Technical Handbook

Research and Recommendations on Bamboo Resources for Pulp and Paper Making in Thailand

by

Dr. Koichiro UEDA

OVERSEAS TECHNICAL COOPERATION AGENCY

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PREFACE

This report is a compilation of the field survey carried our by Mr. Hiroyuki Watanabe and Mr. Kyozo Chiba, technical experts dispatched to Thailand at the request of the Thai Government, for the purpose of developing the bamboo resources of the country. Their field survey commenced in February, 1965 and continued over a period of two months under the guidance of Dr. Koichiro Ueda, who was also dispatched as an F.A.O. specialist to the country at its government's request.

Abundant useful information about increased production and the preservation of the country's bamboo resources are contained in this report. We believe that the publication of the report will contribute a great deal to the development of the pulp resources in Thailand.

Shin-ichi Shibusawa

Director General

Overseas Technical Cooperation Agency

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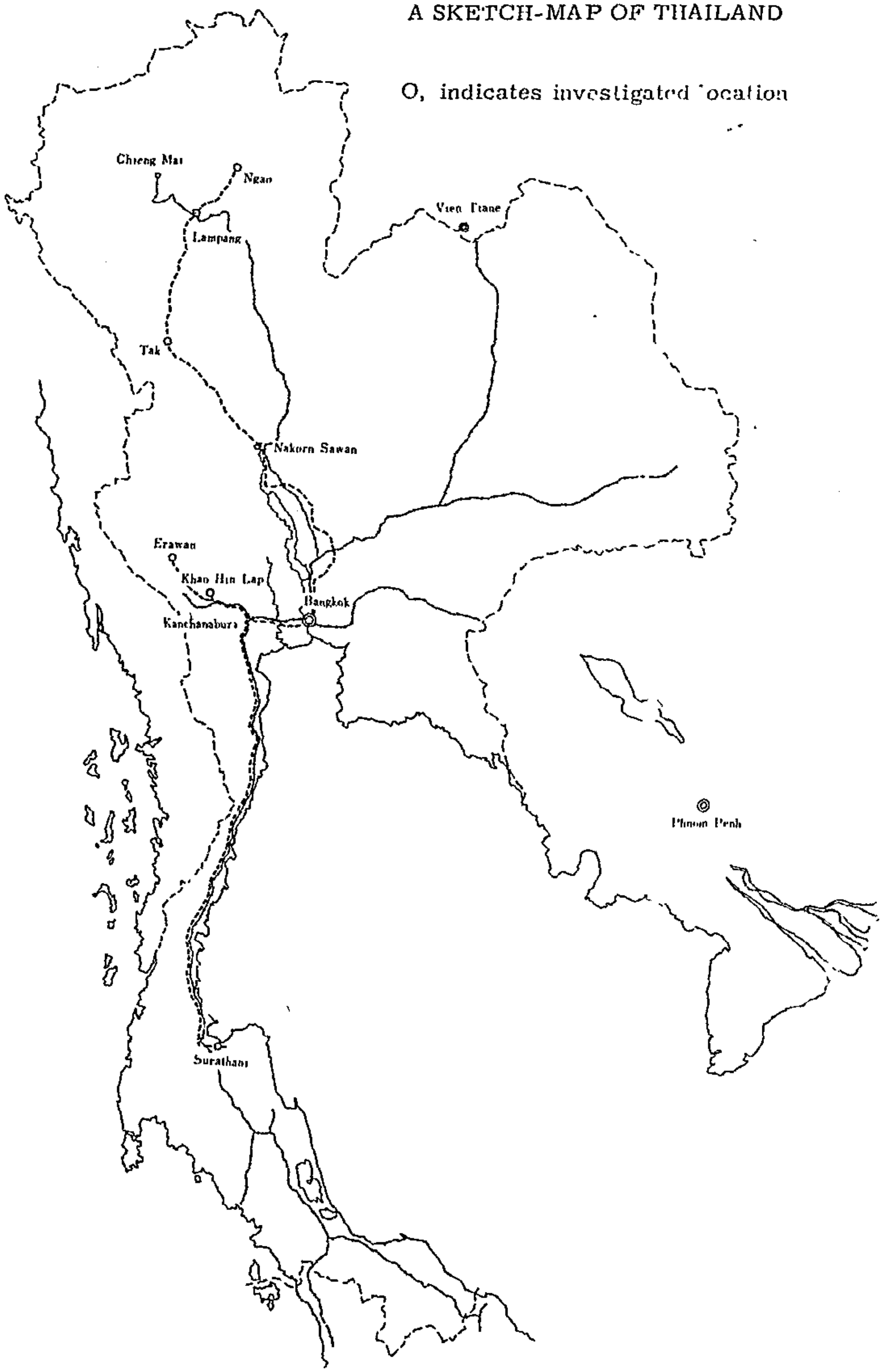
A SKETCH-MAP OF THAILAND

O, indicates investigated location



CONTENTS

I. Bamboo Species and Their Distribution

I-1. Common species and their areas of distribution

The majority of bamboo forests in Thailand, except those growing around farm houses, consist of natural forests. The area, as estimated by the Royal Forestry Department of Thailand on the basis of aerial photographs and upon our own field observations, is represented approximately as on the following list:

Region	Common Species		Area (approx.)
	Scientific name	Local name	
Central region Kanchanaburi Khao Hin Lap Erawan	Thyrsostachys siamensis	Pai Ruak	hectares 450,000
	Bambusa arundinacea	Pai Pah	250,000
	Dendrocalamus longispathus	Pai Lamalog	100,000
	Others		* Total =800,000ha =8,000km^2
Nothern region Lampang Ngao	T. siamensis	Pai Ruak	Over 100,000 ha
	T. Oliveri	Pai Ruak	
	B. arundinacea	Pai Pah	
	B. blumeana	Pai sisook	
	Oxytenanthera albociliata	Pai Rai	
	B. tulda	Pai Bong	
	D. membranaceus	Pai Sang	
	Schizostachyum aciculare	Pai Lowt	
Southern region Surat-thani	O. hossensii	Pai Kai	Over 100,000 ha
	O. Nigrociliata	Pai Phak	
	B. arundinacea	Pai Pah	
	S. aciculare	Pai Lowt	
	S. Zollingeri	Pai Po	

* The area of bamboo and tree forests covers approximately 17,829 km^2 (1,782,900 ha.), about one half of which is estimated to be bamboo forests.

I-2. General growth conditions of bamboo species

The sizes of culms and conditions of the stands of the common species are shown on the list on next page.

Among the species listed above, those considered suitable for pulp making are no.1. Thyrsostachys siamensis; 4. Bambusa blumeana; 5. Dendrocalamus longispathus; 6. Dendrocalamus menbranaceus; 8. Oxythenanthera nigrociliata; and 11. Schyzostachyum zollingeri. Neither no.2. Bambusa arundinacea nor 3. Bambusa blumeana are at present utilizable due to their large thorny branches, but we believe that they can be utilized if studies are conducted leading to proper methods for thinning, etc.

The mixed stand of bamboo species in a forest occurs as follows. The T. siamensis forms a definite stand consisting of the species alone. The B. arundianacea constitutes an unmixed stand in most cases, but it is sometimes interspersed with D. longispathus here and there. As for the other bamboo species, a mixed or unmixed stand of bamboo is formed according to the particular place of growth.

Local Name (Scientific Name)	Diameter at breast height	Spreading and form of branches	Wall thickness of culm	Density of culms in a clump	Mixed growth with trees	Soil quality and other comments
1 Pai Ruak (Thyrsostachys siamensis)	2-3-6 cm	Small branches spread from upper third of culm	Solid in lower part	Tufted	Slightly mixed with trees	Dry soil and poor soil T. oliveri is abundant around farm-houses
2 Pai Pah (Bambusa arundinacea)	3-8-15	A number of branches, large and thorny as well, spread from lower part of culm	Thick	Rather tufted	Slightly mixed with trees	Rather wet soil; especially riverside and around farm-houses
3 Pai Sisook (Bambusa blumeana)	3-7-10	Manner of spreading of thorny branches is like that of Pai Pah (2)	Thick	Rather tufted	Slightly mixed with trees	Rather wet soil; riverside and around farm-houses
4. Pai Bong (Bambusa tulda)	3-7-10	Branches are thornless	Rather thick	Rather tufted	Slightly mixed with trees	Rather fertile land; riverside and on other soil
5 Pai Lamalog (Dendrocalamus longispathus	5-6-10	Branches are slender and spread from upper third of culm	Thick	Rather sparse	Slightly mixed with trees	Rather fertile soil; riverside and on other soil
6 Pai Song (Dendrocalamus membranaceus)	3-6-10	Thornless branches spread from upper third of culm	Thin	Rather sparse	Slightly mixed with trees	Rather fertile soil and mountainous districts
7 Pai Rai (Oxytenanthera albociliata)	1-2-3	Branches spread from lower part of culm	Rather thick	Rather tufted	Undergrowth of teaks, etc.	Rather fertile soil and mountainous districts
8 Pai Phak (Oxytenanthera nigrociliata	3-6-10	Branches spread from upper third of culm	Thick	Rather tufted	Mixed with trees	Fertile soil and gentle slopes
9 Pai Kai (Oxytenanthera hossensi)	1-2-3	Branches are numerous	Thick	Rather tufted	Undergrowth of Dipterocarpacea, etc.	Poor soil
10 Pai Lowt (Schyzostachyum aciculare)	1-2-3	Branches are rather numerous	Thin	Rather sparse	Undergrowth of trees	Rather fertile soil
11 Pai Po (Schyzostachum zollingeri)	2-3-6	Branches are few	Rather thin	Rather sparse	Mixed with trees	Rather fertile soil

I-3. Soil aspects in each region

It is in the Kanchanaburi region where large and compact T. siamensis forests occur and where there is a paper-making plant utilizing this species. Other species suitable for pulp-making are found also in the northern regions, but the forest area is not so great. In the northern region, the T. siamensis is widely distributed but the growth is short in height, as in most cases it occurs as an undergrowth of trees.

In the southern regions many mixed forests occur where the trees are more dominant than the bamboos and thus have become overhead growths, but here the bamboo forests are not so widely distributed. (photo 4)

Generally speaking, the natural features of the land where bamboo forests are distributed consist of a flat country or of a gentle slope, or in the mountainous districts, many bamboo forests grow on hillsides of low mountain zones.

I-4. Climate

In the regions north of central Thailand, the climate is rather of a continental type, varying to the south where the climate is of rather an ocean type. According to the government meteorological observations, in Lampang in the northern region the highest temperature is 43.0°C. (April) and the lowest 5.7°C. (January); in the Kanchanaburi region in central Thailand, the high is 43.5°C. (April) and the low is 5.5°C. (January); in Bangkok the high is 39.9°C. (April) and the low 9.9°C. (January); in Ban Don in the south the climate is rather oceanic, showing a high of 39.5°C. (April) and a low of 12.4°C. (January).

The annual rainfall is greater in the southern region (over 1,000 mm) than in the northern region (under 1,000 mm). During the dry season, November to March, the south still has a measure of rainfall. Accordingly, such differences in rainfall result in differences in the vegetation of bamboo forests, species of bamboos and their conditions of growth. For instance, bamboo species with larger sized leaves are found in the southern region than in the central-nothern region.

The monthly observation values shown in the statistics of the Governmental Meteorological Department are those used for our own field observations and are listed on Appendix Table I.

II. Structure of Bamboo Forests

II-1. Structure of a clump

A. Number of culms per clump and number of clumps and culms per hectare

The results of our field survey based mainly on T. siamensis and B. arundinacea are summarized in Tables I, II-1, 2, 3, 4, 5, and Appendix Table I. From those, we have been able to make the following observations:

a. The number of culms per clump varies greatly, ranging from 2 to 160. In the case of a bamboo forest of the T. siamensis species, we consider that the optimum number of culms per clump should range between 30-100. If there are less than 20-30 culms per clump, the diameter of the individual culms is usually too small and the culm is therefore too slender. Generally the culms of clumps ranging over 30 are large, but a clump whose culms exceed 100 in number becomes so dense as to make the cutting extremely difficult and impedes the entry of a cutting machete. (photo 1-3)

b. Generally speaking, we consider a poor bamboo forest on poor soil as one with numerous small culms. The proper number of culms in a forest of T. siamensis after thinning is about 15,000 when their average diameter at breast height is 2-3 cm. As mentioned above, too dense a standing of culms in one clump cannot be considered a proper clump structure. In the case of a B. arundinacea forest, the proper number of culms with an average diameter of 6-7 cm. at breast height is 5,000-8,000 (see Appendix Table II).

c. Among the reasons for the formation of small clumps with few culms are the overcutting of sprouts by people and their consumption by cows. The cutting of young one or two-year-old culms also weakens the assimilation process, resulting not only in the decrease in the number of new bamboo culms but also in the early death of culms and rhizomes (see Appendix Table II).

d. We shall consider now the culm diameters. The bamboo now in use for pulp-making in the Kanchanaburi factory consists of those culms with a diameter of 2.0 cm and more. Considering T. siamensis forests, bamboo culms with diameters of 1.9 cm. or less represents no more than 4.9% of the total in the Erawan region; it is from 44.4-57.7% in the Khao Hin Lap region (see

Table I).

From the viewpoint of economy, such a large percentage of bamboo unusable for pulp making is a great disadvantage. Improved management would greatly enhance the increased production of usable bamboo culms with a larger diameter. Methods for such improvement will be discussed later.

Table I. Number of living culms by diameter and age

Bamboo species (No. of clumps)	Diameter at breast height	Number of total culms of clumps				1 plot area	Location and date
		1-year old	over 2-years old	total	%		
T. siamensis	under 1.9cm	47	271	318	57.7	20x10m	Khao Hin Lap March 1965
(plot 1)	over 2.0	119	112	231	42.3	($200m^2$)	
(96)	total	166	383	549	100.0		
T. siamensis	under 1.9	23	93	116	44.5	10x10	Khao Hin Lap March 1965
(plot 2)	over 2.0	55	90	145	55.5		
(11)	total	78	183	261	100.0		
T. siamensis	under 1.9	0	10	10	4.9	10x10	Erawan March 1965
(8)	over 2.0	13	184	197	95.1		
	total	13	194	207	100.0		
B. arundianacea	under 1.9	3	12	15	14.6	10x10	Khao Hin Lap March 1965
(9)	over 2.0	20	68	88	85.4		
	total	23	80	103	100.0		

Note: "One-year-old" denotes culms which completed their growth from buds to culms in 1964.

Tables II-1, 2, 3, 4. Distribution of culms by age and diameter on a clump

Table II-1. A large clump of T. siamensis in Khao Hin Lap

Diam. at breast height / Age	under 1 cm	1.1-2.0	2.1-3.0	3.1-4.0	Total
1 year	0	1	40	7	48
2	0	8	40	1	49
Over 3	0	6	55	6	67
Total	0	15	135	14	164

In addition, 4 dead culms and 16 stumps were found.

Note: This clump contained a comparatively large number of large culms and a small number of old ones. The average diameter of the culms is 2.7 cm. The area occupied per culm (including dead ones) is 107 cm^2. This clump occupied an area of 17,548 cm^2.

Table II-2. A small clump of T. siamensis in Khao Hin Lap

Diam. at breast height / Age	under 1 cm	1.1-2.0	Total	
1	0	3	3	In addition, 25 sprouts removed for food and 5 stumps were found.
2	1	4	5	
3	0	1	1	
4	1	3	4	
5	1	1	2	
6	⊗ 1	⊗ 1	⊗ 2	
7	⊗ 1	⊗ 1	⊗ 2	
8	0	0	0	
9	0	1	1	
Total	5	15	20	

Note: ⊗ indicates dead culms
Average diameter per culm, 1.3 cm.
Area occupied per culm, 78 cm^2
Clump occupied an area of 1,560 cm^2
The completeness of the details of this particular clump is due to the fact that it was dug up and the rhizomes were counted and studied.

Table II-3. A comparatively large clump of T. siamensis in Erawan

Diam. at breast ht. / Age		1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	Total
	1	3	4	3	1	11
Living	2	2	10	7	1	20
Culms	over 3	2	21	23	1	47
	Total	7	35	33	3	78
Dead culms		13	27	14	0	54

Note: Average diameter of culms, 3.0 cm.
Area occupied per culm, 177 cm^2
Clump occupied an area of 23,364 cm^2

Table II-4. A clump of Dendrocalamus longispathus in Khao Hin Lap

Diam. at breast ht. / Age		2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	Total
	1	0	2	10	2	14
Living	2	3	5	10	1	19
culms	over 3	8	23	23	2	56
	Total	11	30	43	5	89
Dead culms		9	3	2	1	15

In addition, 7 stumps were found.

