectively) and for smaller size bamboo species, their hole-sizes can be 80 x 50 x 30 cm (Fu, 1998b).

The hole-size is also pre-determined based on the planting materials. If the seedling is used as planting material, the hole-sizes depend on the sizes of seedlings (Fu, 1998b). If the plantlet is used, the suitable hole-size is 60 x 60 x 50 cm (Le, 2000; MARD, 2000). If running rhizomes are used to plant directly, the soil should be loosed along the strips in about 30 to 40 cm depth and 100 cm width.

#### **4.4.3.3 Planting techniques**

To reduce the mortality to a minimum, the planting material should be nursed. The nursing period is about 4 to 6 months which is sufficient for new shoots to fully develop to plantlets with spreading branches and unfolding leaves. It is important that the selected plantlets are not damaged by any pests and diseases.

The plantlets or stumps used for planting are placed in the center of the holes in a depth of about 30 cm, slanted at 60 to 70 degrees ensuring that the branches are spreading and finally fill the holes with soil and jam it moderately.

Being directly planted, running rhizomes are horizontally laid on the strip in a depth of about 20 to 30 cm and covered with soil. After the soil is firmly pressed, the running rhizomes are finally covered with grass to maintain soil humidity. It is important that the plantlet should be protected from damages by animals, drought, and water-logged. If there is no precipitation after planting, watering is required every 3 to 5 days.

#### **4.4.4 Tending**

New planted bamboo stands need to be tended three times per year during the first three years. The first tending time in the year should be carried out in spring season. The tending practices are climber cutting, soil loosening to a depth of 15 to 20 cm, and clearance of weed in a radius of 1m around the bamboo clumps. Only climber cutting is required in the following tending times.

In the first three years, agro-forestry techniques can be applied to reduce labor of watering, loosening and weeding. Inter-cropping with nitrogen-fixing plants like species of the *Fabaceae* family and application of green manure from the intercrop itself is useful to reduce fertilize cost. Otherwise, proper bamboo agro-forestry models accelerate the growth of all components increasing both yield and quality of multiple products (Fu et al., 1994).

Both organic and chemical fertilizers are important to ensure higher and sustainable productivity of bamboo stands (Fu and Banik, 1996; Kleinhenz and Midmore, 2001). Organic fertilizer is best applied during the dry season while chemical fertilizer may be used in the wet season (Fu and Banik, 1996). According to Le (2000) and MARD (2000), fertilizer (1 kg NPK/clump) can be applied only once a year, best in spring. Lin (1995) suggested that a suitable fertilizer should be applied twice per year: the first time should be done when shoot buds differentiate from lateral buds of rhizomes, and the second time could be applied when shoots are in their highest production.

#### **4.4.5 Thinning**

Thinning is applied when new bamboo stands reach the age of four or five years. The suitable time is the dry seasons, from September to January (Le, 2000). All of the culms up to three years of age should be thinned. Unwanted formed culms such as topless culms, horseshoed culms and dry-out culms are removed as well (Dransfield and Widjaja, 1995). In addition, thinning of bamboo stands should be done before spring. After thinning, the ground should be cleaned up and tending operations are required.

Weak shoots should also be removed to ensure sufficient nutrients for the healthy ones (Fu and Banik, 1996). In general, the main period of shooting of sympodial bamboo species is from July to August and that of monopodial species is from February to March. During these periods of time, shoots grow strongly and they should be kept to obtain new culms. The other shoots growing in earlier and later stages need to be thinned.

#### 4.4.6 Pest and disease management

Common pests attacking bamboos are shoot borers, culm borers, sap suckers, leaf rollers, shoot weevils, bamboo aphids and cutworms (Singh, 1988; Mathew and Varma, 1990; Fu and Banik, 1996). According to Le et al. (2007), eight insect species of five families damaging bamboo shoots were found in Northern Vietnam. The most harmful species are *Cyrtotrachelus buqueti* Guer, *Cyrtotrachelus longimanus* Fabricius, *Otidognathus davidis* Fabricius, *Notobitus meleagris* Fabricius, and *Notobitus monatus* Hsiao. Covering the shoots with plastic bags to prevent damage by those insects is a recommended technique.

Bamboo witches' broom caused by *Aciculosporium take* Miyake was first reported in 1909 in Japan (Jung et al., 2006). Similar diseases caused by *Balansia linearis* (Rehm) Diehl affecting red bamboos was recorded in natural stands and plantations in Kerala State, India (Mohanani, 2004). In Vietnam a disease caused by other fungi like *Balansia take* has been diagnosed several times (Le, 2000).

Bamboo witches' broom reduces the internodal length and size of bamboo culms, sheath and leaves. The infection was recorded throughout the year (Mohanani, 1988). This disease has become a serious threat affecting several bamboo species such as the species of *Phyllostachys*, *Dendrocalamus*, and *Bambusa*. Cutting and burning of the infected parts of bamboos are widely used to prevent the spreading of the disease.

There are several other diseases of bamboos such as little leaf disease, rhizome bud rot, and rhizome decay (Mohanani, 1988). However, there are no records of expanded culms being attacked in any serious manner by fungal pathogens (Boa, 1964). Furthermore, pathogens of bamboo diseases have not been clearly identified and rarely have the control measures been discussed. Thus, some silviculture methods like weeding or/and soil loosening to improve diseases resistance of bamboos are recommended (Fu and Banik, 1996; Le, 2000).