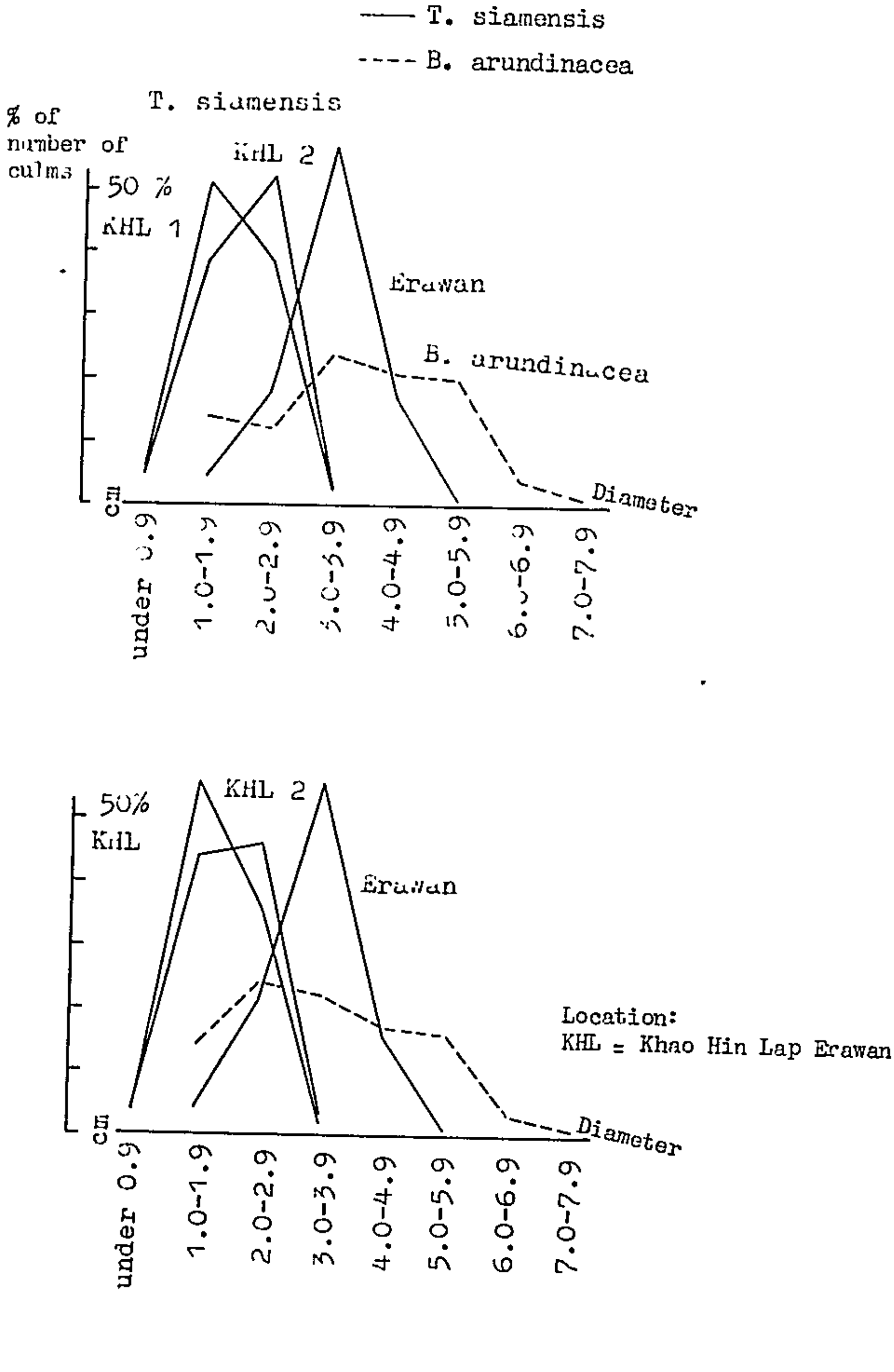
Note: Average diameter of culms, 3.9 cm.
Area occupied per culm, 269 cm^2
Clump occupied an area of 27,857 cm^2

Table II-5. Relation between diameter and number of culms per clump of T. siamensis in Khao Hin Lap

No.of culms per clump \ Diam.(cm)	under 0.9	1.0-1.4	1.5-1.9	2.0-2.4	2.5-2.9	3.0-3.4	3.5-3.9	Total No.of clums	Average diam.	No. of clumps
1 - 4	16	26	33	7				82	1.3	25
5 - 9	4	28	46	28	4	1		111	1.7	16
10 - 19	13	51	86	64	15	1		230	1.7	21
20 - 29	5	8	52	41	11	1		118	1.8	5
30 - 49	6	15	50	49	20	10	2	152	2.1	4
50 - 59	1	11	35	80	43	9	2	181	2.3	3

Note: Numbers include dead culms and stumps.

Fig. I. Distribution of number of culms by diameter



B. Observations

The number of aged or dead culms influence the productivity of bamboo forests to a great extent.

In the various preceding Tables I, II(1 - 5), we have classified culms by age and diameter, according to clump sizes. We have specifically studied a large clump with many culms and a small clump with few culms.

Table II-2 shows the results of a detailed study on a small clump with few culms. Here we investigated the ages of all culms and found the following:

1) The culms which were 6-7 years old appeared dead, that is, they had lost their powers of rejuvenation.
2) The number of new culms in this one clump was from 1-5 each year.
3) Each year, a large number of sprouts are dug up for food, especially in the vicinity of private houses.

In addition to the above, we were also able to make the following observations based not only on the results as tabulated in Tables I, II(1 - 2), but also from observations of other clumps which were not tabulated:

1) Large sized parent bamboos produce new sprouts which are also large, while small parent culms produce small sprouts. This is shown on Figs. IV(1-3), which show the rhizome system.
2) Over-digging of sprouts results in the reduction of the diameter of new bamboos which in turn causes a diminished productivity of the forests, caused by a gradual decrease in the number of culms per clump.
3) Compared to a large clump, a small one has a greater number of culms of small diameter, and the area occupied per culm is also smaller. (In the case of T. siamensis, for instance, Tables II-1 - 5 show statistics for comparisons. Tables II-1 and 3 show that the average diameter of culms belonging to a large clump is 2.7-3.0 cm., while that of the smaller is 1.3 cm as shown on Table II-2. The area occupied per culm of the former is 107-177 cm^2 as against the smaller 78 cm^2.)
4) Section III-1 will explain that the culms which are over 5-6 years old are considered old and losing their vitality, that is, the ability to assimilate and sprout. Of course dead or useless culms mean wasted forest grounds.

II-2. Number of dead culms

It is natural that in bamboo forests which seldom undergo cutting, there are found many dead culms. Generally, a natural forest with "no cutting" produces approximately the same number of new culms as dead ones each year. But it not economical in managed forests where repeated cutting is executed to leave old culms intact until they die, as this causes diminished productivity as well as being a waste of space.

A well-managed and skillfully cut bamboo forest usually has few dead culms, but in Khao Hin Lap, a bamboo forest with a fairly high degree of utilization, we found many dead culms. The number of dead culms per ha. in the case of the T. siamensis forests amounted to 4,600-10,950 which represented 18.2-28.5% of the total culms (Table III). Those culms which are losing their vitality should be cut and utilized before they die. The proper cutting age is usually when they are 3-5 years old.

Table III. Number of living culms and dead culms per ha.

Species	Location	No. of living culms	No. of dead culms	No. of dead/total
T. siamensis	Khao Hin Lap (1)	27,450	10,950	28.5%
	" (2)	26,100	8,800	25.1
	Erawan	20,700	4,600	18.2
B. arundinacea	Khao Hin Lap	10,300	2,400	19.0

II-3. Distance between clumps

The proper number of clumps per unit area cannot be uniformly determined, as this varies with the size of the clumps. According to our survey (see Appendix Table II-1), the number of clumps per 100 m^2 in the case of T. siamensis forests ranges between 8-96, indicating sporadic distribution; the smaller the clumps, the shorter the distance between them (Fig. II,1-4 and

Appendix Table II, 1).

The suitable number of clumps per 100 m^2 is 30-50. The lesser number being suitable for large clumps. The proper distances between clumps should insure that a suitable amount of sunshine, that is, not too strong, be allowed.

Fig. II-1. Position of clumps of T. siamensis (plot 1)
Number (8) shows number of culms
- • shows tree
- o shows size of clump (diameter at breast height)

Khao Hin Lap, Kanchanaburi, March 10, 1965

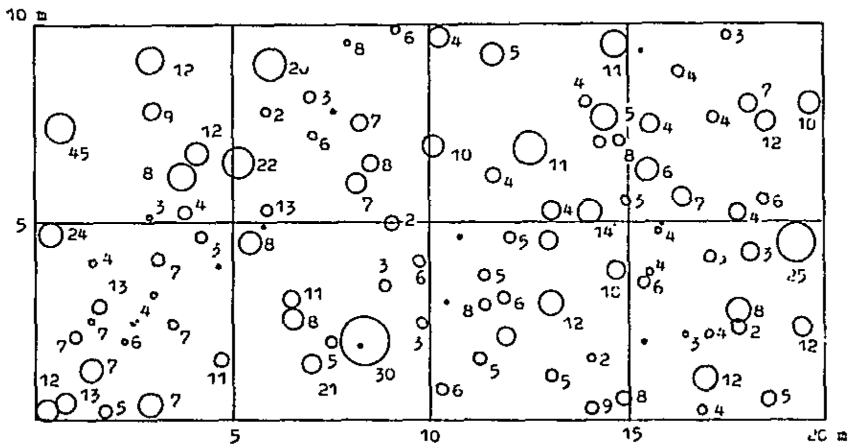


Fig. II-2. Position of clumps of T. siamensis (plot 2) Khao Hin Lap

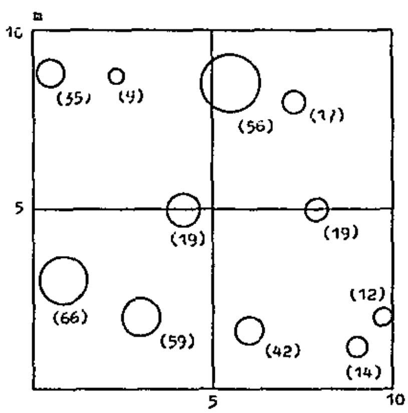


Fig. II-3. Position of clumps of T. siamensis, at Erawan

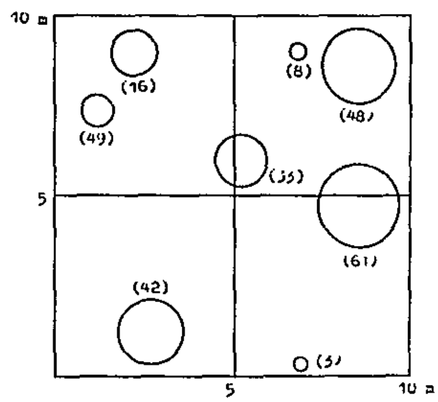
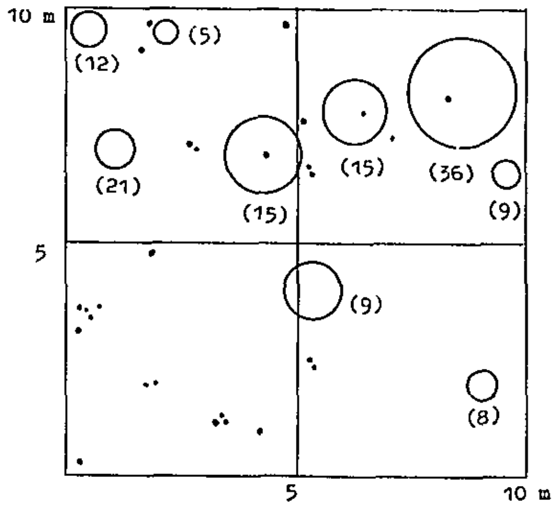


Fig. II-4. Position of clumps of *Bambusa arundinacea* Khao Hin Lap



II-4. Intermixing with trees.

Bamboo forests often grow in mixture with trees. In the north, since there is relatively little rainfall during the dry season, the species of trees most often found in mixture with bamboo forests are deciduous. While in the south, where there is much rainfall during both the rainy and dry seasons, the trees found here are the evergreens.

As bamboos usually have an aversion to very sunny places, a mixed growth with trees which provide proper shade for bamboos is preferable. The degree of this mixing with trees varies with the respective species and their sizes, as well as the quality of the soil, the physical aspects of the land, and other factors. Nevertheless, conditions are considered satisfactory when the projected area of the tree crowns represents less than 20% of the total forest area. As for the species of such trees, the Leguminosae are the most desirable.

II-5. Soil

Soil investigations were conducted in the Khao Hin Lap region (hereafter referred to as K.H.L.) and in the Erawan region (E.R.W.), both constituting main target areas of our survey. In K.H.L., investigations were made of the forest soils of the T. siamensis, which is widely distributed here, and of the forest soils of the B. arundinacea species, which often grows on the riversides. In E.R.W., investigations were made of the soils of the bamboo stands of the T. siamensis which grows better here than in K.H.L.

The depths of the core-tested soil in K.H.L. were 60 cm. in the T. siamensis forest and 70 cm. in the B. arundinacea. In E.R.W. the depth was 30 cm. as the soil layers here were shallow. As the time of investigations happened to be towards the end of the dry season, the soil was extremely dry, and that below 20 cm. was most often found solidified. The bamboo rootlets extending below 30-40 cm. were dried up and almost all appeared dead.

The acidity (PH) and results of an analysis of elements of the soil are shown on Appendix Table III. A comparison of the soils of the three bamboo stands as shown on this table show the following:

1) In each bamboo stand the PH value (1:1, air dried) was found to be high PH.(6.2 - 7.8) and showed no regularity in its vertical variation. In general the T. siamensis forest in K.H.L. has a stronger acidity value than the two other bamboo stands (B. arundinacea forest in K.H.L. and T. siamensis forest in E.R.W.).

However, these values seem to be too high compared with the soil of other countries (Appendix Table III-2). Therefore, the investigation on the soil of other sites in Thailand should be done.

2) The organic carbon content of the T. siamensis forest soil in E.R.W. is high throughout the surface and lower layers, and decreases like an exponential function in a vertical direction, while that in K.H.L., though it decreases approximately like an exponential function, is much lower. The organic carbon content of the B. arundinacea forest soil is still lower than that of the T. siamensis, but the content begins to increase again from its lowest point of 25-30 cm. as the soil depth increases. Such a vertical distribution in soil of B. arundinacea forests, which is common with other elements (available P and K, and exchangeable Ca, Mg and K), is a very interesting phenomenon.

The water content of the soils during the dry season is considered to exert an influence on such differences as organic carbon content; that is to say, a high water content during the dry season causes more organic carbon to permeate into the lower layers. In the case of B. arundinacea forests which are distributed on riversides, the soil washed away or deposited by floods in the rainy season may be one of the causes of such a vertical distribution. This can be assumed from the soil cross-sections which indicate that between the two neighboring forests, the T. siamensis and the B. arundinacea forests, which are located in the same region of K.H.L., the former consists of a loamy residual soil of a deep red color, while the latter is composed of transported sandy soil of a deep gray color.

3) As for the other bases, the exchangeable Mg content is almost the same in all three bamboo stands, and the soil of the B. arundinacea forests is richer to some extent in exchangeable Na content as compared with the soil of the other two bamboo stands. Aside from these two points, the soil of the B. arundinacea forests contains the smallest amount of bases, while that of T. siamensis forests in E.R.W. contains the largest amount, and that of the T. siamensis forests in K.H.L., the second largest.

The soil of T. siamensis forests in E.R.W., though shallow, is generally rich in nutrients. The formation process of the soil of T. siamensis forests and B. arundinacea forests of K.H.L., is different from that in E.R.W., and the former is considered to be quite different. Moreover, the soil of B. arundinacea forests is richer in nutrients than that of T. siamensis forests. The fact that bamboos in E.R.W. grow better than those in K.H.L. may be due to soil conditions.

III. Physiological Study of Bamboo Propagation

III-1. Asexual propagation

A. Extension by rhizomes

The vigorous propagation of bamboos takes place asexually in branching of rhizomes. There are two main types of propagation: the monopodial, found generally in Japan and China, and the sympodial, found in most species throughout the tropical regions, also in Thailand*. The internodes of the upper part of the rhizome which has nodes but no buds such as do the monopodial types, protrudes out of the ground and grows into a culm. The following year, the bud on the basal part of the culm develops into a short rhizome, which protrudes out of the ground to make a secondary culm; the continuing process thus forming a clump.

As the rhizome itself is usually short, and the sprouts develop closely together (within 30 cm.), this formation becomes a clump. In the case of Melocanna bambusoides, the rhizome is long (about 1 m.) and thus the sprouts develop into a single culm without any clump formation.

In considering the development of new rhizomes and new culms, generally, these develop from a parent one-year-old culm. We found that culms two-years-old or older usually did not produce new culms or rhizomes. The usual process is that the parent one-year-old culm produces one new culm, although exceptions have been observed of more. Underground, the parent one-year-old bamboo has 3-7 large buds on each side, one of which grows into a rhizome which develops into a culm. (Figure IV.)

In the case of a two-year-old parent producing new growths, this happens only on occasion, especially after clear cutting (cutting all bamboos) and the resultant culms, if they do grow, usually are extremely slender for 2-3 years.

In the case of the one-year-old parent culm, although some of the other buds on the base tend to grow, the greater part of them fail to develop fully, and as mentioned, in natural forests, only one of them can complete its growth to become a fully grown culm. But, if supplied with nutrients such as fertilizers, one or more of them can grow up into mature culms.

The bud of a small rhizome generally develops into a small culm, but, by supplying nutrients, even a small culm can produce, through vigorous assimilation, a new culm of a large size. The vitality of buds classified by ages of the parent culm is listed in Table IV. The observations were based on studies conducted by means of digging up the rhizomes.

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* For detailed explanations, see K. Ueda: Studies on the Physiology of Bamboo, in Resources Bureau Reference Data No.34, Resources Bureau Science and Technics Agency Prime Ministers Office, Tokyo, Japan, pp. 29-38.

Generally, new culms develop on the outside of a clump and many of the old ones, on the inside (Figures III-1, 2, 3, 4, 5, IV-1, 2, 3, and photos 9-11), but when the latter are cut off, the void is filled with new culms. A rhizome can be made long by methods such as skillful cutting or by fertilizing. When a rhizome is long, the space between culms is wide, which makes it easy to cut mature culms, and thus makes the management of bamboo forests easier.