#### **4.4.7 Harvesting**

##### **4.4.7.1 Shoot harvesting**

Harvesting is one of the most important activities to improve the production of bamboo stands in both quantity and quality (Roxas, 1998). Silvicultural treatments and harvesting operations are essentially required to reverse the degradation process of bamboo stands (Embaye, 2003). There have been no general models of harvesting which can be applied for all bamboo species so far. However, the harvesting time, the number of felling shoots and culms, and the harvesting cycles of an individual species should be considered for harvesting activities.

Each rhizome has several lateral buds and some of them differentiate into shoot buds. Under the ground, in a period of about three months, shoot buds mainly grow in diameter. After this development stage, shoots emerge out of the ground and mainly grow in height, now containing the highest contents of nutrition. Therefore, the time when bamboo shoots emerge out of the ground (at the end of the diameter development stage) is suitable as harvesting time.

Within the mature bamboo stands, all of the shoots that grow in earlier and later stages of shooting can be harvested. In the main shooting stage, excluding a reasonable number of shoots kept to produce new culms, the remaining are to be harvested. In addition, each mother rhizome has several shoot buds but only one or two of them can develop into new culms. Thus, the other shoots need to be removed to save nutrients.

Before harvesting the top soil around the shoot should be raked off. The shoot must be cut at the culm neck and along the culm base by using sharp tools to leave a flat cut surface (Lin, 1996). In case of monopodial bamboos, their shoots grow far from the mother culms, so that it is difficult to identify running rhizomes under the ground. Therefore, shoots should be dug carefully to protect the rhizomes during the harvest.



#### 4.4.7.2 Culm harvesting

Harvesting should be carried out during the dry season, from November to following January when the culm nutrient and starch content are the lowest with the aim to prevent culms being attacked by borers. Otherwise, in the rainy season, young culms still develop and they are considered to be strong enough in winter to withstand mechanical damages of harvesting activities (Dransfield and Widjaja, 1995; Fu and Banik, 1996; Le, 2000; MARD, 2000; Upreti and Sundriyal, 2001; Embaye, 2003).

Two methods of bamboo stands harvesting are clear felling and selective cutting. However, the clear felling method is applied only for the stands that show mass flowering. This method should not be used for the young and mature stands because it allows the cutting of all culms, so that young culms in the following years will have no supports to prop up, their top parts may easily be broken by the wind, and the vitality will decrease. The consequences will be a decline of production in both quantity and quality.

The analysis of mechanical properties of the six bamboo species show that several technological feature as bending and compression strengths reach their optimum at age 3, so that based on this and different purposes of uses, felling age of culms is two or three years. In case of *Oligostachyum* sp., *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* one year old culms can also be used but cutting those culms may influence the regeneration capacity of the bamboo stands, and thus, cutting at this age is not recommended.

In India, a three or four year cutting cycle was suggested for common bamboo species (Negi and Naithani, 1994). This cutting cycle was recommended by Upreti and Sundriyal (2001) for bamboo plantation stands as well. According to MARD (2000), the cutting cycle of some species of the *Dendrocalamus* family in Vietnam is one or two years depending on cultivation levels. If one-year cutting cycle is applied, 30% of the

total number of bamboo culms can be harvested, and in case of two-year cutting cycle a percentage of 40% is recommended. According to the variations of physical and mechanical properties of bamboo culms observed here, the cutting cycle of three years is an option for the study stands and cutting can take place for all three year old culms. However, one or two years cutting cycles can be applied as well if necessary.

Harvesting is applied when new established bamboo stands reach an age of six years (MARD, 2000). Before the harvesting operations, pruning should be applied. The selected culms to harvest culms need to be marked with red paint. Culms should be cut just above a node to make sure that water will not accumulate in the hollow internodal segment to avoid rotting of the base. The remaining stumps should keep at least two nodes to protect the whole rhizome part. Shoots and other culms have to be protected from mechanical damages during harvesting.

After the harvest, tending activities are needed before February. Soil loosening in a depth of 15 to 20 cm around clumps in a radius of 1 m is required and fertilizer (1 kg NPK/clump) should be applied.