Fig. III-1. Position of culms of a small clump of T. siamensis

○ living culm

□ dead culm

× stump of cut culm

Numbers showing ages of culm

Location, Khao Hin Lap
15, March, 1965

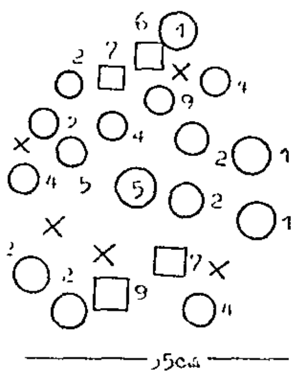

Fig. III-2. Position of culms of Bambusa arundinacea

◎ 1-year-old culm
● dead culm
(4.4) shows diameter in cm at breast height

○ culm over 2 years old
△ cut stump
Location, Khao Hin Lap
14, March, 1965

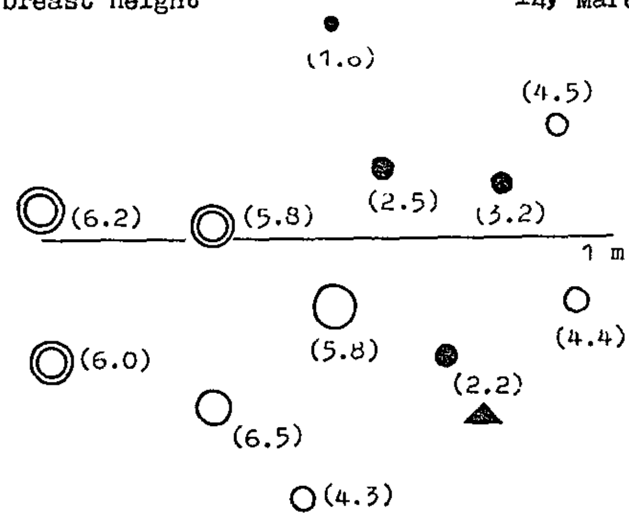

Fig. III-3. Position of culms of B. arundinacea

△ cut stump (living) ▲ cut stump (dead)
◎ 1-year-old culm ○ culm over 2 years old
● dead culm

Location, Khao Hin Lap
14, March, 1965

Figure in parentheses shows diameter at breast height.

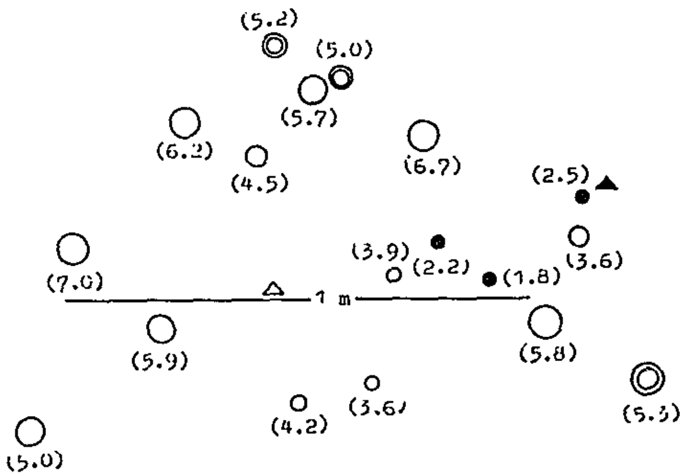

Fig. III-4. Position of culms of B. arundinacea

◎ 1-year-old culm ○ culm over 2 years old
△ cut stump ● tree
5.5 shows diameter at breast height

Location, Khao Hin Lap
14, March, 1965

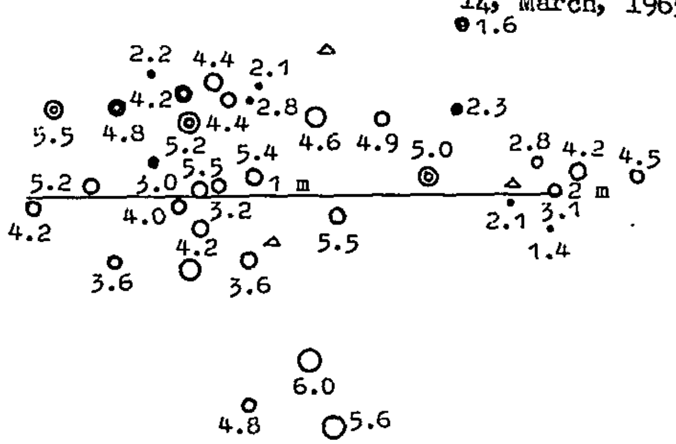

Fig. III-5. Position of culms of D. longispathus

○ 1-year-old culm
◎ culm 2 years old
⊙ culm over 3 years old
× dead culm
△ cut stump

Location, Khao Him Lap
15, March, 1965

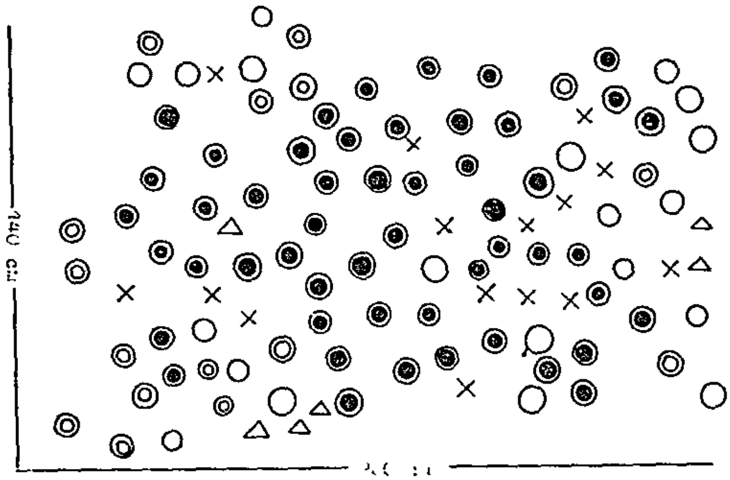

Fig. IV-1. Rhizome system of T. siamensis (Part of a clump)

Location, Erawan, March, 1965

× stump of sprout used for food
□ undeveloped sprout
① ~ ⑤, age

Number above culm indicates diameter of living culm in cm. taken at breast height.

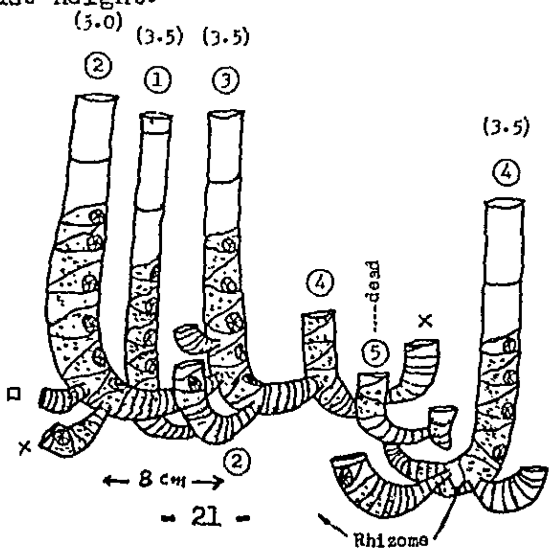

Fig. IV-2. Rhizome system of Bambusa arundinacea
(part of a clump)

Location, Khao Hin Lap, March, 1965
① ~ ⑥ Age
6.0 .... Breast height diameter (cm.)

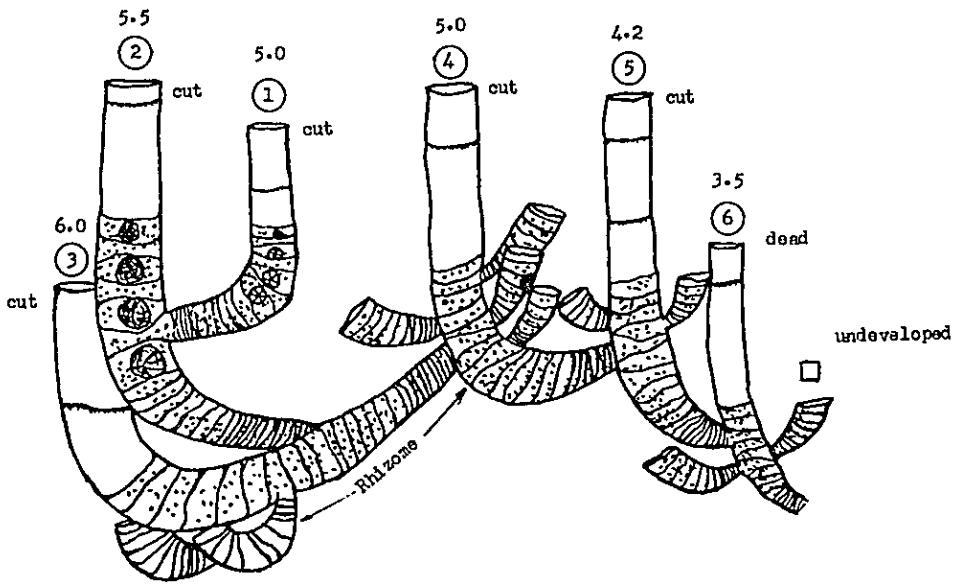

Fig. IV-3. Small clump with four living culms
Species, T. siamensis

Location, Khao Hin Lap, March 22, 1965

△ stump of cut culm
× stump of sprout used for food
①~⑧, age
□ undeveloped sprout
Number above culm indicates diameter of living culm in cm, taken 10 cm. above ground.

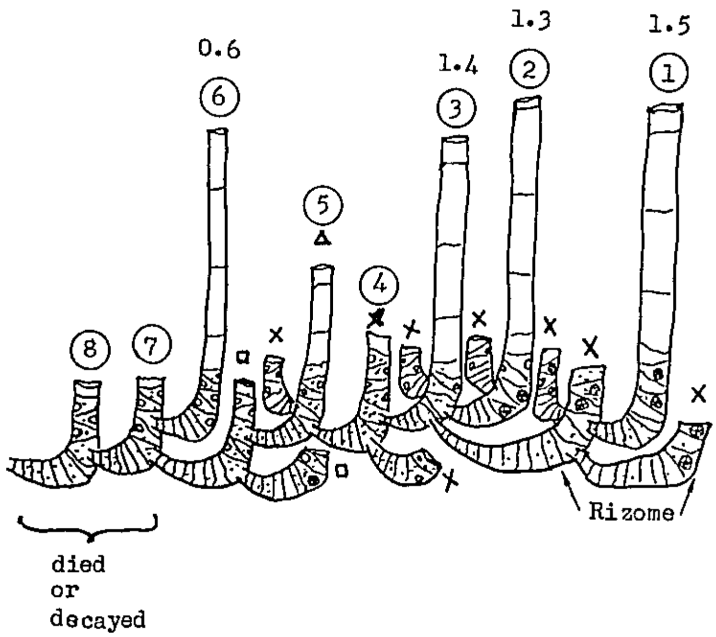

Table IV-1. Activity of buds on base of culm by age of culms in clumps

Bamboo species	Age	Total number of buds on base of a culm	Activity of buds				No. of sprouts, used for food	Location
			Bamboo grown completely	Undeveloped sprouts	Bud: vigrous or good	Bud: old or poor, little vitality		
T. siamensis	1	14	0	0	14	0	0	Erawan
	2	14	0	0	0	8	6	
	3	10	1	1	0	3	5	
	4	10	0	2	0	8	0	
T. siamensis	1	12	0	0	12	0	0	Khao Hin Lap
	1	14	0	0	14	0	0	
	2	10	0	0	0	9	1	
	2	10	1	0	0	6	3	
	2	12	1	0	0	11	0	
	3	12	1	2	0	2	7	
T. siamensis	2	10	0	0	0	10	0	
	2	8	1	0	0	7	0	
	4	8	1	1	0	3	3	
B. arundinacea	1	8	0	0	8	0	0	Khao Hin Lap
	2	8	1	1	0	6	0	
	3	8	1	5	0	2	?	
	4	8	1	4	0	3	?	
	5	8	1	2	0	* 5	0	
	6	8	(dead) 1	4	0	* 3	0	
	7	8	(dead) 1	0	0	* 7	0	
D. longis-pathus	1	10	0	0	10	0	0	Khao Hin Lap
	1	12	0	0	12	0	0	
	2	10	1	4	0	5	?	
	2	10	0	0	0	△ 10	0	
	2	10	0	0	0	△ 10	0	
	3	10	1	4	0	5	0	

Remarks: * indicates those with broken buds. △ indicates buds which have lost vitality. March 1965

Table IV-2. Activity of culms of a clump

Bamboo species	No. of culms	D.B.H. (cm)	Distance between clumps (cm)	Death age of culm	Length of rhizome (cm)	No. of sprouts used for food	Location
T. siamensis	Living 6	1.1 - 1.8		7		7	Khao Hin Lap
T. siamensis	Living 4	0.6 - 1.5		7		8	Khao Hin Lap
T. siamensis	Living 16 Dead 6	0.5 - 2.0	2 - 7	6	1.5 - 4.0	25	Khao Hin Lap
T. siamensis	Living 4	2.8 - 4.0	2 - 14	6	6.0 - 8.0	7	Erawan
B. arundinacea	Living 7	3.4 - 5.2	9 - 16	6	8.0 - 17.0	?	Khao Hin Lap
D. longispathus	Living 8	3.3 - 4.8	5 - 6	?	7.0 - 12.0	?	Khao Hin Lap

D.B.H.: Diameter at breast height

B. Active years and natural duration of life of culms and rhizomes

Bamboos, after sprouting, gradually lose their vitality as years go by, until finally they die. According to our studies on Thai bamboos, conducted by digging up rhizomes, those with the most vigorous sprouting activity are one-year-old ones (after budding). In two years this activity diminished a great deal, and when they are 5-6 years old, they become old, with their activity curtailed, and are ready to die. Since culms are extensions of rhizomes, the cyle of activity and death are closely interrelated, this is evidenced by the fact that the underground part rots soon after the death of the culm. (Fig. IV, 1 - 3)

Generally, the natural length of life of culms and rhizomes is shorter in the case of slender or poor ones, than of big or good culms and rhizomes. These conditions have been confirmed earlier by means of digging up rhizomes and injecting isotopes into the culms.*

C. Propagation by cuttings and offset planting

When culms are cut to a proper length (with 2-3 node buds) and stuck in soil, the underground node buds grow into rhizomes and roots, while those above the ground develop into culms. A still better method is to plant culms with rhizomes attached; this method is called offset planting. Usually those culms which are one year old and full of vitality should be used. Those over three years old should not be used as their vitality is declining.

III-2. Sexual propagation

A. Regeneration by seeds in flowering

Bamboos, while repeating asexual propagation for a long time, flower once, at sometime or other, and, if they come into flower, they, with their rhizomes, will die within two to three years. The flowering usually takes place either gregariously or sporadically. When all of the culms of a bamboo forest flower at the same time, they are said to bloom gregariously.

Bamboos which have flowered bear fruit, whose seeds fall to the ground and germinate. The culm growth which arises

* Ibid., p. 138-140.

from seeds are generally slender and do not enlarge in diameter. But in succeeding years, the new rhizomes growing sympodially from the base of the parent culm develop into substantially larger new culms each year. Thus, within about ten years after flowering a bamboo forest can develop culms with diameters as large as those produced before flowering.

B. The effects of flowering upon culm production

Gregarious flowering causes the death of many bamboos, thus suspending culm production temporarily and exerting adverse effects upon bamboo culm production. In our observations during our brief stay in Thailand, we found no instances of this type.

In sporadical flowering, however, culm production can be continued by means of the non-flowering clumps. Therefore, not many adverse effects are exerted on bamboo production. We sighted sporadical flowering in a forest of T. siamensis in the Kanchanaburi region, which did not adversely affect continuous culm production. (photo 12) In addition, we saw a few clumps in a forest of S. aciculare with almost half the culms flowering in the Ngao region in the north. Other than these instances, we did not see bamboos in bloom in other regions.

In cases of gregarious flowering, the following measures may be taken:

1) In order to expedite the recovery of forests, transplant by means of cuttings or offset planting. Culms of 3-5 years in age from regenerated clumps after flowering should be used.*

2) Also, in order to restrict the flowering, one should transplant those bamboos which will flower in different years or use bamboos of different species. In the latter case, such species suitable for pulp-making should be selected.

3) Species such as the Gigantochloa genus (e.g., G. latispiculata, Schizostachyum genus) should be used since they do not die after flowering.

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* Ibid., pp. 83-90.

IV. Qualities of Bamboo culms

IV-1. Measurements

The physical measurements of sample culms are shown in Appendix Table IV.

Figure V shows the relationship between D^2H and the fresh weights of the culms and between height and diameter of the culms under consideration.

Table V, based on Figure V, shows the fresh weights of culms classified by diameter.

Appendix Figure I is a cross-section showing relative wall thicknesses of a culm.

For the making of bamboo ware, the internode length is an important factor. In cutting, the number, the shape and the formation of branches must be considered. In pulp-making, the wall thickness and weight are important considerations.

A general review of the items under discussion in connection with specific species follows:

1) T. siamensis, like D. strictus, has a culm with thick walls whose lower part is solid and accordingly, is heavy in relation to its diameter. (photo 15) The branches are small in diameter and not numerous, thus making it easy to cut them off and also to cut the culms themselves. The culms are relatively slender, but the density of the culms makes cutting difficult.

2) B. arundinacea is also suitable for pulp-making, as it has a large diameter and also a thick wall. (photo 15) But its cutting costs are high because of its numerous large thorny branches.

3) Among other species, those considered suitable for pulp-making are Dendrocalamus longispathus, (photo 15) Bambusa tulda, Dendrocalamus membranaceus and Schizostachyum Zollingeri.

Table V. Fresh weight by diameter of a culm.