#### 4.4.8 Silviculture operations for bamboo management in Northern Vietnam

##### 4.4.8.1 Schematic plan for natural bamboo forest enrichment

Year	Activities	Main decisions	Description
- 1	Thinning (high pruning)	<ul style="list-style-type: none"> <li>- Removing undesirable and inferior trees</li> <li>- Cutting all culms without top part, dry-out culms, horseshoe culms and over-mature culms</li> </ul>	<ul style="list-style-type: none"> <li>- Thinning to be carried out in dry season<sup>(1)</sup></li> <li>- The distance of residual culms is 2-5 m</li> </ul>
- 0.5	Raise plantlets in nursery	<ul style="list-style-type: none"> <li>- Layers to be raised in containers in about 4 months</li> <li>- Stumps and rhizomes can be planted without rising</li> </ul>	<ul style="list-style-type: none"> <li>- Prospect plantlets have spreading branches and uninfected by pests and diseases</li> </ul>
-0.1	Prepare ground	<ul style="list-style-type: none"> <li>- Clearing shrubs and weeds</li> <li>- Digging holes</li> <li>- Bed-dressing application</li> </ul>	<ul style="list-style-type: none"> <li>- The hole size: 60 x 60 x 50 cm (length, width, depth)</li> <li>- Applying 5 - 10 kg Bio-fertilizer<sup>(4)</sup>/ hole</li> </ul>
0	Planting	<ul style="list-style-type: none"> <li>- Sympodial bamboos planted in spacing of 4 x 10 m or 5 x 10 m</li> <li>- Monopodial and Amphipodial planted in spacing of 2 x 2m</li> </ul>	<ul style="list-style-type: none"> <li>- Line enrichment and gap planting</li> <li>- Planting times are spring<sup>(2)</sup> and autumn<sup>(3)</sup></li> </ul>
+ 1-2	Tending	<ul style="list-style-type: none"> <li>- Tending applied at two times a year in spring and autumn</li> <li>- Cutting climber, loosening soil and top-dressing application</li> </ul>	<ul style="list-style-type: none"> <li>- Soil to be loosed in 15 - 20 cm depth surrounding clumps</li> <li>- Applying 1 kg NPK/ clump</li> </ul>
+ 3	Low pruning	<ul style="list-style-type: none"> <li>- Climber cutting</li> <li>- Removing undesirable culms</li> </ul>	<ul style="list-style-type: none"> <li>- Suitable time is dry season</li> </ul>
+ 5 and following years	Harvesting	<ul style="list-style-type: none"> <li>(1) Shoot harvesting               <ul style="list-style-type: none"> <li>- The cutting cycle is one year</li> <li>- Keep a number of shoots equal with the number of cut culms in the main shooting stage</li> </ul> </li> <li>(2) Culm harvesting               <ul style="list-style-type: none"> <li>- The cutting cycle is three years</li> <li>- Harvest 40% of culms</li> <li>- Culms 2- 3 years old can be cut</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>- Harvesting shoots when they just emerge out of the soil in early and late stages of shooting</li> <li>- Harvesting culms during the dry season</li> <li>- Fertilizing (1 kg NPK/clump) after harvest</li> </ul>

Note: (1) - from Oct to Jan; (2) - from Jan to Mar; (3) - from Jun to Aug;

(4) - mixture of rice husk or/and remain of crops and dung of cattle

#### 4.4.8.2 Schematic plan for open land bamboo plantation

Year	Activities	Main decisions	Description
-0.5	Propagation	<ul style="list-style-type: none"> <li>- Air layering (in spring<sup>(1)</sup> or autumn<sup>(2)</sup>)</li> <li>- Rhizome cutting (in spring)</li> <li>- Stump digging (in spring)</li> </ul>	<ul style="list-style-type: none"> <li>- Branches (3-10 months) of culms at 1-2 years of age</li> <li>- Rhizome of culms at 2 - 3 years of age</li> <li>- Stumps of culms at 1-2 years of age</li> </ul>
- 0.5	Raise plantlets	<ul style="list-style-type: none"> <li>- Layers to be raised in containers</li> <li>- Stumps and rhizomes can be raised in raising beds</li> </ul>	<ul style="list-style-type: none"> <li>- The raising time is at last four months</li> </ul>
- 0.1	Prepare ground	<ul style="list-style-type: none"> <li>- Clearing shrubs and weeds</li> <li>- Digging holes</li> <li>- Bed-dressing application</li> </ul>	<ul style="list-style-type: none"> <li>- The hole size: 60 x 60 x 50 cm (length, width, depth)</li> <li>- 5 -10 kg Bio-fertilizer<sup>(4)</sup>/ hole</li> </ul>
0	Planting	<ul style="list-style-type: none"> <li>- Sympodial bamboos planted in density of 200 – 250 clumps/ha (4 x 10 m or 5 x 10 m)</li> <li>- Monopodial and Amphipodial planted in density of 2500 clumps/ha (2 x 2m)</li> </ul>	<ul style="list-style-type: none"> <li>- Planting times are spring and autumn</li> <li>- Plantlets placed in 30 cm depth, slanted at 60 degrees</li> </ul>
+ 1 - 3	Tending	<ul style="list-style-type: none"> <li>- Tending applied at two times a year in spring and autumn</li> <li>- Clearing weeds, loosening soil and top-dressing application</li> </ul>	<ul style="list-style-type: none"> <li>- Soil to be loosed in 15 - 20 cm depth surrounding clumps</li> <li>- Applying 1 kg NPK/ clump</li> </ul>
+ 4	Thinning	<ul style="list-style-type: none"> <li>- Cutting culms above 3 years of age</li> <li>- Removing culms without top part, dry-out culms and horseshoe culms</li> </ul>	<ul style="list-style-type: none"> <li>- Thinning in dry season<sup>(3)</sup></li> </ul>
+ 6 - 20 - (-30)	Harvesting	<p>(1) Shoot harvesting</p> <ul style="list-style-type: none"> <li>- The cutting cycle is one year</li> <li>- Keeping a number of shoots equal with the number of cut culms in the main shooting stage</li> </ul> <p>(2) Culm harvesting</p> <ul style="list-style-type: none"> <li>- The cutting cycle is three years</li> <li>- Harvest 40% of culms</li> <li>- Clear cut is only applied for the stands showing mass flowering</li> </ul>	<ul style="list-style-type: none"> <li>- Shoots growing up in the early and late stages of shooting are to be harvested</li> <li>- Harvesting shoots when they just emerge out of the soil</li> <li>- Harvesting time is dry season</li> <li>- Cutting culms 2- 3 years of age</li> <li>- Fertilizing (1 kg NPK/clump) after harvest</li> </ul>

Note: (1) - from Jan to Mar; (2) - from Jun to Aug; (3) - from Oct to Jan  
 (4) - mixture of rice husk or/and remain of crops and dung of cattle

## 5 Summary

Forest resources in Vietnam are abundant and diversified, with bamboo playing an important role in socio-economic development and ecological environment, especially in bio-diversity conservation. As a result, the plantation of many bamboo species was outlined in the “5 Million Hectares Reforestation Programme” which was approved by the Vietnamese Government in 1998. However, problems still exist in propagation, harvesting, storage, processing, and marketing of most bamboo species. To contribute to solving some of these abovementioned issues and in order to provide additional knowledge of sustainable management practices in bamboo forests, this research focuses on the six indigenous bamboo species in the mountainous regions of Northern Vietnam.

This study was conducted in four different locations, all of which are located in the mountainous regions of Northern Vietnam:

- 1) The Nguyen Binh district in the Cao Bang Province (22°40' N, 105°53' E) is a limestone highland area with a complex topography. This area has a sub-tropical climate with cold winters (sometimes with snow); the mean annual temperature is 20.3°C, and the mean annual precipitation is about 1763 mm.
- 2) The Yen Binh district in the Yen Bai Province (21°48' N, 104°58' E) has a tropical monsoon climate with cold-wet winters and rainy summers; the mean annual precipitation of this region is about 2106 mm while the mean annual temperature is 22.7°C.
- 3) The Doan Hung district in the Phu Tho Province (21°32' N, 105°11' E) is a transition area in between the mountainous region and the plains. The district has four separate seasons with cold winters and rainy summers; the mean annual temperature is about 23.1°C, and the mean annual precipitation of the area is about 1850 mm.

- 4) The Tan Lac district in the Hoa Binh Province (20°38' N, 105°12' E) is a combination of valleys and high limestone mountains of the northwest region of Vietnam. The district has a tropical climate affected by annual monsoons. As a result, it has cold winters consisting of low rainfall (dry period from 4 to 5 months). The mean annual temperature is 23.0°C, and the mean annual precipitation is about 1833 mm.

In this study, six indigenous bamboo species found in the mountainous areas of Northern Vietnam were selected since those species have high economic value and on satisfy certain requirements of available technologies in Vietnam. Based on their growing habits, these species can be differentiated into three groups:

- 1) The group of sympodial bamboo species includes *Dendrocalamus latiflorus* Munro, *Dendrocalamopsis* sp. 2, and *Dendrocalamus barbatus* Hsueh et D.Z.Li
- 2) The group of monopodial bamboo species consists of *Phyllostachys edulis* Lehaie and *Indosasa angustata* McClure
- 3) The group of amphipodial bamboo species embraces *Oligostachyum* sp.

To obtain the necessary information of bamboo management systems including the activities and time schedule of seeding, planting, tending, pruning and logging, etc., a field survey was conducted in three steps: first, available relevant documents about bamboo management systems and elaborating semi-structure questionnaires were collected; second, the field work was conducted; and third, the collected data were analyzed.

To investigate the stand structure, the sampling stands were selected separately for each bamboo species and the sample plots were set up in squares of 20 m x 20 m. For each species, 9 sample plots were randomly selected. In each sample plot, the total number of culms, the total number of clumps, and the total number of culms per clump were

counted. The age of the culms was identified based on the traditional experience of foresters. The diameter at breast height of all culms was measured. For each study species, one representative sample plot was selected to measure the height of all bamboo culms.

To determine the dendrometric characteristics of the bamboo species, four culms in four different age classes were randomly selected within each sample plot (36 culms per species). After measuring their culm height ( $h$ ) and diameter at breast high ( $d$ ) they were cut to count the total number of internodes ( $I$ ) and measure the total culm length ( $l$ ) and culm wall thickness ( $t$ ).

To determine the physical and mechanical properties of bamboo culms, at the height of 3 meters from the base of each cut culm, a section of six internodes (three above and three under the point of three meters) was cut and dried to 12% moisture content. Within each bamboo species, the physical and mechanical properties were tested in four age classes (from age one to age four) using 30 samples for each test.

The specimens used to determine the moisture contents (MC) were 25 mm wide, 25 mm long and as thick as their culm wall thickness. The specimens used for the basic wood density test were 15 mm wide, 15 mm long, and as thick as their culm wall thickness.

The radial bending test was conducted, and the specimens used for this test had dimensions of 12 mm wide, 200 mm long, and as deep as their culm wall thickness. The compression strength was tested in the longitudinal direction and the specimens used for this test had the prism form with 15 mm long, 15 mm deep and as wide as culm wall thickness. Those tests were conducted based on the standard TCVN 356-70 of Vietnam using Universal Testing Machine MTS QT/25 (USA) in the wood laboratory of the Forestry University of Vietnam.