Diameter at breast height	Height	Fresh weight
0.5 (cm)	2.43 (m)	42.5 (g)
1.0	4.11	238.8
1.5	5.58	656.1
2.0	6.94	1,341.0
2.5	8.22	2,339.0
3.0	9.44	3,681.3
3.5	16.62	5,421.6
4.0	11.75	7,551.0
4.5	12.88	10,163.0
5.0	13.93	13,183.0
5.5	14.95	16,635.0
6.0	15.99	20,702.0
6.5	16.98	25,317.0
7.0	17.95	30,436.0

Note: 1 culm of both T. siamensis and B. arundinacea
Location, Khao Hin Lap, Kanchanaburi
March, 1965

Fig. V-1. Relation between weight and D^2H of culm

× B. arundinacea
△ D. longispathus
○ T. siamensis, 1-year-old culm
● T. siamensis, culm over 2 years old

$$\log Ws = 0.9031 \log D^2H + 1.8244$$

D = Diameter in cm. H = Height

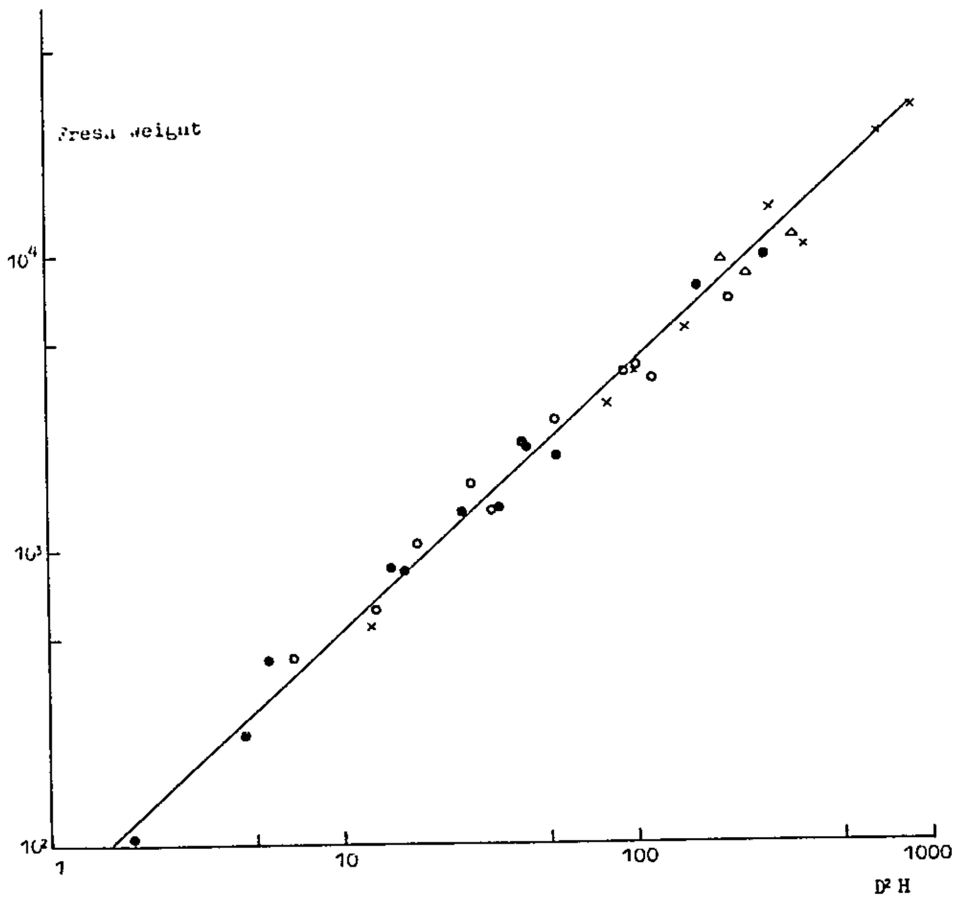
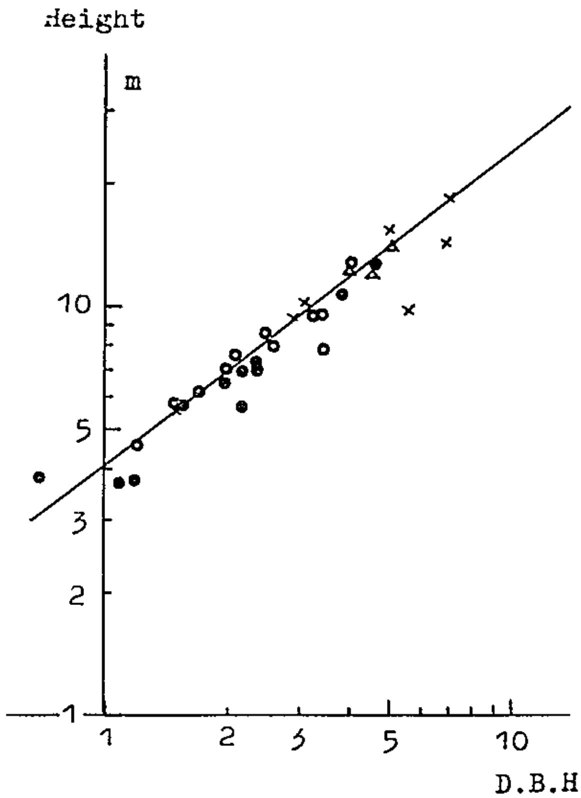


Fig. V-2. Relation between height and D.B.H. of culm

× Bambusa arundinacea
△ Dendrocalmus longispathus
○ Thyrsostachys siamensis, 1-year-old culm
● Culm over 2 years old

$\log H = 0.7578 \log D + 0.6139$

D.B.H. = Diameter in cm at breast height



IV-2. Fresh and air dried weight

The fresh weight is that which is obtained by weighing the culm immediately after cutting. We took fresh weight measurements in the Ngao region and in Khao Hin Lap, Kanchanaburi. The air dried weight is that which has reached a constant value calculated through weighing the cut culm once a week during a period of 2-3 months. In our survey, the weighing after cutting was performed by Mr. Prasert of the Royal Thai Forestry Department, the results of which are shown in Table VI.

Table VI. Ratio of air dried weight of a culm in percentage (air dried weight/fresh weight)

Species	Culm age	Max.	Min.	Mean	Remarks
T. siamensis	1	53	37	47	March 11-19, 1965
	2	72	59	66	
B. arundinacea	1	62	43	52	Khao Hin Lap
	2			67	
D. longispathus	1			54	
	2			67	
	3			68	
B. tulda	2			61	
O. albociliata	2			61	March 2, 1965
D. menbranaceus	2			68	
S. aciculare	2			62	Lampang

The percentage of the water content of the culms varies with the age of the culms. Table VI shows a high percentage in the case of one-year-old culms. The percentage of the air dried weight for 2-3 year-old culms is estimated at about 65%.

IV-3. Actual volume of culms

The volume of a culm minus its hollow part is called actual volume. Table VII shows this actual volume (m^3) calculated by diameters. According to this table, 1 m^3 of actual volume of culms corresponds approximately to 1 ton. The ratio of actual volume to the whole volume including the hollow part is larger than that in the case of bamboos produced in Japan. As for the Phyllostachys species, which is produced in Japan, this ratio is 29-46%, corresponding to about 1/3 of all bamboo produced in

Japan. Bamboos of Thailand have thick walls and thus a high ratio of actual volume. Table VII indicates that the ratio of actual volume to the whole volume is 76% for T. siamensis and 50% for B. arundinacea.

Table VII. Relation between whole volume including hollow volume and actual volume of a culm

Bamboo species	Height	Diameter at breast height	Hollow diameter	Whole volume	Hollow volume	Actual volume	Actual volume/ whole volume	Fresh weight
	(m)	(cm)	(cm)	(m^3)	(m^3)	(m^3)	(%)	(g)
T. siamensis	0.0-0.3	3.85	0.25	0.0003	-			
	0.3-1.3	3.50	1.05	0.0010	0.0001			
	1.3-3.3	3.25	1.80	0.0017	0.0005			
	3.3-5.3	2.95	1.80	0.0013	0.0002			
	5.3-7.3	2.65	1.25	0.0011	-			
	over 7.3	1.60	0.90	0.0001	0.0013			
	Total			0.0055		0.0042	76.3	4,120
B. arundinacea	0.0-0.3	4.55	1.40	0.0005				
	0.3-1.3	4.75	2.55	0.0018	0.0005			
	1.3-3.3	5.15	3.75	0.0042	0.0022			
	3.3-5.3	5.10	3.90	0.0041	0.0024			
	5.3-7.3	4.70	3.55	0.0035	0.0019			
	7.3-9.3	4.15	3.15	0.0027	0.0016			
	9.3-11.3	3.00	2.00	0.0014	0.0006			
	11.3-13.3	1.70	0.55	0.0005	-			
	over 13.3	1.20		0.0001	-			
	Total			0.0188	0.0092	0.0096	49.5	10,407

Table VIII shows the percentage of the basal area occupied by bamboo culms and intermixed trees. The percentage occupied by bamboo culms is thus 0.14-0.22% while that of the intermixed trees, 0.01-0.05%. These values are small, as compared with those of forests consisting of large trees alone, and indicate the existence of open spaces in bamboo forests. Moreover, the area ratio of good forests with many big bamboos is greater than that of poor forests. Table VIII shows, for T. siamensis forests, that the basal area of good forests in Erawan which is rich in large bamboos is 0.2% while that of poor forests in the Khao Hin Lap region is no more than 0.1%.

Table VIII. Percentage of basal area occupied by bamboo culms and trees in bamboo forest

Bamboo species in forest	Location	Basal area of living culms (%)	Basal area of living and dead culms (%)	Basal area of trees (%)	Number of trees	Investigared area (m^2)
T. siamensis	Khao Hin Lap (plot 1)	0.0766	0.1025	0.0131	11	200
T. siamensis	Khao Hin Lap (plot 2)	0.0851	0.1096			100
T. siamensis	Erawan	0.1909	0.2257			100
B. arundinacea	Khao Hin Lap	0.1316	0.1432	0.0555	25	100

IV-4. Length and thickness of fibers

Regarding the length and thickness of bamboo fibers produced in Thailand, Table IX-1 shows the results of an analysis by Dr. Yoshinori Shigematsu of Miyazaki University in Japan on fibers, using bamboo culms collected by us in Thailand. Table IX-2 is a compilation of results of Mr. Krit Sampuddhi of the Royal Thai Forestry Department.

Mr. Krit's analysis was upon bamboos produced mainly in the northern region and showed the species with long fibers to be B. tulda and D. membranaceus. Dr. Shigematsu's analysis was on bamboos collected by us from the forests of Kanchanaburi Province. We find here that among the three species we collected, T. siamensis, B. arundinacea, and D. longispathus, that the fiber length ranges from the longest in D. longispathus, which fact makes it good for use in pulp-making; followed by T. siamensis now being widely used for pulp-making; and B. arundinacea whose fiber length makes it suitable for pulp-making. An additional observation is that differences in ages do not affect fiber length to any great extent.

Table IX-3 are the results of analyses on other species from other Southeast Asian countries. Dr. T. Tsutsumi of Kyoto University analyzed bamboos of Pakistan and Viet Nam which were brought back by Professor K. Ueda. Dr. K. Ono of Osaka University studied bamboos of Burma and Indonesia and Dr. M. Nikuni and Dr. S. Uno, the bamboos of Formosa.

Table IX-1. Fiber length and fiber thickness of bamboo culms of Thailand

Bamboo species		Age	Length(L) mm.			Thickness(T) μ			L/T
Scientific name	Local name		Max.	Min.	Mean	Max.	Min.	Mean	
B. arundinacea	Pai Pah	1	3.795	0.660	1.799	49.0	1.0	23.3	78
		2	4.125	0.495	2.096	34.3	1.0	22.8	92
		3	4.125	0.825	2.096	34.3	1.0	19.9	105
T. siamensis	Pai Ruak	1.	4.290	0.660	2.211	21.2	0.9	17.6	126
		2	3.630	0.825	1.729	28.3	1.0	21.0	82
		3.	3.300	0.660	1.505	29.4	1.0	22.1	68
D. longispathus	Pai Lamalog	1	5.270	1.240	3.092	30.0	0.9	18.5	167
		2	4.950	0.825	2.624	30.8	0.9	20.9	125
		3.	4.950	0.990	2.878	58.6	1.0	24.0	120

Note: Collected date, March, 1965.
1 μ = 0.001 mm
Number measured for fiber length: 400 pieces
Number measured for fiber thickness: 50 pieces

Table IX-2. Fiber length and fiber thickness of bamboo culms of Thailand

Species (Local name)	Fiber length (mm)	2X-thickness (micron)
Bambusa tulda (Pai Bong)	4.68	12
Cephalostachyum pergracile (Pai Kaolarm)	2.32	10
Oxythenanthera albociliata (Pai Rai)	2.59	12
Dendrocalamus membranaceus (Pai Sang)	4.32	14
D. giganteus (Pai Hok)	3.22	10

Table IX-3. Fiber length and fiber thickness of bamboo culms from other Southeast Asian countries

Species	Fiber Length (mm)	Fiber Thickness (mm)	Location	Analyzer
Melocanna bambusoides	1.92-2.73-4.48	0.056-0.057	East Pakistan	Dr. T. Tsutumi (1962)
Bambusa longispathus	1.52-2.28-3.54	0.054-0.055	"	"
B. arundinacea	1.68-2.65-3.90	0.051-0.056	Viet-Nam	"
Schizostachyum zollingeri	1.41-2.54-4.85	0.046-0.058	"	"
M. bambusoides	1.87	0.016	Burma	Dr. K.Ono
Dendrocalamus strictus	2.23	0.022	"	"
Gigantochloa apus	2.38	0.015	Indonesia	"
B. stenostachya	1.48	0.012	Formosa	Dr. S. Uno
Phyllostachys Makinoi	2.50	0.015	"	Dr. M. Nikuni

IV-5. Silica content of leaves and culms

Silica (SiO_2) is said to be detrimental to the process of pulp-making, but a series of many varied experiments shows clearly that silica is one of the constituents necessary for the growth of bamboos. A matter which calls for attention is that the silica content varies greatly with the species, the time of the year, the structural part of the culm and other factors.

Generally, for all bamboos, the leaf contains the greatest amount of silica and an old leaf contains more than a young one. As for the culm, the quantity of silica is rather great in the epidermis, especially in the green part, but there is a little contained in the rest of the wall.

As for the bamboos of Thailand, the analyses of Mr. Krit and one obtained by using materials we had collected in Kanchanaburi in March, 1965 and analyzed by Mr. Chiba, are shown in Table X, where the silica content is shown in leaves and culms.

According to this table, the quantity of silica contained in the leaves is small, in the case of new leaves which have just come out, 4.4-5.8%; and is large in old leaves which are ready to fall, 11.2-24.8%.(a)(The formation of leaves is a almost continuous process; once a year, the old leaves fall during the dry season and new ones come out in the beginning of the rainy season.) The absorbed SiO_2 is thus accumulated in the leaves, but an excessive accumulation, on the contrary, does harm the entire plant. A high SiO_2 content especially in that part of the leaves where chlorophyl exists is considered to help considerably in the process of assimilation. The great importance of SiO_2 to the growth process of bamboos can be seen from the fact that the quantity of SiO_2 in bamboo leaves from good forests is larger than that from poor forests and that an application of SiO_2 results in an increased production of bamboo culms.

As for the silica content in culms, the analysis of Mr. Krit does not indicate specific details as to season or whether the materials were absolute or air dried, but they do show 0.02% of SiO_2 content in the epidermis and only 0.007-0.003% in the rest of the wall. According to Mr. Chiba's analysis, the SiO_2 content (a) is 15.0-27.0% in the epidermis, and 0.5-5.8% in the rest of the wall.

(a), indicates SiO_2 content to absolute matter

Table X. Silica (SiO_2) content (%) of leaves and culms

	Bamboo species	Leave	Culm			Location	Date of collection	Analizer
			Epidermis	Rest of Wall	Mean			
1	Bambusa tulda		0.020	0.0020		Thailand		Mr. Kilt
2	Cephalostachyum pergracile		0.019	0.0015		"		"
3	Oxytbenanthera albociliata		0.020	0.0009		"		"
4	Dendrocalamus menbranaceus		0.019	0.0031		"		"
5	D. giganteus		0.018	0.0027		"		"
6	Thyrsostachys siamensis							
	1 year old		27.65	0.622			March, 1965	Mr. K. Chiba
	2 years old	new 5.8 old 11.2	26.19	5.790		Khao Hin Lap,	"	"
7	B. arundinacea					Kanchanaburi,		
	1 year old			0.473			"	"
	2 years old		14.99	3.440		Thailand	"	"
8	D. longispathus							
	1 year old		20.11	2.61			"	"
	2 years old	new old 24.8	25.00	2.45			"	"
	3 years old		18.61				"	"
9	B. arundinacea	6.35-16.00	*4.76-12.20	0.25-0.46	0.39	Viet-Num	Jan. 1962	Mr. S. Ueda
10	Schzostachyum Zollingeri	9.95-11.35	*12.60-21.12	0.20-1.04	0.60-2.28	"	"	"
11	B. longispathus		*8.60	0.56	0.74	East Pakistan	July, 1961	"
12	Melocanna bambusoides		*8.90	1.72	2.40	"	"	"
13	Phyllostachys pubescens	new 1.05 old 9.00	4.20-5.10	0.10-0.13	0.29-0.33	Kyoto, Japan	1958	Mr. S. Ueda
14	P. Bambusoides	new 2.20 old 10.85	4.35-4.60	0.13-0.18	0.47-0.60	"	"	"

Note: 1-5: Based on a preminary study on the structure of bamboo.
9-14: Ratio to air dried matter. 6-8: Ratio to absolute dried matter.
* indicates green parts.

As to the removing of silica in the pulp-making process, methods such as treatment by chemicals or stripping of the epidermis (green part) should be studied. The silica thus obtained might be used as fertilizer in the form of silicate calcium.