To achieve information on the general soil conditions of the research areas, some physical and chemical characteristics of the soil were analyzed. For each bamboo species, 9 single soil samples were taken at the center of the 9 field plots, at the depth of

35 cm since the rhizome systems of almost all bamboo species develop at that depth. The investigated parameters of soil were soil texture (sand, silt and clay), hydrolysis acidity (Hs), organic materials (OM), soil pH, cation exchange capacity (CEO), and major nutrients ( $\text{NH}_4^+$ ,  $\text{K}_2\text{O}$  and  $\text{P}_2\text{O}_5$ ). The analyzing process was carried out at the laboratory of the Forestry University of Vietnam.

To analyze plant osmotic potential at midday and in the state of full water re-saturation, six individual culms were randomly selected from each bamboo species during the dry season. Each leaf sample consisted of 8-10 grams of fresh leaves taken from sun-exposed branches at an insertion height of 6 - 8 m in Northern exposition. For each selected bamboo culm, one leaf sample was directly collected at 12h00 - 13h00 and one other was harvested after full water re-saturated. After being picked, these leaves were weighed in the fresh state immediately, and then were killed-off by using a mobile gas stove to avoid enzymatic changes. Further processing was carried out at the laboratory in Goettingen following the standard processing described by Kreeb (1990) using a semi-micro osmometer (Knauer, Berlin, Germany).

The following major results were obtained:

- 1) The observed data of plant osmotic potential vary due to bamboo species. Owing to different values of osmotic potential, each species adapted itself to different site conditions. Of the six bamboo species, *Phyllostachys edulis* has a limited distribution as it only grows well in some of the mountainous provinces of northwestern Vietnam, under the soil conditions consist of high concentrations of osmotically active solutes when compared with the sites of the other bamboo species. The group of *Indosasa angustata*, *Dendrocalamus latiflorus*, *Dendrocalamopsis* sp. 2 and *Dendrocalamus barbatus* can grow under about the same site conditions with poorer soil concentrations and *Oligostachyum* sp. falls between these groups.
- 2) In this study, the inverse relationship between yield and diameter of shoots and culms determined by standing culm density was confirmed. The defined



principal is that lower standing culm densities promote their diameter but reduce the total yield and, in contrast, higher standing culm densities increase the total yield but reduce diameter of shoots and culms. Therefore, depending on different purposes of use, the standing culm density of bamboos can be maintained in an appropriate manner to obtain expected products.

- 3) The age of bamboo culms was determined by using the combination of three methods including judging of culm color, counting twig scars, and positioning of culms. Judging of culm color showed higher efficiency to assess young culms (under five years old). After this age, the true color of the culms can not be judged because lichen, fungi, and mosses grow on the culm surface and as a result, a white-grey color appears.
- 4) The diameter of bamboo culms are the stable parameters and are not affected by the aging process. Therefore, the difference of mean values of diameter at different age classes can be used to illustrate the current situation of bamboo stands. In this study, the diameter distribution based on age classes shows the degradation of the *Oligostachyum* sp., *Indosasa angustata*, and *Dendrocalamopsis* sp. 2 stands whereas the others are being the relatively stable status.
- 5) The Weibull function was used to test the form of diameter distributions of the six bamboo stands. The results showed the poor performance of the model at 95% confidence level, and thus, it can be said that the close-to-nature diameter distribution of those stands was significantly affected by human interventions.
- 6) In this study, the diameter and height relation was described using logarithmic and polynomial functions. The result showed that the polynomial function was more suitable than the logarithmic function to describe the relation of those bamboo stands.

- 7) The culm wall thickness is one of the most important parameters in assessing the utilization value of bamboos. However, the prediction of culm wall thickness of internodes at breast height using the values of their diameters as predictors (denoted through linear, logarithmic, and polynomial functions) in this study was not successful, showing low values of coefficient of determination.
- 8) Both basic wood density and moisture content were affected by culm aging. The result indicates that the moisture content decreases while the basic wood density increases. The mature stage of the bamboo culms can be identified by reference to the variation of basic wood density and moisture content with different age classes. For the six study species, this stage occurred at the age of three or four, when bamboo culms switch to the stable stage with a minor change in physical properties.
- 9) Bending strength and compression strength of bamboo culms are influenced by aging and varying among species. For each species, the increase in strength properties accompanied by the increase of fiber density, reaches maximum values in a specific period of time before decreasing. The result shows that after year two, bamboo culms of the six bamboo species have sufficient potential for construction and their mechanical properties reach optimum at age three. However, the proper cutting age should be identified based on particular requirements of the available technologies. In addition, culms of some species may be used in age class 1, but cutting at this age may influence the regeneration capacity of the bamboo stands.
- 10) To increase bamboo forest areas in Vietnam, propagation is the most important application. At present, however, it is faced many problems due to usage of some traditional methods which lead to the shortage of planting materials when a high expenditure of labor and transportation is required. Air layering has been successfully applied for *Dendrocalamus barbatus* and

*Dendrocalamopsis* sp. 2, but this method can only be used for some bamboo species with developing branch systems.