V. Increment, yield and Growing Stock in Bamboo Forests

V-1. Growth of the bamboo sprout

Most of the sprouts begin to appear above the ground usually in the beginning of the rainy season (May-June) and others continue to appear each day until none appear about November. They complete their growth during these months, and there is no growth in any way after this time. Thus, a bamboo culm completes its full growth during this relatively short growing period (within one year). No further treatment such as applications of fertilizers can affect its growth. However, fertilizing can affect the growth of new culms.

V-2. Yearly increment

Yearly increment per unit area corresponds to the sum of the new culms which are produced each year. As the new culms are abundant and poor in number in alternate years, "on" and "off" years, their yearly increment may be obtained by taking the average of two years.

A. Number of new culms produced each year

As we found it difficult to distinguish some of the culms which were two years old at our investigation site, we calculated only one-year-old ones which had developed in 1964. The results are shown on Table XI.

Table XI. Number of culms by age

Species	Location	Plot size (m)	1 year old culms	1 year old culms (ha)	over 2 years old culms	over 2 years old culms (ha)	Total (ha)	Total culms including dead culms
T. siamonsis	Khao Hin Lap	10x20	166	8,300	383	19,150	27,450	38,400
T. siamensis	".	10x10	78	7,800	183	18,300	26,100	34,900
T. siamensis	Erawan	10x10	13	1,300	194	19,400	20,700	25,300
B. arundinacea	Khao Hin Lap	10x10	23	2,300	80	8,000	10,300	12,700

For T. siamensis forests, for instance, the year 1964 falls in the "on" year, and the quantity of new culms is large in Khao Hin Lap. According to other investigations classified by clumps, the quantity in the "off" year is about 1/2-1/3 that of the "on" year. But in the Erawan region, there were found sites which were of the "on" year, and others of the "off" year.

For most bamboos, in the "on" year, the number of new culms is large and they are of a large diameter. In an "off" year, although the number of new culms is small, their diameter is also small. An explanation of these alternate "on" and "off" years, is in the abundant assimilation of nutrients every other year. Since this is a natural phenomenon of most forests, whether good or poor, the application of fertilizers in the "off" years can produce abundant and large-diametered culms.

The following conditions have been observed per unit area. In a good forest on good soil, the number of culms per unit area is relatively small, but the culms themsolves are large in diameter. In a poor forest on poor soil, the number of culms per unit area is relatively large, but they are small in diameter.

Since the values shown on Table XI apply to a relatively small area, the same values when applied to a larger area cannot be used in the same ratio. This is because most bamboo forests have large areas with no bamboo growth. Considering these facts, the average number of new culms each year per ha. is estimated, in the case of T. siamensis forests, at 2,000 for a good forest to 3,000 for a poor one.

The number of culms by diameter in the case of new culms (one-year-old) is shown in Appendix Tables II-1, 2. For the T. siamensis forests, the sites investigated in Khao Hin Lap containing many small culms with diameters of less than 4.0 cm. indicated a poor forest. Those in Erawan containing almost all culms with diameters of more than 4.0 cm. indicated a good forest. In addition, it should be noted that the forests in Khao Hin Lap contained as much as 50% slender culms of less than 2.0 cm. in diameter, and therefore of little use.

B. Yearly volume increment

The yearly volume increment of culms is generally expressed in weight, the calculated results of which are shown on Tables XII and XIII. According to these, the yearly volume increment of culms (total weight of one-year-old culms) is 8.8-14.9 tons fresh weight per ha. in T. siamensis forests, and 24.7 tons in B. arundinacea forests.

Table XII. Yearly increment and growing stock per ha. (weight of new culms)

Bamboo Species	Plot size (m^2)	1 year old culms (kg)	Ton per ha.	culms over 2 years (kg.)	Total (kg)	Ton per ha.
T. siamensis (Khao Hin Lap, plot 1)	10x20	298.3	14.9	370.2	668.5	33.4
T. siamensis (Khao Hin Lap, plot 2)	10x10	148.3	14.8	235.9	384.2	38.4
T. siamensis (Erawan)	10x10	87.9	8.8	1,003.9	1,091.8	109.2
B. arundinacea (Khao Hin Lap)	10x10	246.6	24.7	634.5	881.1	88.1

Table XIII. Yearly increment and growing stock by diameter

(1). T. siamensis, plot 1 (10 m x 20 m)

Location, Khao Hin Lap

(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.B.H. (cm)	1 year old culms (g)	%	Culms over 2 years old (g)	%	Total (g)	%
0.3 - 0.9	443.4	10.1	2,808.0	48.9	3,251.4	0.4
1.0 - 1.9	29,630.8		178,650.0		208,280.8	31.2
2.0 - 2.9	211,406.8	89.9	180,736.7	51.1	392,143.5	58.7
3.0 - 3.9	56,832.1		8,016.5		64,848.6	9.7
Total	298,313.1	100.0	370,211.2	100.0	668,524.3	100.0

(2). T. siamensis, plot 2 (10 m x 10 m)

Khao Hin Lap

(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.3 - 0.9	262.7	11.6	1,299.8	24.2	1,562.5	0.5
1.0 - 1.9	17,088.5		56,096.9		73,185.4	19.2
2.0 - 2.9	111,280.3	88.4	162,824.5	75.8	274,104.8	71.1
3.0 - 3.9	19,692.8		15,688.1		35,380.9	9.2
Total	148,324.3	100.0	235,909.3	100.0	384,233.6	100.0

(3). T. siamensis (10 m x 10 m)

Erawan

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.0 - 1.9	0	0	8,706.3	0.8	8,706.3	0.8
2.0 - 2.9	1,694.4	100.0	91,359.1	99.2	93,053.5	8.5
3.0 - 3.9	34,868.1		583,431.5		618,299.6	56.7
4.0 - 4.9	51,301.4		280,900.3		332,201.7	30.4
5.0 - 5.9	0		39,549.0		39,549.0	3.6
Total	87,863.9	100.0	1,003,946.2	100.0	1,091,810.1	100.0

Note: D.B.H.; Diameter at broast height

It should be noted that the slender culms which are unusable for pulp-making, that is, those with diameters less than 1.9 cm make up 19.7-31.6% of the total culm fresh weight in K.H.L. Since the above values were obtained by converting those from the investigated area of 100-200 m^2, it must be mentioned again that the same tons cannot be applied to larger areas. Also, these values used for Tables XII and XIII did not take into consideration "on" or "off" years. But, the yearly volume increment applicable to general cases is 1/2-1/3 the above; that means 3-5 tons in fresh weight per ha. for T. siamensis forests and 5-8 tons for B. arundinacea forests.

V-3. Growing stock (Total fresh weight of culms)

Growing stock means the total fresh weight of living bamboo culms. This fresh weight per ha. according to Table XII, is 33-38 tons in poor T. siamensis forests in K.H.L., and 109 tons fresh weight in Erawan forests rich in large bamboos. This is about three times that of K.H.L. forests. In B. arundinacea forests, the value is 88 tons in K.H.L.

The above values, if applied to a large area, should be given a fairly large allowance, as mentioned above. The growing stock shown here may be useful when comparing good and poor forests.

A large growing stock is desirable, and, at the same time, a large yearly increment is necessary. In such bamboo forests as have many old culms (over 5 years old), in spite of their large growing stock, their productivity diminishes, resulting in a yearly decrease in the annual production of new culms. Therefore, in the studies of the productivity of bamboo forests in Thailand, the relationship between the growing stock and yearly volume increment should further be examined because the yearly volume increment plays a very vital role in the productivity of a bamboo forest.

V-4. Yearly culm yield.

The yearly culm yield corresponds to the yearly volume increment or the quantity of new culms produced each year.

In the practical utilization of culms, the following facts should be noted:

1) The top most part of a culm is too slender for use, thus about 2 meters is cut off and not used; the weight of this upper-most part is about 3-5% of the total weight of the culm.

2) The culm is then cut at a height of about 1 meter above the ground; the weight of this part remaining on the ground is about 20% of the total weight. Therefore, the real volume available is the whole volume minus 23-25% of the culm. Usually, the quantity of cut culms is designated in air dried weight, which is considered to be 65-70% of the fresh weight.

Thus, the yearly yield of cut culms per ha. is no more than 1.5-2.5 tons in air dried weight in the T. siamensis forests. But, if culms are cut at the surface of the ground, it can be estimated to be 2-4 tons. But the yield, when examined in the light of the qualities of forests, in T.siamensis forests, is low in K.H.L. because of the poor forests with an abundance of slender bamboos, while it is high in the Erawan because of good forests rich in large bamboos. Since these good forests in the Erawan are a part of a forest reserve system, we believe that they can be studied for optimum conditions for productivity.

The fore-going dealt with existing conditions having bearing on the yearly culm yield in Thailand. At least more than two times the present yield of culms can be expected by means of thinning, proper cutting and other improvements in forest management.

Table XIV gives the yearly culm yield, the results of our investigations in Thailand as well as in other countries.

Table XIV. Culm yield in round numbers by yearly and 3-year felling cycles

(air dried weight)

Country	Bamboo species	Yield per year per ha.	Yield at third year per ha.	Surveyd year
Thailand	T. siamensis B. arundinacea	2 - 4 tons 4 - 7	6-12 tons 12-21	1965
India	D. strictus B. arundinacea	3 - 4 5 - 6	9-12 15-18	1959
Formosa	B. stenostachya	3 - 5	9-15	1963

Note: The shape and volume of T. siamensis species resemble those of D. strictus species.

VI. Utilization

VI-1. Utilization of bamboo culms

The major uses of bamboo culms at present are listed below in Table XV.

Table XV. Utilization of bamboo culms.

Kanchanaburi region	T. siamensis (pai Ruak)	Paper making, fences, fishing poles, baskets, housing, used for rice (Kao Lham) and others
	B. arundinacea (pai Pah)	housing, baskets and others
Northern region	T. siamensis and others	fences, fishing poles, baskets, housing, Kao Lham and others
Southern region	B. arundinacea and others	fences, fishing poles, baskets, housing and others

There are no exact figures for the amounts of bamboo culms consumed for the above uses. But, in the Kanchanaburi mill, there are 3,500 tons of paper produced yearly. In this production, some 600 million culms or about 9,000 tons air dried weight is used in addition to 300 tons of bagasse pulp. (photo 13,14) For other uses, the consumption is estimated to be a fairly large amount, but the exact quantity is unknown.

VI-2. Utilization of bamboo sprouts

Bamboo sprouts are used for food by the farming population and are also canned. Moreover, some are consumed by cattle. The amount of bamboo sprouts cut for these uses is large, a fact clearly observable in our studies when digging up the rhizomes.

If such sprouts as can grow into good culms are removed and the poorer sprouts are left, this will probably result in the development of poor new culms and therefore poor production. This means that the overcutting of bamboo sprouts does exert an adverse effect on the production of culms.

VI-3. Utilization of living bamboos

Bamboos which grow on the sides of rivers or sloping hills play an important role in the preservation of land by preventing the erosion of soil and mitigating damages caused by floods and inundations, etc. This is proved by the example of the embankments of the River Kwai, which are sound where there are bamboo forests, and heavily demolished where there are no such forests. (photos 17, 18) In addition, we cannot overlook the bamboo forests around farm houses, used for windbreaks or as preventive measures from the houses being washed away. (photo 19)

VII. Protection

VII-1. Forest fires

Forest fires break out in various places during the dry season. (photo 20) Such fires often seem to be of intentional incendiary origins. Forest fires are often surface fires, whose spreading not only kills bamboos but also considerably arrests the process of regeneration of bamboo forests. Moreover, the ashes from the burned fallen leaves are highly soluble and therefore easily washed away during the rainy season, rendering insufficient organic nutrients and lowering the productivity of bamboo forests.

VII-2. Damage by insects

Living bamboos suffer little damage by diseases or by insects, but occasionally longicorn beetles which eat living bamboos as well as cut culms were found. Cut culms are attacked by bamboo borers. Noteworthy is the damage done by insects to cut culms used for making bamboo ware. Those culms cut in the rainy season are subject to considerable damage by bamboo borers, whereas those cut during the dry season are not. Although the season for cutting culms for pulp-making does not matter since culms are crushed before processing, those for other uses should be cut during the dry season or treated with chemicals in order to prevent insect damage.

VIII. Summary and Recommendations

VIII-1. Yearly consumption and production of paper in Thailand.

According to the statistics of the Thai government, the yearly consumption of paper was 38,440 tons in 1955, and increased to 110,000 tons in 1964. With modernization and an increase in population, the demand for paper did increase and will continue to do so. Also, if, for example, rayon is produced from domestic raw materials, the demand for pulp from bamboo will increase even more in the future.

As for the production of paper in Thailand, the paper mill in Kanchanaburi produces yearly 3,500 tons using bamboo as its raw material. There is a mill in Bang Pain which manufacture about 15,000 tons of paper from rice straw and imported pulp. In the Bangkok Paper Mill, 5,400 tons of paper are manufactured from imported pulp, waste paper and others. A plan to establish another paper mill is said to be under consideration. However, in order to meet the increasing yearly consumption of paper, increased production of domestic raw materials is desirable. For the time being, that which is considered a stable raw material for paper is bamboo. In the future, the production of pulp by means of bamboo mixed with wood is anticipated.

VIII-2. Characteristics of bamboo

Important characteristics of bamboo which must be considered follow:

1) Sprouts, after first beginning to appear above the ground, complete their growth within a few months, and do not continue their growth in any direction thereafter. In the tropics, the respiration process of trees is adversely affected by high temperatures, thus the consumption of energy on their part is great. As for bamboos, since they reach their full growth during a very short time and utilize their energy during the rainy season, they are not much affected by the high temperatures.

2) The proper ages for cutting of culms is relatively short, and bamboos should be cut when they are 3-5 years old. A three-year felling cycle can be practiced and the same forest can be cut every third year. As the yearly yield of culms corresponds to their yearly volume increment, a large yield can be continued each year by employing skillful cutting methods.

3) As there is no need to plant new seedlings after cutting, planting costs can be saved.

4) Large new culms of good quality can be grown by using such methods as fertilizing within 1-2 years, such treatments take effect rapidly, resulting in a rapid recovery of capital. Particularly in the case of existing poor forests, the yearly production per ha. of 2-3 tons (1 ton in terms of pulp) can be increased to over 5 tons by improving management.

5) Bamboo forests are widely distributed on level lands or gentle slops where culms can be easily extracted, thus saving labor costs.

VIII-3. Present state of culm production for pulp-making and possibilities of increased production

There is only one mill in Kanchanaburi that is making paper from bamboo, and yet the number of bamboo culms extracted here for making paper amounts to no more than 6 million culms (about 9,000 tons). The reason for the paucity is said to be that the greater part of the cut culms is used for other purposes, such as bamboo ware and others listed before.

Will it be possible to utilize more bamboo culms than those extracted presently for the process of making paper?

By applying even one method such as skillful thinning to 80,000 ha., which represents 10% of the 800,000 ha. of bamboo forests in the Kanchanaburi region alone, it is possible to cut 240,000 tons (air dried weight) of culms each year to make 80,000 tons of paper yearly. If the bamboo forests, whose productive capacity is now low, are improved together with their management by methods which will be stated in the following section, an increased production of larger and better bamboo culms can be expected.

As for the bamboo forests in the northern and southern regions, the culms here should be utilized for pulp making as a material mixed with wood including rubber waste wood. If a pulp mill to use raw materials is built, in this section, it must utilize the wood and bamboo available here as raw materials.

VIII-4. Improvement of forest management to increase production.

A. Transplanting

Bamboo culms of the T. siamensis species (Pai Ruak) are now mainly used as raw material in the paper factory at Kanchanaburi, but the B. arundinacea (Pai Pah) species should also be used. The treatment of forests of this species will be discussed later. The D. longispathus (Pai Lamalog) species is also suitable for pulp-making, as its walls are thick and its fibers long, its cutting operation is easy, as its branches are neither thorny nor numerous. This species grows now intermixed with the B. arundinacea species in the Kanchanaburi region. It is desirable that all of the B. arundinacea species there be cut or dug up and as replacement, transplant the D. longispathus by means of cuttings or offset planting.

Chemical analyses of culms and experiments in the mill on the selection of the most suitable species for pulp-making should be continued, and, at the same time, studies should be undertaken to produce species of superior quality by plant breeding.

B. Thinning methods

1). In the case of bamboo species which have no thorny branches (T. siamensis, D. longispathus, D. membranaceus and B. tulda),

The following selective cutting methods are the most advisable.

i) a felling cycle (rotation of 3 years) applicable either to an entire forest or to individual clumps; the cutting of all bamboos even if slender which are over 3 years old and leaving those that are 1-2 years old (see III-1).

As explained before, the whole forest is divided into three parts, and cutting is repeated every three years. In the part to undergo cutting, all of the culms of each clump over three years old are cut, leaving only those that are one or two years old. This procedure, of course, may be applied also to individual clumps which are divided into three parts, and cutting is repeated every three years.

ii) proper cutting height

It is advantageous to cut culms as near ground level as possible. At present, the culms stand so densely that they make cutting difficult, thus, they are now cut at a height of about 1 m. above the ground. The weight of a culm which is 1 m. above the ground corresponds to 20% of the total culm weight, so it is uneconomical to cut culms so high. If cutting culms at ground level is applied, then the distance between the individual culms will also gradually grow larger, resulting in an easier cutting operation.

iii) suitable cutting season

The proper time for cutting is during the dry season. But because culms for pulp making are in demand all the year round, it is inevitable that they are cut during other months, except during the sprouting season which is June, July, and August.

If the above practices cannot be effected, it would be preferable that clear cutting (cutting of all culms), an easy method, be practiced, since at present the practice is to leave the poor slender culms to grow old and thus decrease forest productivity for long time. But the felling ensuing cycle (rotation 7-10 years) becomes longer. In this case, follow the notes mentioned below (2).