- 11) A new bamboo forest needs a well-established schedule with specific activities that must be obeyed carefully. In this study, two schematic plans were developed for the six bamboo species in management operations that can be practically applied in the field. However, further assessments and improvements should be conducted to obtain higher applied effectiveness.

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## 7 Appendices

### 7.1 List bamboo genera and species of Vietnam (Nguyen, 2006)

No.	Genera		Number of species
	Scientific name	Vietnamese name	
1	<i>Acidosasa</i>	Vầu xanh	5
2	<i>Ampelocalamus</i>	Trúc dây	3
3	<i>Arundinaria</i>	Sặt	8
4	<i>Bambusa</i>	Tre	67
5	<i>Bonia</i>	Le bắc bộ	2
6	<i>Cephalostachyum</i>	Cơm lam	4
7	<i>Chimonobambusa</i>	Trúc vuông	3
8	<i>Chimonocalamus</i>	Sặt gai	2
9	<i>Dendrocalamopsis</i>	Bạc mây	3
10	<i>Dendrocalamus</i>	Luồng	29
11	<i>Fargesia</i>	Hào dúi	1
12	<i>Ferocalamus</i>	Mạ lênh lang	1
13	<i>Gigiantochloa</i>	Le mum	18
14	<i>Indosasa</i>	Vầu đắng	12
15	<i>Maclurochloa</i>	Giang	16
16	<i>Melocalamus</i>	Tre quả thịt	8
17	<i>Oligostachyum</i>	Lành anh	1
18	<i>Phyllostachys</i>	Trúc	8
19	<i>Pseudostachyum</i>	Nứa mọc tản	1
20	<i>Sasa</i>	Thia ma	1
21	<i>Schizostachyum</i>	Nứa	16
22	<i>Sinarundinaria</i>	Sặt núi cao	2
23	<i>Thyrsostachys</i>	Tâm vông	2
24	<i>Vietnamosasa</i>	Le cỏ	2
25	<i>Sinobambusa</i>	Vầu cục phương	1
Total			216



**7.2 List of bamboo species of Vietnam that have been re-identified with updated scientific name (Vu and Le, 2004)**

<b>Vietnamese name</b>	<b>Old scientific name</b>	<b>New scientific name</b>
Hóp cần câu	<i>Bambusa. nana</i> Roxb	<i>B. multiplex</i> Raeusch. Ex J.A. & J.H. Schultes
Tầm vông	<i>B. variabilis</i> Munro	<i>Thyrsostachys siamamensis</i> Gamble
Tre gai	<i>B. spinosa</i> Roxb; <i>B. stenostachya</i> Hack	<i>B. blumena</i> J.A et J.H Schult
Tre là ngà	<i>B. blumeana</i> Schult.f.	<i>B. bambos</i> (L) Voss
Tre là ngà bắc	<i>B. blumeana</i> Schult.f.	<i>B. sinospinosa</i> McClure
Tre mõ miền nam	<i>B. arundinacea</i> Retz	<i>B.vulgaris</i> Schrad. ex Wendland cv. Vittata
Tre lộc ngọc	<i>B. arundinacea</i> Retz	<i>B. bicorniculata</i> nov. sp.
Tre vàng sọc	<i>B. arundinacea</i> var. <i>aurea-variegata</i> Pham Hoang	<i>B. vulgaris</i> Schrad ex Wendland cv. Vittata
Trúc đuôi gà	<i>B. ventricosa</i> McClure	<i>B. tuldoides</i> Munro
Bương	<i>Dendrocalamus flagellifer</i> Munro	<i>D. asper</i> Backer ex Heyne
Giang	<i>D. patellaris</i> Gamble	<i>Maclurochloa vietnamensis</i> sp. nov
Luồng	<i>D. membranaceus</i> Munro	<i>D. barbatus</i> Hsueh et D.Z:Li
Mạ sang mú	<i>D. membranaceus</i> Munro	<i>D. barbatus</i> var. <i>internodiiradicatus</i> Hsueh et D.Z.Li
Tre mõ Lạng sơn	<i>D. farinosus</i> Chia et Fung	<i>D. minor</i> (McClure) Chia et H.L. Fung
Vầu đắng	<i>Indosasa sinica</i> C.D. Chu et C.S. Chao; <i>Indosasa amabilis</i>	<i>I. angustata</i> McClure
Dùng	<i>Lingania chungii</i> McClure	<i>Bambusa chungii</i> McClure
Dùng nhà	<i>Lingania cerocissima</i> McClure	<i>B. cerocissima</i> McClure
Nửa lá to	<i>Neohouzeaua dullooa</i> (Gamble) A. Camus	<i>Schizostachyum pseudolima</i> Mc'Clure