2). In order to assure better and larger culms of species which have thorny branches (B. arundinacea), the following recommendations should be considered:

i) cut all culms leaving one-year-old ones

ii) cut all culms including one-year-old culms

iii) a felling cycle (7-10 years)

iv) proper cutting height of about 50 cm. above the ground, especially for one and two-year old culms.

The taller the stump is, the better, for by doing this, new branches from young bamboos will develop with the growth of buds on the stump, which will promote, through the assimilation process, the growth of new culms in the following season. (photos 6, 21,) In this procedure the whole forest is divided into 7-10 parts, and cutting is repeated every 7-10 years.

v) proper cutting season

Cutting should not be conducted during the sprouting season (as mentioned above).

C. Instruments for cutting

A sharp machete or an automatic saw serves the purpose woll. Out of the automatic saws for cutting trees, select those usable for bamboos. An automatic saw is especially good for cutting B. arundinacea forests.

For removing branches a machete is a convenient instrument for large branches; a saw for slender ones.

D. Chipped bamboo

It would be advantageous to chip bamboo by mobile chipping machines placed along the road where trucks can have access, thus facilitating the transportation of chipped bamboo to the factory.

E. Intermixing with trees

A mixed growth with some trees in bamboo forests is desirable. The growth of bamboos is expedited by the proper tree shade. When planting trees anew, leguminous trees are preferable.

F. Irrigation and fertilizing

It is a great advantage to store water by construction of dams to lead water to bamboo forests as well as to paddy-fields and farm lands.

Fertilizing is a very effective way of improving bamboo forests. If fertilizer is applied for 2-3 consecutive years, poor forests can be changed into good ones. Such forests, once improved, can continue to produce a fairly large amount of culms without much fertilizing thereafter.

Proper amounts of fertilizers per ha. are 100 kg. of N, 50 kg. of P_2O_5, 50 kg. of K_2O and 100 kg. of SiO_2. Fertilizing should be done several times during the months between June and October, during the sprouting or growing season. A drawback of this method is that fertilizer and labor costs must be added, but it is desirable to perform it for 2-3 years especially in forest near paper mill in order to improve poor bamboo forests.

The planting of leguminous grasses and trees also helps to improve the fertility of the soil.

G. Proper treatment of fallen leaves

As fallen leaves constitute a source of organic matter, devices should be construed so as not to let them escape. One preventive measure would be to lay cut bamboo culms here and there.

VIII-5. Proper treatment after flowering

At the present time, the flowering is of a sporadic type which does little harm to forests. In these cases, bamboos which have flowered should be cut and utilized while their culms are green, before they die.

Countermeasures against flowering, and especially against gregarious flowering, were stated in III-2.

VIII-6. Administration and Policies

1) The outbreak of forest fires and their spreading should be prevented.

2) The overcutting of bamboo sprouts by people and cattle should be prevented.

3) State-owned bamboo forests for pulp-making should be marked off. Notices of "State-owned forest for pulp-making" should be put up.

4) Carriage ways and truck roads should be constructed and bridges particularly should be put into good repair so that they can be used even in the rainy season.

5) A section in the Royal Foresty Department specifically in charge of bamboo forest administration staffed by bamboo experts should be established.

VIII-7. Training of technical experts in bamboo forest management

1) The government of Thailand should dispatch technicians to Japan.

2) Japanese bamboo experts should be dispatched to Thailand.

These measures could be arranged conveniently in conformity with the existing Colombo Plan.

VIII-8. Expansion of existing experimental station site

The items and methods of experimentation were stated in our preliminary report which has been already submitted. We believe that the results obtained in the existing experimental site at Khao Hin Lap would provide good material for reference in the management of forests and that this site and personnel be expanded.

VIII-9. Improving the state of pulp factories

There is one bamboo pulp making factory in Thailand at Kanchanaburi. This existing factory is too small to be economical.

1) Expansion of facilities of the existing bamboo pulp factory.

2) Establishment of a new factory near the present one because of convenience for extraction of bamboo culms.

VIII-10. Feasibility study for establishing and expanding pulp factories

Feasibility studies are indispensable to the establishment of a pulp factory. Satisfactory results will be obtained if conducted by those who have experience in bamboo pulp making. We can recommend a Japanese maker with excellent techniques.

The items of such studies would consist of the following:

1) Estimation of pulp and paper consumption in the future.

2) Recommendation of suitable location for the plant.

3) Design and estimation of costs of establishing a bamboo paper factory.

4) Annual paper production program.

5) Plan for dispersement of parsonnel in the factory.

6) Expenses for design and project.

7) Itemized cost per ton of paper produced.

8) Estimates of income and the economics of bamboo paper.

VIII-11. Items of study

The items which demand studies at the present are:

1) Further study and classification of existing bamboo species. Some existing species are known and have been classified, but many are still unclassified. Specialists of classification (e.g., Mr. McClure or Mr. R.E. Holttum) should be engaged for the work.

2) Analyses of bamboo culms. For each existing species, further detailed analyses of chemical and physical properties such as fibers, silica content, cellulose, etc., should be continued in order to determine the most suitable species available in Thailand for pulp-making.

3) Further study of other natural good bamboo forests. Natural good bamboo forests exist other than in the Erawan region. The conditions of these should be studied and used as material for reference in formulating plans for increased production. The conditions of such natural forests should be investigated by studies conducted on the forest stand and on the soil conditions.

4) Further studies on distribution. Further detailed studies should be made on the distribution of bamboo species as the existing information is quite incomplete.

5) Yearly volume increment studies. It is necessary to investigate in detail the yearly volume increment per ha. classified by species and by site, applied to wider and more varied areas and conditions.

6) New bamboo species. It is necessary to find a bamboo species which will not die after flowering. It is known that such species occur in the Gigantochloa and Schizostachyum species, but it is not known whether they can be found in Thailand.

7) Further culm and clump studies. The cause of clumps with few culms should be investigated.

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Appendix Table I. Meteorological statistics.

(1) Rainfall (average 1931 - 1960) (mm.)

Month / Station	Jan.	Feb.	Mar.	Apr.	May	June	Jily	Aug.	Sep.	Oct.	Nov.	Dec.	Seasonal		Annual
													Nov.-Mar.	Apr.-Oct.	
Lampang	6.9	9.0	22.5	71.5	136.1	128.2	128.7	190.1	203.1	123.3	23.6	4.6	66.6	981.0	1047.6
Tak	1.2	6.4	9.1	53.7	142.6	112.4	104.4	103.7	215.9	166.8	33.9	1.0	51.6	899.5	951.1
Kancha-naburi	1.3	13.6	34.5	68.9	141.8	82.7	121.3	86.2	192.2	188.2	57.4	4.0	110.8	881.3	992.1
Bangkok	8.9	25.2	34.4	89.0	166.3	168.1	179.4	176.8	304.7	253.1	56.9	7.1	132.5	1337.4	1469.9
(Surat-Thani) Ban Don	62.7	27.9	30.4	95.4	203.7	144.9	130.9	143.9	196.6	269.4	312.2	240.0	673.2	1184.8	1858.0

(2) Temperatures in Centigrade

Station \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
Lampang	30.3	32.9	35.2	36.2	34.7	33.0	32.2	31.7	31.5	31.0	30.6	29.5	Max.
	13.5	14.6	18.4	22.2	23.5	23.7	23.5	23.4	23.1	21.5	18.6	14.8	Min.
Tak	32.2	34.9	37.4	38.1	35.2	32.7	32.4	32.2	31.8	31.1	31.1	30.5	Max.
	14.5	18.1	23.2	25.6	25.2	24.8	24.4	24.4	24.0	22.2	19.1	15.3	Min.
Kanchanaburi	33.0	35.3	37.5	37.9	35.9	33.8	33.2	32.9	32.7	31.3	31.0	31.0	Max.
	17.4	20.5	23.2	25.0	25.1	24.6	24.1	24.1	23.8	23.0	20.7	17.3	Min.
Bangkok	32.1	33.1	34.3	34.8	34.3	33.1	32.5	32.3	31.9	31.3	31.0	30.9	Max.
	20.2	22.7	24.4	25.3	25.2	24.9	24.5	24.5	24.3	24.1	22.9	20.4	Min.
Ban Don	31.3	33.4	34.8	35.2	33.8	32.7	32.3	32.5	32.3	31.5	30.3	29.9	Max.
	20.5	20.4	21.2	22.8	23.4	23.4	23.2	23.1	22.8	22.7	22.4	21.8	Min.

By the table of Tahi Meteorological Department

Appendix Table II-1. Number of culms and clumps

Bamboo species	Location	Area sampled	No. of clumps (A)	No. of clumps (ha)	No. of living culms (B)	(B)/(A)	No. of culms including dead culms (C)	(C)/(A)	No. of living culms (ha)	No. of culms per clump	
										Min.	Max.
T. siamensis	Khao Hin Lap (plot 1)	20x10m	96	4,800	549	5.7	768	8.0	27,450	2	45
T. siamensis	Khao Hin Lap (plot 2)	10x10m	11	1,100	261	23.7	349	31.7	26,100	9	66
T. siamensis	Erawan	10x10m	8	800	207	25.9	253	31.6	20,700	3	61
B. arundinacea	Khao Hin Lap	10x10m	9	900	103	11.4	127	14.1	10,300	5	36

Appendix Table II-2. Number of culms by diameter and age

(1) Species, T. Siamensis,
plot area, 10 x 20 m
Location, Khao Hin Lap in Kanchanaburi

(2) B. arundinacea, 10 x 10 m
(Khao Hin Lap)

Diameter	1 year old (new culm)	over 2 years	Dead culms	Total	1 year old (new culm)	over 2 years	Dead culm	Total
under 0.9 cm	5	30	2	37				
1.0-1.9	42	241	150	433	3	12	3	18
2.0-2.9	106	110	66	282	4	9	18	31
3.0-3.9	13	2	1	16	3	22	3	28
4.0-4.9					1	21	0	22
5.0-5.9					9	12	0	21
6.0-6.9					2	3	0	5
7.0-7.9					1	1	0	2
Total	166	383	219	768	23	80	24	127
(%)	21.6	49.8	28.5	100.0	18.1	62.9	19.0	100.0
Per ha	8,300	19,150	10,950	38,400	2,300	8,000	2,400	12,700

	(3) *T. siamensis*, 10 x 10 m (Khao Hin Lap)				(4) *T. siamensis*, 10 x 10m (Erawan)			
Diameter	1 year old (new culm)	over 2 years	Dead culm	Total	1 year old (new culm)	Over 2 years	Dead culm	Total
under 0.9 cm	3	11	4	18	0	0	0	0
1.0-1.9	20	82	53	155	0	10	2	12
2.0-2.9	51	86	26	163	1	37	17	55
3.0-3.9	4	4	5	13	7	112	23	142
4.0-4.9					5	32	4	41
5.0-5.9					0	3	0	3
Total	78	183	88	349	13	194	46	253
(%)	22.5	52.4	25.1	100.0	5.2	76.6	18.2	100.0
per ha	7,800	18,300	8,800	34,900	1,300	19,400	4,600	25,300

Appendix Table III-1. Chemical properties of the soils of bamboo forests in Thailand

1	2	3	4	5	6	7	8	9	10	11	12	
Location (Bamboo species)	Depth (cm)	Soil color	PH	Organic carbon (%)	Available		Exchangeable cation (me/100g)				Water Content (%)	Re-marks
					P (P.P.m.)	K (P.P.m.)	ca	mg	K	Na		
Khao Hin Lap (T. siamensis)	0- 5	10 YR 3/3	6.2	2.62	3.2	161	12.94	1.86	0.67	0.15	14.2	loam
	5-10	"	6.4	4.43	2.8	93	12.11	2.59	0.40	0.15	11.0	
	10-15	10 YR 3/4	6.7	3.02	4.0	118	11.99	1.53	0.44	0.10	12.8	
	15-20	"	6.5	1.95	3.2	108	11.16	1.77	0.44	0.10	13.0	
	20-25	7.5 YR 3/4	6.4	1.65	3.2	139	11.16	1.53	0.51	0.11	13.5	
	25-30	7.5 YR 6/4	6.7	1.24	2.1	174	10.21	1.77	0.48	0.14	11.5	
	30-35	5 YR 3/3	6.6	1.10	2.1	113	9.02	1.38	0.40	0.11	11.0	
	35-40	5 YR 3/6	6.9	1.04	2.2	108	9.02	1.38	0.39	0.13	12.9	
	40-45	"	6.8	0.94	2.8	97	9.02	0.87	0.35	0.14	10.9	
	45-50	5 YR 4/8	6.8	0.60	1.7	85	8.56	1.38	0.28	0.13	11.5	
	50-55	"	6.9	1.08	1.8	91	8.56	1.38	0.33	0.13	11.5	
	55-60	"	6.6	0.68	2.8	103	7.12	1.38	0.32	0.17	12.7	
Erawan (T. siamensis)	0- 5	7.5 YR 2/2	7.1	6.72	29.1	210	19.84	1.90	0.83	0.14	15.5	sandy loam
	5-10	7.5 YR 2/3	7.2	5.44	7.5	170	16.44	1.38	0.58	0.11	13.7	
	10-15	7.5 YR 3/3	7.4	3.30	6.1	174	15.02	1.38	0.62	0.22	14.0	
	15-20	"	7.0	2.79	4.5	200	14.86	1.38	0.57	0.11	13.4	
	20-25	7.5 YR 3/4	7.0	2.82	4.5	216	14.32	0.69	0.61	0.17	13.1	
	25-30	5 YR 3/3	7.2	2.08	3.1	177	13.80	1.04	0.61	0.10	13.3	

(continued next page)

1	2	3	4	5	6	7	8	9	10	11	12	
Location (Bamboo species)	Depth (cm)	Soil color	PH	Organic carbon (%)			Exchangeable cation (me/100g)				Water content (%)	Re-Marks
					P (P.P.m.)	K (P.P.m.)	ca	mg	K	Na		
	0- 5	10 YR 3/3	6.7	1.78	9.0	50	9.43	1.28	0.22	0.17	10.9	
	5-10	"	7.0	0.77	4.8	32	6.39	1.17	0.21	0.25	10.7	
	10-15	7.5 YR 3/3	7.0	0.64	2.7	30	5.42	1.17	0.19	0.18	10.9	
	15-20	7.5 YR 4/3	7.3	0.40	2.4	26	3.58	1.06	0.13	0.14	9.2	
	20-25	7.5 YR 4/4	7.1	0.34	2.4	22	3.03	1.17	0.13	0.13	9.1	
	25-30	10 YR 5/3	7.6	0.27	1.5	20	2.49	0.74	0.14	0.15	8.8	
Khao Hin	30-35	"	7.2	0.32	2.2	26	2.82	1.17	0.08	0.26	8.9	samdy
Lap	35-40	"	7.2	0.37	1.8	26	3.34	1.49	0.08	0.26	9.0	soil
	40-45	"	7.3	0.37	1.8	28	3.68	1.38	0.10	0.29	9.2	
(B.	45-50	7.5 YR 5/3	7.3	0.34	2.5	34	4.01	2.13	0.13	0.27	8.9	
arundi-	50-55	"	7.3	0.44	2.4	34	4.33	2.02	0.15	0.22	9.0	
nacea)	55-60	"	7.2	0.57	1.9	34	4.66	2.02	0.11	0.22	9.1	
	60-65	7.5 YR 5/4	7.2	0.44	2.1	36	4.77	2.23	0.11	0.25	10.0	
	65-70	"	7.3	0.44	2.5	36	4.88	1.91	0.14	0.35	10.3	
Analyzer		Mr. K. Chiba	Mr. F.R. Moormann, F.A.O. in Bangkok				Mr. K. Chiba					

Note: All soils collected by Mr. K. Chiba
me = Milliequivalent
As for water content, column 12 indicates figures for absolute matter and columns 8-11 those for air dried matter. sampling date, March, 1965.

Appendix Table III-2. Chemical properties of the soils of bamboo forests in other countries.

(1). In Viet-Nam

(a) Schizostachyum species forest in Nong-Son, Viet-Nam

Depth	Water Content of soils	PH		Total N	Total P_2O_5	Total K_2O	Total Ca	Remarks
cm	%	H_2O	HCL	%	%	%	%	
0 - 5	15.96-19.54	5.0-5.8	3.5-3.8	0.045-0.090	0.008-0.013	0.261-0.300	0.055-0.097	Results of examination. Agricultural Experimental station, Viet-Nam, Jan, 1962
30	15.74-24.76	4.7-6.0	3.5-3.7	0.028-0.073	0.010-0.013	0.238-0.317	0.047-0.120	

(b) S. Zollingeri forest in Phuoc Long, Viet-Nam

	Depth of soil	PH		Soluble			Absorption Capacity P_2O_5	Remarks
		HCL	H_2O	N	P_2O_5	K_2O	PPM	
dense stand	0- 5	4.5	5.0	trace	none	trace	1,000	By Dr. N. Shibata, in Kyoto University, Japan February, 1962
	50-55	4.5	5.3	trace	none	none	1,000	
poor-stand	0- 5	4.5	5.5	trace	none	trace	1,000	
	50-55	4.8	5.8	trace	none	none	1,000	

(a), (b) both, for air dried matter, collected by Dr. N. Shibata

(2) In Malaysia

Bamboo species	Total N %	Conc.HCL soluble		SiO_2	PH	Locality
		P_2O_5 ppm	K_2O ppm			
S. Zollingeri	0.17	92	2,450	Not det.	5.5	Grik
"	0.22	242	1,205	"	4.4	Ulu-Lungat
D. strictus	0.08	78	1,090	"	5.3	Bukit
"	0.08	52	610	"	5.4	"

Note: Soil collected from surface layer, collected by Dr. K. Ueda and analyzed by Agr. Exp. Sta. in Malaysia, collected date: December, 1962

Appendix IV. Qualities of bamboo (1)

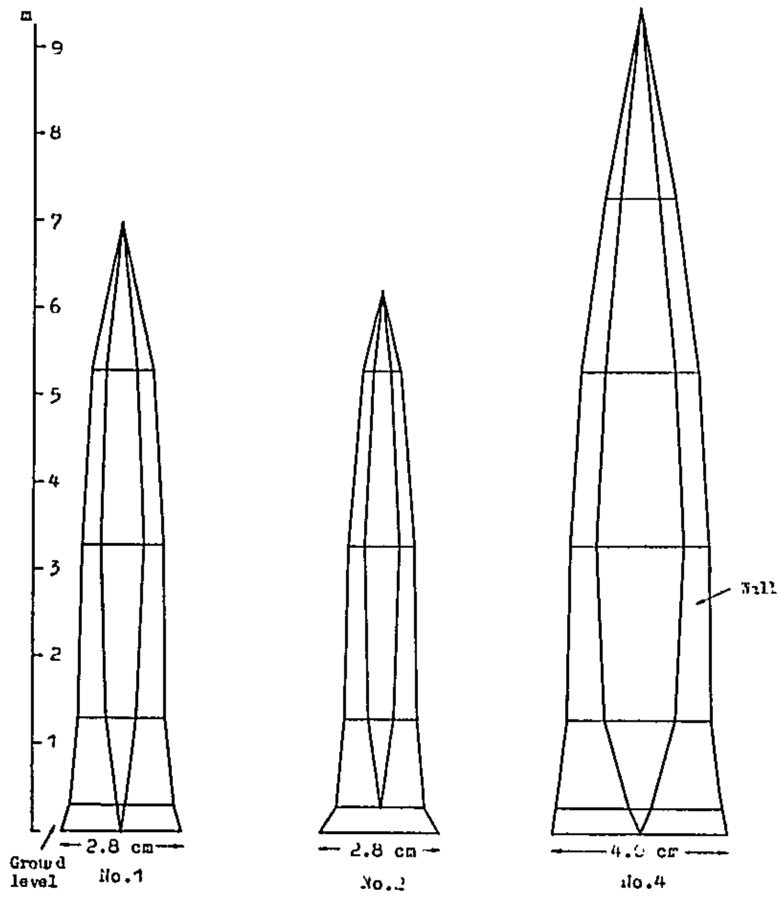
No.	Bamboo species	Age	Location	Height	Diameter			*Clear length	No. of Nodes	Longest inter-node length	Position at longest internode length		Extension of branches (Projection of branches)	Fresh weight	Fresh weight of leaves with branches	Wall thickness		Remarks
					at ground level	at 30 cm	at 130 cm				Height above ground	No. of nodes above ground				at ground level	at breast height	
1	Thyrsostachys siamensis	1	Khao Hin Lap	6.95m	2.8	2.4m	2.0cm	4.75m	38	30cm	m 2.55-2.85	15th	1.3-1.3m	g 1,678	255g	1.4	1.1	lower, part, solid
2	"	1	"	6.20	2.8	2.1	1.7	4.37	31	30	2.15-2.45	13	1.6-1.5	1,045	140	1.4	1.1	"
3	"	1	"	7.98	3.8	3.1	2.6	4.93	45	32	2.85-3.17	17	1.2-0.9	2,673	350	1.9	1.2	"
4	"	1	"	9.48	4.0	3.7	3.3	6.7	50	33.5	2.60-2.935	14	2.3-1.5	4,120	400	2.0	1.6	"
5	"	1	"	4.62	2.2	1.7	1.2	3.15	29	25	1.94-2.19	16	1.4-1.1	430	80	1.1	0.8	"
6	"	3	"	7.40	3.4	2.8	2.4	2.53	41	30.5	1.935-2.24	12	1.8-1.5	2,194	650	1.7	1.4	"
7	"	3	"	6.46	2.9	2.3	2.0	2.09	39	28	1.54-1.82	11	1.5-2.0	1,316	250	1.5	1.1	"
8	"	2	"	5.70	2.2	1.9	1.7	2.43	33	29	2.97-3.26	17	1.2-7.0	854	194	1.1	0.9	"
9	"	2	"	3.80	1.3	1.2	1.1	1.36	25	25.5	0.86-1.12	6	1.4-1.0	236	105	0.6	0.5	"
10	"	2	"	3.90	1.0	0.7	0.7	1.85	28	22	1.42-1.64	11	0.9-1.0	107	55	0.5	0.3	"
11	Dendrocalamus, longispathus	1	Khao Hin Lap	12.00	5.45	4.8	4.5	5.40	58	37.5	6.63-7.05	20		8,350		2.3	1.7	
12	"	2	"	13.90	5.8	5.1	5.0	3.20	62	36	4.00-4.36	16		11,119		2.3	1.2	
13	"	3	"	12.50	4.5	4.3	4.0	1.95	51	36.5	4.76-5.25	18		9,100		2.0	1.1	
14	Bambusa arundinacea	2	Khao Hin Lap	14.45	7.1	6.6	6.9	0.67	65	34	5.38-5.72	23		24,388		2.7	2.2	
15	"	1	"	18.50	7.3	7.1	7.0	0.72	70	36	5.95-6.31	25		30,910		2.3	2.2	
16	"	1	"	15.64	4.6	4.5	5.0	0.61	70	39	7.70-8.09	36		10,407		1.7	1.4	
17	"	2	"	5.60	2.0	1.7	1.5	0.35	30	25	2.62-2.87	17		545		0.9	0.5	
18	"	2	"	o9.75	6.1	6.2	5.5	0.32	42	30.5	3.45-3.720	16		13,880		2.8	2.7	
19	"	1	"	10.45	3.8	3.3	3.1	0.33	46	35.5	3.925-4.43	19		4,037			0.8	
20	"	1	"	9.55	3.2	2.9	2.9	0.62	41	33	4.98-5.31	22		3,045		1.3	1.0	
21	"	3	"	10.65	4.2	3.9	3.75	0.43	51	30.5	3.625-3.93	35		5,572		1.7	1.2	

Note: Date, March, 1965
* Height from ground to lowest branch
o Top part of culm lost

No.	Bamboo species	Age	Location	Height	Diameter at ground level	Diameter at 30 cm	Diameter at 130 cm	*Clear length	No. of nodes	Longest inter-node length	Position at longest internode length: Height above ground	Position at longest internode length: No. of nodes above ground	Extension of branches (Projection of branches)	Fresh weight	Fresh weight of leaves with branches	Wall thickness at ground level	Wall thickness at breast height	Remarks
22	T. siamensis	2	Khao Hin Lap	2.80			0.6											
23	"	1	"	7.15			2.2											
24	"	1	"	8.44			2.9											
25	"	1	"	6.16			1.6											
26	"	2	"	o5.34			1.5											
27	"	3	"	6.70			1.8											
28	"	3	"	3.81			0.9											
29	T. siamensis	1	Khao Hin Lap	7.70	4.0	3.5	3.5	4.82	42	30	1.89-2.19	11	1.0-1.0	3,918	720	1.7	1.3	Lower part, solid
30	"	1	"	7.55	2.7	2.1	2.1	4.10	38	35	2.46-2.81	13	0.7-0.5	1,338	260	1.4	1.8	"
31	"	1	"	5.75	1.9	1.7	1.5	3.55	35	30	1.32-1.62	10	0.4-0.6	615	110	0.9	0.8	"
32	"	2	"	7.00	3.1	2.6	2.2	2.18	43	24	2.12-2.36	14	1.2-0.8	1,378	300	1.0	1.3	"
33	"	2	"	5.80	2.0	1.7	1.6	2.30	30	29	2.10-2.39	13	1.0-0.8	870	270	1.0	0.9	"
34	"	2	"	3.80	2.1	1.6	1.2	1.24	25	24	1.00-1.24	9	0.6-0.5	428	105	1.1	0.8	"
35.	T. siamensis	2	Erawan	7.10	3.3	2.9	2.4	3.90	31	31	2.66-2.97	15	1.0-0.6	2,300	320	1.7	1.5	solid
36	"	2	"	10.90	4.8	4.3	3.9	6.65	45	33	4.53-4.85	20	1.3-0.8	7,745	940	2.1	0.7	
37	"	2	"	12.80	5.85	5.1	4.7	4.55	54	33	4.54-4.87	21	1.3-1.2	9,695	1220	2.4	1.7	
38	"	1	"	9.55	4.5	3.9	3.5	5.8	46	30	2.40-2.70	15	1.0-1.0	3,670	315	2.3	1.7	
39	"	1	"	12.90	5.0	4.7	4.1	8.05	50	38	5.97-6.35	20	1.0-1.2	6,870	400	2.3	1.8	
40	"	1	"	8.00	3.2	2.8	2.5	5.50	38	31	2.50-2.81	16		2,000	220	2.0	1.2	solid
41	"	2	"	10.83	5.6		4.3	6.87	63	26	3.29	19	1.00	6,630	500	2.8	0.7	solid
42	B. tulda	2	Ngao	13.85	6.6		6.3	64	40	66	6.85	13		19,580		2.5	1.2	
43	D. membranaceus	2	Ngao	18.00	7.7		6.8	25	65	46	4.00	12		26,740		2.8	1.8	
44	Oxytenanthera albociliata	2	Ngao	8.90	4.0		3.4	1.45	23	40	3.53	13		4,860		2.0	0.8	
45	Schizostachyum aciculare	2	Ngao	13.54	5.5		5.4	8.10	40	47	4.70	14		13,140		0.6	0.9	

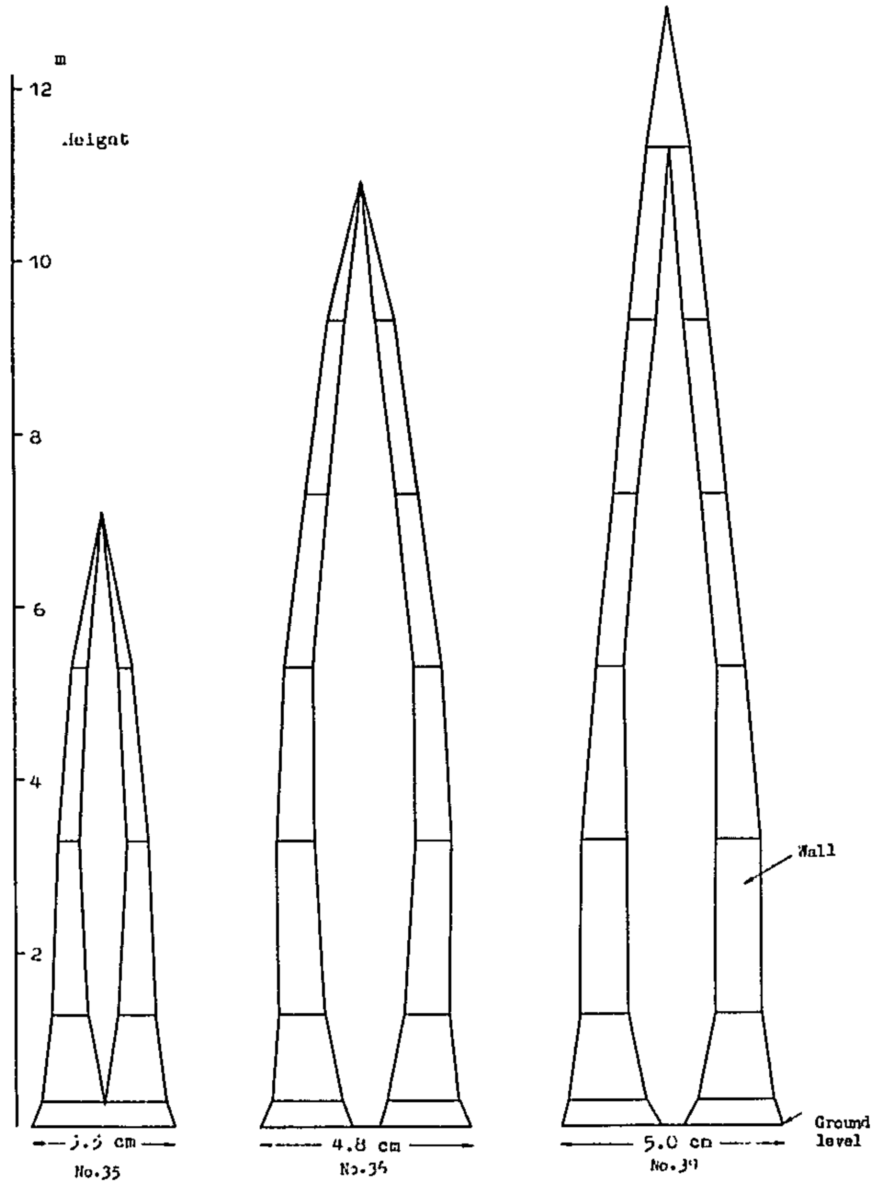
Appendix Fig.I. A cross-section of bamboo culm

(1). T. siamensis, Khao Hin Lap
Details are shown on the Appendix Table IV, No.1, 2, 4.



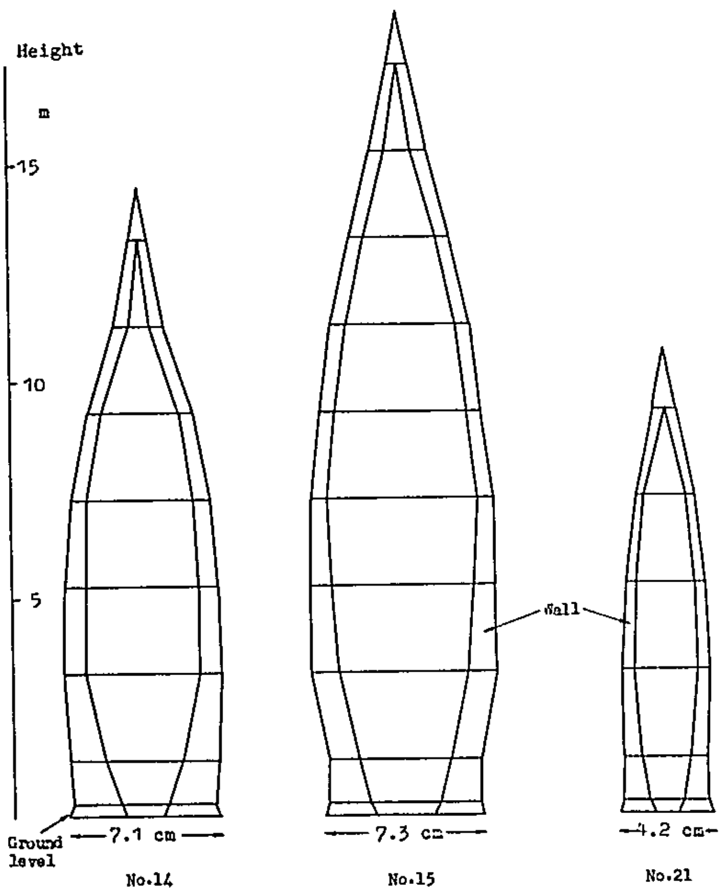
Appendix Fig.I. A cross-section of bamboo culm

(2). T. siamensis, Erawan
Details are shown on the Appendix Table IV, No.35, 36, 39.