### 7.3 Climate of the research regions in Northern Vietnam (Nguyen, 2000)

Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
<b>Nguyen Binh</b>													
T	12.3	13.8	17.5	21.7	24.6	25.9	26.1	25.6	24.2	21.2	17.4	13.8	20.3
R	39.7	39.0	52.9	93.7	205.6	290.2	311.8	312.1	215.7	109.6	57.8	34.7	1763
$\Delta T$	7.3	6.7	7.4	7.7	8.1	7.7	7.9	8.0	8.5	8.3	8.4	8.5	7.9
U	83	83	83	81	80	83	84	85	83	81	81	82	82
S													
<b>Yen Binh</b>													
T	15.3	16.5	19.7	23.3	26.7	27.8	28.0	27.5	26.4	23.9	20.4	17.0	22.7
R	32.1	49.6	73.7	131.2	225.9	306.9	346	399.8	288.5	167.1	59.8	26.3	2107
$\Delta T$	5.7	5.1	5.3	5.9	7.7	7.7	7.5	7.7	7.8	7.7	7.4	7.0	6.9
U	88	89	90	89	84	85	86	87	86	85	85	86	87
S	1.8	1.5	1.4	2.3	5	5.1	5.7	5.6	5.7	4.9	4.0	3.1	3.8
<b>Doan Hung</b>													
T	15.7	16.9	19.8	23.5	27.1	28.3	28.3	27.8	26.9	24.3	20.8	17.6	23.1
R	31.5	39.8	50.3	108.9	202.3	247.9	382.5	328.5	219.4	159.7	54.3	24.9	1850
$\Delta T$	5.7	5.0	5.4	6.3	8.0	7.7	7.8	7.5	7.5	7.7	7.5	6.8	6.9
U	85	87	87	86	82	83	83	85	84	82	82	82	84
S	2.2	1.7	1.6	2.9	5.7	5.5	6.5	5.7	6.1	5.3	4.6	3.6	4.3
<b>Tan Lac</b>													
T	16.3	17.9	21.2	24.7	26.9	27.5	27.6	26.9	25.7	23.4	20.2	17.3	23
R	16.4	9.4	21.3	103.6	199.8	264.1	314.2	344.4	336.1	183	34.8	6.3	1833
$\Delta T$	7.5	7.0	7.1	8.9	9.7	8.8	9.0	8.0	8.0	8.3	8.1	8.3	8.2
U	80	79	79	79	80	82	83	86	86	84	82	80	82
S	2.6	2.8	3.3	4.5	5.7	5.1	5.7	4.6	5.0	4.4	3.6	3.8	4.3

Note: T- The monthly mean temperature; R- Total monthly precipitation

$\Delta T$ - The monthly mean of day/night fluctuation of temperature

U- The relative ambient humidity; S- Daily sunshine hour

**7.4 Mean and standard deviation of moisture content (MC) in four age classes of bamboo species (n = 30 test pieces per species) in Northern Vietnam**

Species	MC (%)			
	Age 1	Age 2	Age 3	Age 4
<i>Oligostachyum</i> sp.	91.2 ± 23.8	72.9 ± 21.0	72.6 ± 18.7	71.7 ± 18.4
<i>Phyllostachys edulis</i>	104.7 ± 25.8	81.8 ± 23.3	60.4 ± 14.9	58.6 ± 14.5
<i>Indosasa angustata</i>	105.1 ± 28.7	97.9 ± 27.3	95.7 ± 23.8	72.1 ± 19.9
<i>Dendrocalamus latiflorus</i>	92.8 ± 22.9	89.4 ± 22.0	85.1 ± 22.2	83.6 ± 22.4
<i>Dendrocalamopsis</i> sp. 2	101.8 ± 25.0	98.3 ± 24.5	91.8 ± 23.0	88.9 ± 22.8
<i>Dendrocalamus barbatus</i>	85.6 ± 20.8	70.7 ± 17.6	69.1 ± 17.4	67.5 ± 16.9

**7.5 Mean and standard deviation of basic wood density ( $\rho$ ) in four age classes of bamboo species (n = 30 test pieces) in Northern Vietnam**

Species	$\rho$ (g/cm <sup>3</sup> )			
	Age 1	Age 2	Age 3	Age 4
<i>Oligostachyum</i> sp.	0.66 ± 0.03	0.68 ± 0.05	0.75 ± 0.03	0.72 ± 0.04
<i>Phyllostachys edulis</i>	0.59 ± 0.07	0.72 ± 0.09	0.89 ± 0.07	0.97 ± 0.08
<i>Indosasa angustata</i>	0.61 ± 0.05	0.69 ± 0.06	0.67 ± 0.03	0.79 ± 0.11
<i>Dendrocalamus latiflorus</i>	0.69 ± 0.09	0.71 ± 0.09	0.77 ± 0.10	0.80 ± 0.03
<i>Dendrocalamopsis</i> sp. 2	0.58 ± 0.11	0.57 ± 0.07	0.61 ± 0.11	0.63 ± 0.07
<i>Dendrocalamus barbatus</i>	0.61 ± 0.10	0.66 ± 0.05	0.68 ± 0.10	0.75 ± 0.08

**7.6 Mean and standard deviation of the bending strength ( $f_m$ ) in four age classes of bamboo species (n = 30 test pieces per species) in Northern Vietnam**