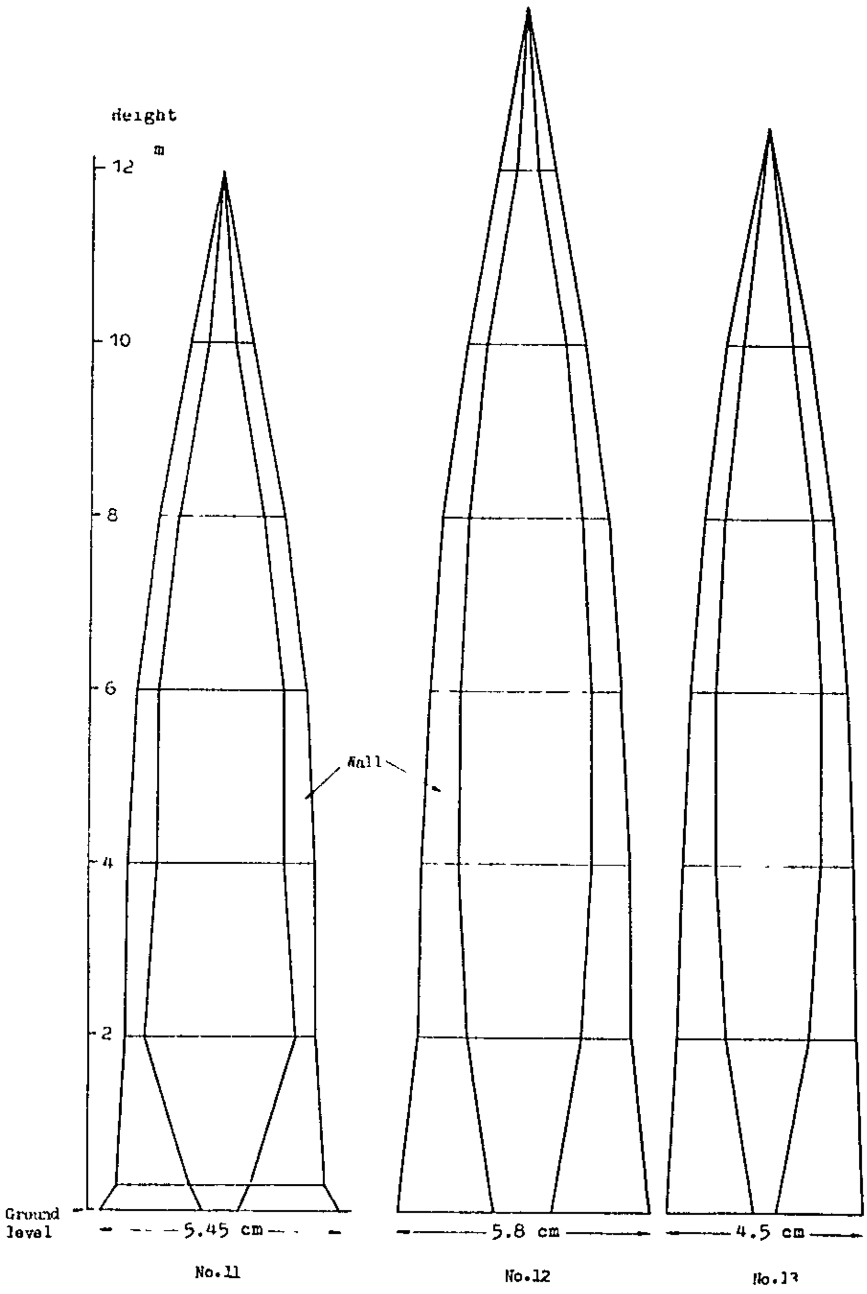
Appendix Fig.I. A cross-section of bamboo culm

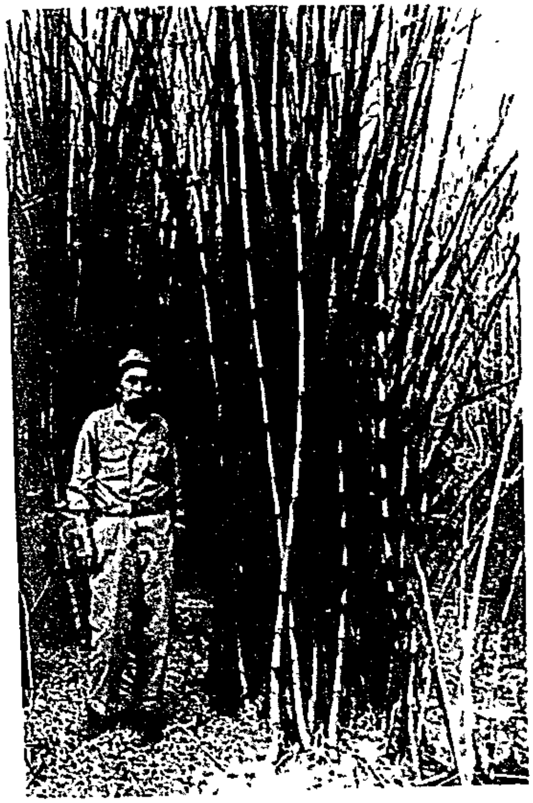
(3). B. arundinacea, Khao Hin Lap
Details are shown on the Appendix Table IV, No.14, 15, 21.



Appendix Fig.I. A cross-section of bamboo culm

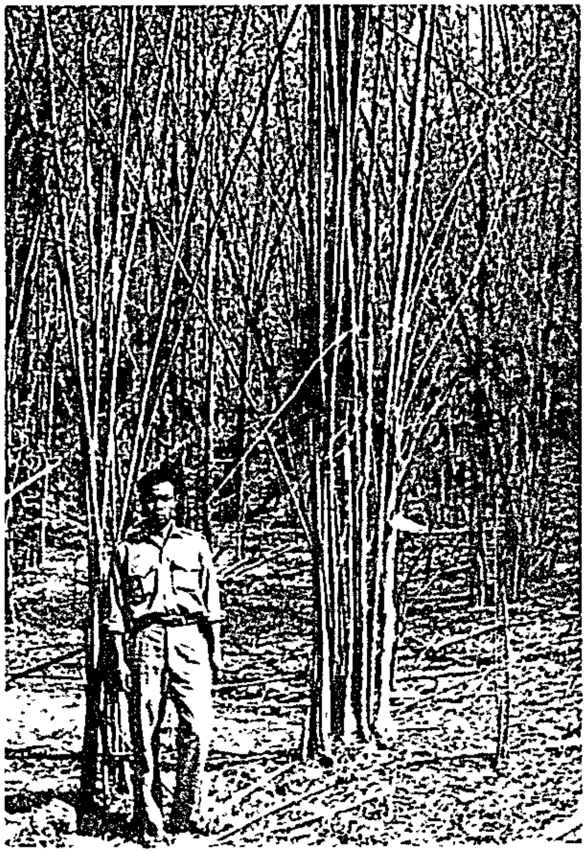
(4). D. longispathus, Khao Hin Lap
Details are shown on the Appendix Table IV, No.11, 12, 13.





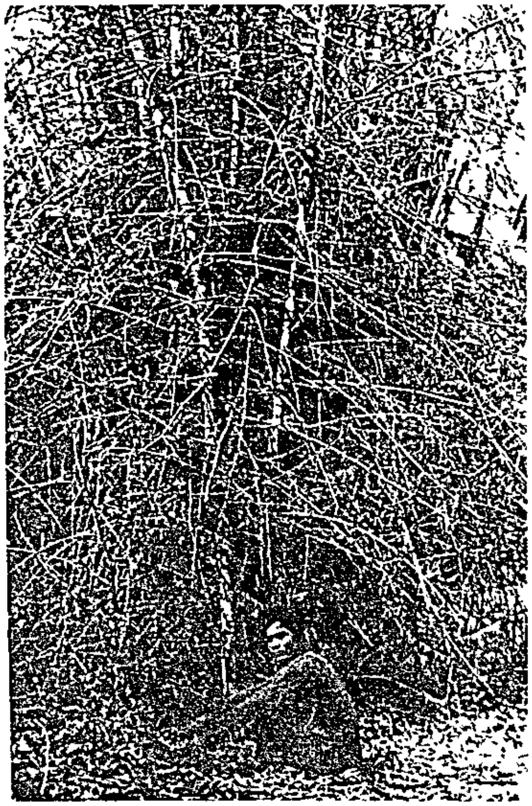
1. A clump of Thyrsostachys siamensis (Pai Ruak).
Dr. K. Ueda, author, stands beside clump
Locality: Khao Hin Lap in Kanchanaburi region

2. Clumps of
a T. Siamensis forest
Kao Hin Lap



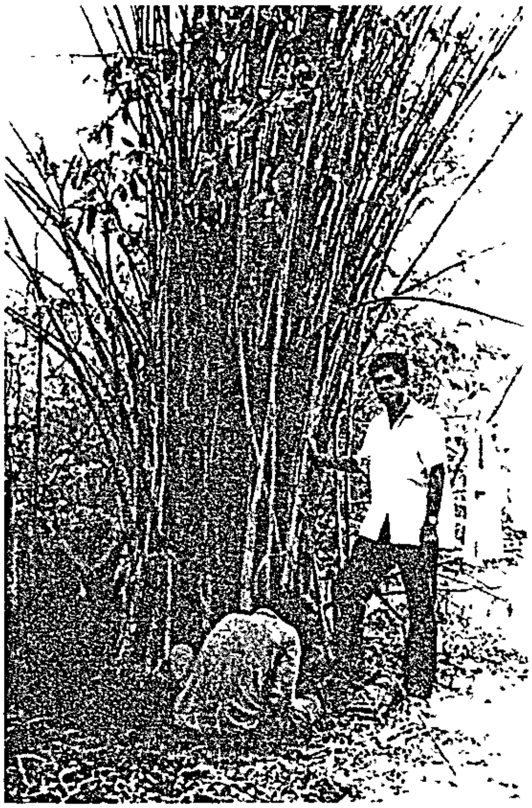
3. T. siamensis forest
Ngao

4. Forest mixed with trees,
Oxytenanthera hossensii (Pai Kai)
Surathani



5. A clump of Bamb . arundinacea
(Pai Pah)
Khao Hin Lap

6. . arundinacea clump with culms
whose lower branches have been
cut and thus culms stand apart
Erawan, Kanchanaburi



7. Digging rhizomes of T siamensis clump, Mr. Prasarn of Royal Forestry Dept. stands beside clump, Khao Hin Lap

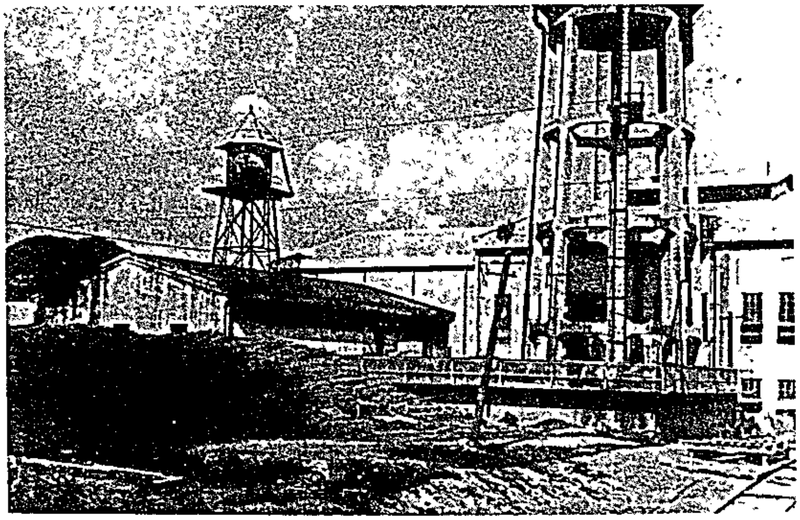
8. A rhizome system of B. arundinacea
1: one year old
2: two years old
3: three years old
4: four years old

9. A rhizome system of Dendrocalamus longispathus (Pai Lamalog) Khao Hin Lap

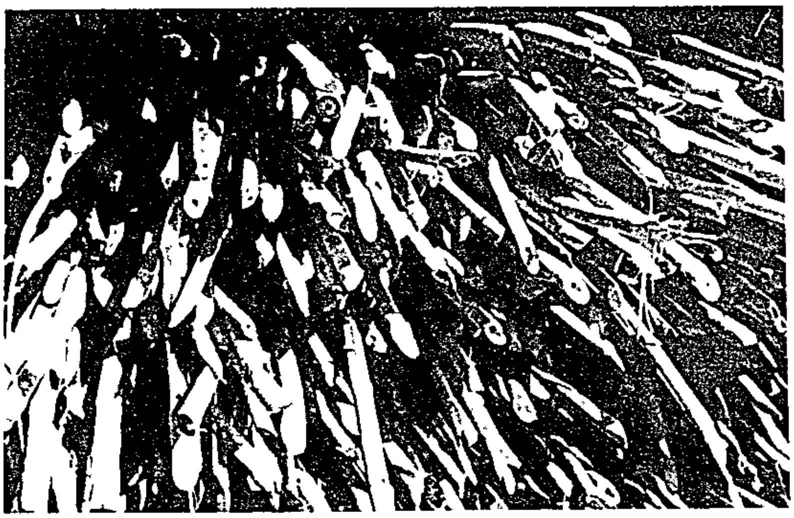
10. A rhizome system of T. siamensis showing large culms, Erawan

11. A rhizome system of T. siamensis showing small culms
Khao Hin Lap

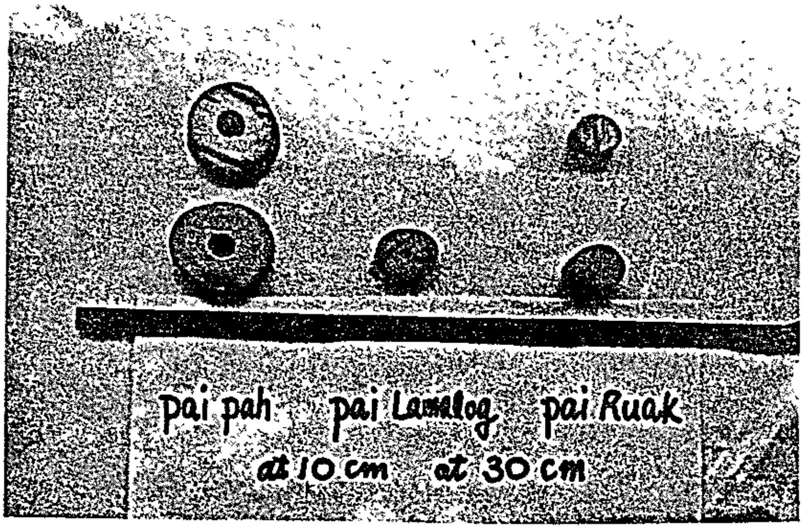
12. Flowering of T. siamensis clumps occurs sporadically
Khao Hin Lap



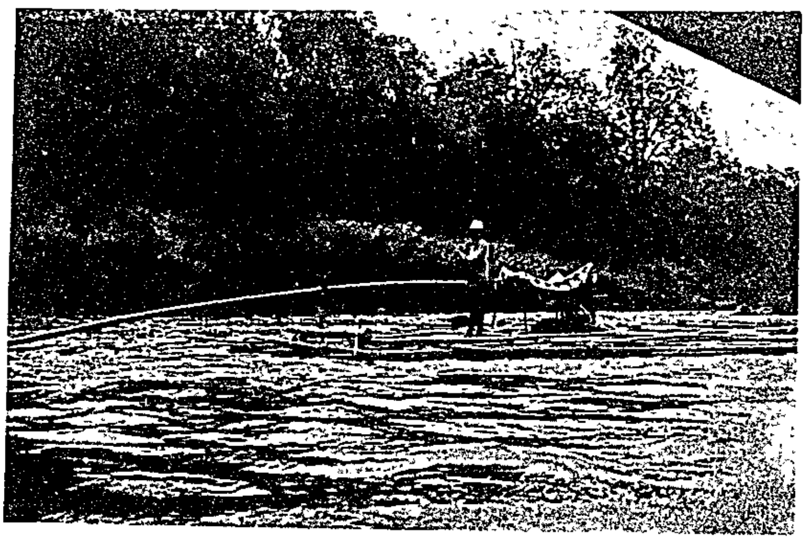
13. Bamboo paper factory in
Kanchanaburi



14. Raw material (culms of T. siamensis)
for paper making, Kanchanaburi
paper factory

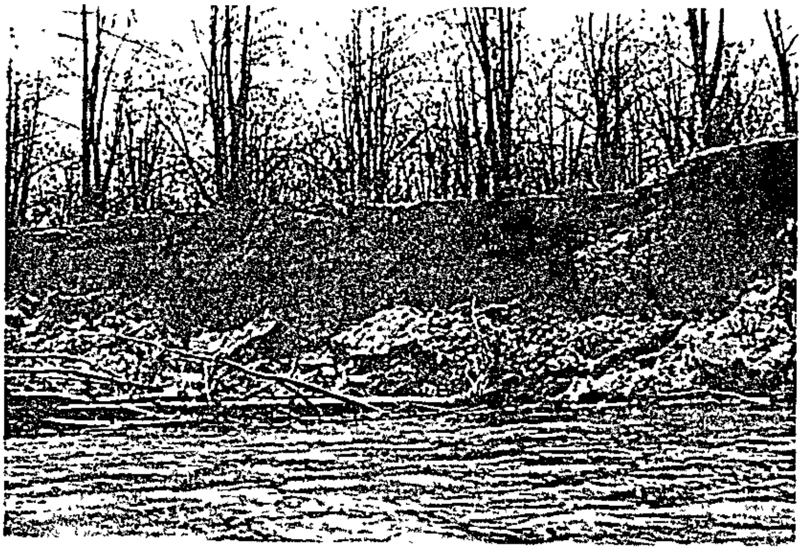


15. Cross sections showing wall thickness
Left: B. arundinacea (Pai Pah)
Center: D. longispathus (Pai Lamalog)
Right: T. siamensis (Pai Ruak)
Lower culms at 10 cm above ground
Upper culms at 30 cm above ground



16. Transporting of T. siamensis culms
River Kwai (From Erawan to Kanchanaburi)

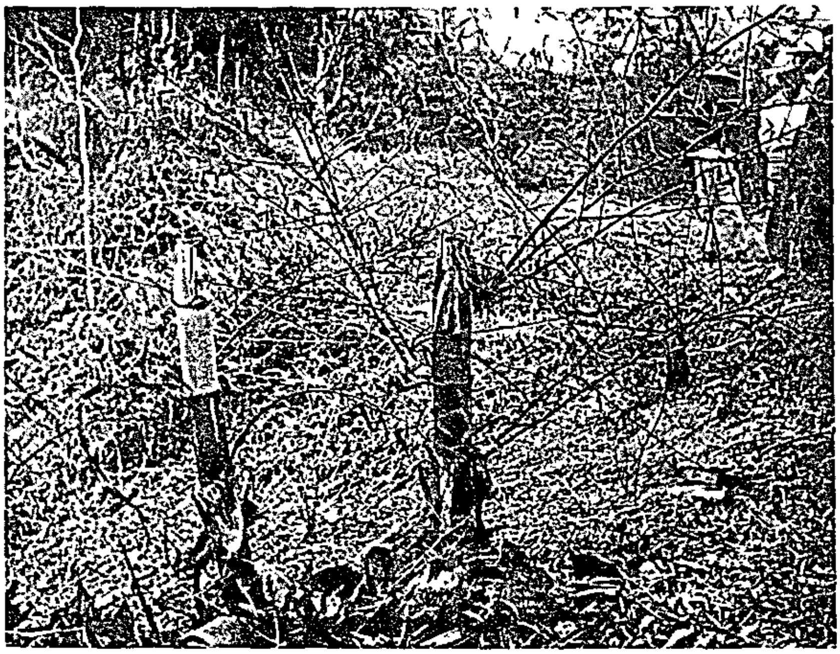
17. Bamboo stands on banks as defense against destruction by floods
Kwai riverside



18. Effects on banks where no bamboo was grown
Kwai riverside

19. B. arundinacea grove used for windbreak
Suburbs of Bangkok

20. Fire in bamboo forest
Khao Hin Lap



21. New branches showing growth
from stump of 1 year old culm,
B. stenostachya species
Formosa