Species	$f_m$ (N/mm <sup>2</sup> )			
	Age 1	Age 2	Age 3	Age 4
<i>Oligostachyum</i> sp.	148.3 ± 24.6	150.4 ± 18.6	168.0 ± 29.1	172.1 ± 20.9
<i>Phyllostachys edulis</i>	100.3 ± 23.9	122.8 ± 34.5	162.8 ± 22.3	170.9 ± 15.7
<i>Indosasa angustata</i>	141.4 ± 16.5	146.2 ± 26.1	151.0 ± 22.5	155.7 ± 16.8
<i>Dendrocalamus latiflorus</i>	95.7 ± 11.0	141.2 ± 13.8	153.3 ± 20.8	164.3 ± 11.7
<i>Dendrocalamopsis</i> sp. 2	133.7 ± 21.7	141.5 ± 20.7	148.1 ± 24.3	157.7 ± 23.0
<i>Dendrocalamus barbatus</i>	148.9 ± 11.8	156.3 ± 15.1	161.3 ± 19.9	179.2 ± 16.0

**7.7 Mean and standard deviation of the compression strength ( $\sigma$ ) in four age classes of bamboo species (n = 30 test pieces per species) in Northern Vietnam**

Species	$\sigma$ (N/mm <sup>2</sup> )			
	Age 1	Age 2	Age 3	Age 4
<i>Oligostachyum</i> sp.	108.8 ± 7.7	119.0 ± 11.7	125.4 ± 13.0	121.9 ± 14.0
<i>Phyllostachys edulis</i>	40.9 ± 9.6	55.3 ± 16.4	73.8 ± 5.7	78.0 ± 5.9
<i>Indosasa angustata</i>	64.1 ± 7.6	71.3 ± 9.4	75.3 ± 11.1	82.0 ± 10.6
<i>Dendrocalamus latiflorus</i>	61.7 ± 7.1	68.8 ± 8.4	72.9 ± 8.5	78.4 ± 8.3
<i>Dendrocalamopsis</i> sp. 2	59.5 ± 5.7	62.9 ± 10.2	65.7 ± 4.7	70.8 ± 6.4
<i>Dendrocalamus barbatus</i>	71.9 ± 8.6	76.2 ± 4.7	88.7 ± 5.5	99.9 ± 2.9

## 7.6 Interview results

### 7.6.1 Summary of interview results on propagation methods <sup>(1)</sup>

Features	Rhizome cutting <sup>(2)</sup>	Stump digging <sup>(3)</sup>	Air layering <sup>(4)</sup>
Seasons	Jan to Apr	Jan to Apr	Jan to Aug
Materials	Running rhizome	Stumps with rhizomes	Branches
a) Features of the materials	Running rhizome of 2-3 year old culms	Stumps with rhizomes of 1-2 year old culms	3-10 month old branches of 1 - 2 year old culms
b) dimensions of the material	The segments of 50-60 cm long of the running rhizome	Hole rhizome part with 1-3 internodes	Cut the top part of the selected branches and keep only 30-40 cm length
Mediums	Not use	Not use	Rice husk and mud
Solutions	Not use	Not use	Not use
Success rates	About 60 %	100%	Above 90%
Nursing time	No need	No need	3 - 4 months

Note: (1) the result from 5 to 7 interviewees per each of the study areas

(2) the method has been applied for *Phyllostachys edulis* by farmers

(3) the method has been applied for all the study species by farmers

(4) the method has been applied for *Dendrocalamus barbatus* by farmers

### 7.6.2 Summary of interview results on management system analysis <sup>(1)</sup>

Activities	Sympodial species <sup>(2)</sup>	<i>Oligostachyum</i> sp.	<i>Phyllostachys edulis</i>	<i>Indosasa angutata</i>
Land preparation	New plantation	Un know	New plantation	Enrichment
a) Season	Jan or Jun		Jan – Mar	Jan – Mar
b) Techniques	Overall land clearing, hole dimensions of 60 x 60 x 60 cm		Strip land clearing in 30 cm deep, 1 m wide	Hole dimensions of 40 x 40 x 40 cm
Planting		Un know		
a) Season	Jan – Mar, Jun - Aug		Jan – Mar	Jan – Mar
b) Spacing	7 x 7 m		4 x 4 m	4 x 4 m
Tending	Yearly	Once per 2, 3 years	Yearly	Un know
a) Season	Spring	Spring	Spring	
b) Techniques	Loosening soil, cutting climber	Cutting climber	Soil loosening	
Fertilizing				
Bed-dressing application	5-10 kg Bio-fertilizer <sup>(3)</sup> /hole	Not used	3-5 kg Bio-fertilizer/hole	3-5 kg Bio-fertilizer/hole
Top-dressing application	1 kg NPK	Bio-fertilizer (un-known the volume)	1 kg NPK	Not used
Culms harvesting				
a) Season	Nov – Jan	Nov – Jan	Nov – Jan	Nov – Jan
b) Volume	30% of total culms/year	30 – 40% culms/year	30% culms/year	30 – 40% culms/ year
Shouts harvesting				
a) Season	Early and late shoot stages	Early and late shoot stages	Early and late shoot stages	Early and late shoot stages
b) Residual shoots	3 – 5 shoots/clump	1 -2 shoot/mother culm	1 - 2 shoot/mother culm	1 - 2 shoot/mother culm
Pest and disease	Unknown	Unknown	Unknown	Unknown

Note: (1) the result from 5 to 7 interviewees per each of the study areas

(2) *Dendrocalamus latiflorus*, *Dendrocalamopsis* sp. 2, and *Dendrocalamus barbatus*

(3) mixture of rice husk or/and remain of crops and dung of cattle

## **Curriculum Vitae**

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