VOLUME 4

Resources – Forestry, Plantations and Conservation

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Preface

This session covers forestry and conservation activities in South America, Australia, China, Japan, South East Asia, India, and Africa. The importance of silvicultural management and genetic improvement for enhancing the quality and yield of bamboo are highlighted. Innovative strategies for preserving natural stands are demonstrated, and the impact of bamboo flowering on forests and land use is thoroughly analyzed. Problems and potential solutions related to the protection and enrichment of the resource base are discussed in detail by several speakers. The challenges that face bamboo resources on the policy level are addressed. Likewise, the issue of financing bamboo plantation development, particularly by small landholders, is tackled constructively. The benefits that bamboo forests and plantations provide to the environment is a theme that underlies the presentations of this session.

The session is chaired by Victor Brias and co-chaired by Inder Dev Arya.

Victor Brias is known in the bamboo world as the founder of the popular Bamboo-Plantations Discussion Group (www.bamboo-plantations.com). He has an international background; he is a Spaniard who was born in the Philippines, where he lived for 25 years. He lives in Belgium where he is employed as the Project Development Manager for Oprins Plant N.V. (www.oprins.com), a company in the province of Antwerp that is specialized in bamboo. He is a consultant to the United Nations Industrial Development Organization and has been involved in bamboo projects around the world for many years. His academic background is neither in agronomy nor forestry. He holds a Ph.D. is in philosophy and a Masters degree in Finance. In his own words: “What I know about bamboo and forestry, I have learned through reading, professional experience, and networking. I love bamboo, and work with it every day!”

Inder Dev Arya holds a Ph.D. in Genetics. He currently heads the Forest Genetics & Tree Breeding Division at the Arid Forest Research Institute (www.afri.res.in) at Jodhpur, India, where he is working on the genetic improvement and mass propagation of bamboo using tissue culture techniques. He has been devoted to bamboo research for the last 2 decades. Under his leadership, his research group has developed tissue culture protocols for 7 bamboo species, 3 of which have been extensively used for mass propagation. Dr. Inder Arya is popularly known for the development and establishment of edible bamboo *Dendrocalamus asper* in India. Thanks to his efforts, this edible bamboo species has been established in many parts of India and is being multiplied in millions by commercial companies, NGOs and research institutes.

Planning, Designing and Implementing a Jati Bamboo (*Bambusa tulda*) Plantation Scheme through Bank Credit on Small Landholder's Revenue Wastelands in Assam, India for Sustainable Livelihood

M.S.Haque and K.G.Karmakar
General Manager and Managing Director
National Bank for Agriculture and Rural Development (NABARD), Bandra east, Mumbai, Maharashtra, India

Abstract

National Bank for Agriculture and Rural Development (NABARD) is a developmental bank and provides credit for promoting sustainable agriculture including bamboo cultivation.Hindustan Paper Corporation in Assam uses bamboo as raw materials but faces difficulties in procuring bamboo from forests due to inaccessibility, hence desired seedling based bamboo cultivation under farm forestry and approached NABARD for suitable credit schemes for small land holders. Accordingly it prepared a scheme for raising seedling based ***Dendrocalamus strictus*** plantations. However, the farmers were not interested to raise bamboo through seedlings, rather they requested NABARD for ***Bambusa tulda*** cultivation scheme through rhizomes. After undertaking field visits, holding workshops with NGOs, farmers and bankers, a rhizome based scheme for intensive cultivation of bamboo was formulated for the districts of Assam. The scheme was exclusively designed for farmers who could spare at least one bigha (1 / 3 acre) of wastelands and the cost of cultivation was Rs. 9050 over a period of 4 years (1 US$=INR 50). 85 bamboo rhizomes were planted per bigha with spacing of 4 m x 4 m and in every alternate year 40 clumps would be harvested annually from 5th year onwards. Based on an average price of Rs. 20 per bamboo, income would be Rs. 6400 in 5th year, reaching to Rs. 16,000 in 10th year on retail sale . The interest charged on loan by bank was 8% per annum and IRR of the scheme was 37%. Implementation of the scheme started during 2006-07 and more than 100 farmers were provided loans by Assam Gramin Vikas Bank. Repayment of loan with interest would be completed within 8 years. The financial outlay of the scheme was Rs. 48.86 million for developing 1800 acres of small farmer's wastelands. The scheme can be replicated in other districts of Assam.

Keywords: Bamboo, small landholders, credit, sustainable livelihood

Introduction

NABARD is a national level institution for providing and regulating credit and other facilities for the promotion and development of agriculture, small scale industries, cottage and village industries, handicrafts and other allied economic activities in rural areas. It is responsible for supervision of rural co-operative credit structure and regional rural banks in the country. It also provides refinance to these institutions for their lending activity in rural areas and gives loans to state government for creation of rural infrastructure.Although Forest Departments and Forest Development Corporations (FDCs) have traditionally raised bamboo on degraded forest lands, farmers have also started raising bamboo on farmlands, however, scientific and systematic cultivation of bamboo is a recent trend. In fact bamboos are known in India more for utilization rather than cultivation. Traditionally, bamboos have been used as raw materials by the paper making industries. But as little importance was given for raising plantations, bamboo became already scarce and the industry had to augment bamboo supply with alternative sources of raw materials such as fast growing trees like ***Eucalyptus sp., Acacia sp., Casuarina sp***., ***Leucaena s****p*. etc. In spite of this, for producing quality paper, certain percentage of bamboo mix in the raw material is considered essential, thus compelling the industry to procure bamboos from far-flung places, which has become rather uneconomical due to transportation costs. This has necessitated raising of bamboo plantations on farm lands under Farm forestry and Agroforestry.

Potential for Bamboo

India is one of the richest countries in bamboo population with about 75 genera and 136 species, out of the total 1250 species of bamboo found in the world. The North Eastern Region alone hosts about 90 species under 13 genera (Bhuyan, 2003). Bamboo development is viewed as a program for eco-restoration, economic development, employment generation and livelihood security. These multipurpose species have enormous potential which have only been partly harnessed. There are at least 1500 recorded uses of bamboo. The important usages are mainly in paper industry, building material, tiny and cottage industries, handicrafts, medicinal products, edible shoots and new generation products such as wood substitutes, truck bodies, railway carriages, bamboo boards, tiles etc. In Assam the major traditional industrial use of bamboo is for paper manufacture by Hindustan Paper Corporation Ltd. which functions through its units in Panchgram and Nagaon. It is now increasing its capacity to 800,000 tones p.a. from the present level of 320, 113 tones. Despite its versatile utilities, bamboo in India is currently faced with a number of problems, especially within forest area, such as poor management, low productivity (about 1-2 tonnes per hectare), over exploitation of the available stock, gregarious flowering etc. There is also increasing pressure on forest areas for procurement of bamboo as raw material for industrial uses. These problems invite attention for organised cultivation of bamboo both inside and outside forest areas. In Assam, there is practically no organised cultivation of bamboo. Most of the requirements of raw materials are met through procurement from forests and the bamboos cultivated by farmers on their homestead lands are mainly for their own personal use and consumption.

The Planning Commission, Govt.of India, in the report of the National Mission on Bamboo Technology and Trade Development (2003) suggested raising 2 million ha bamboo plantation during the Xth Five Year Plan and 4 million ha in XI five Year Plan period and had estimated fund requirements of Rs.26,080 millions for the Xth Five Year Plan (2006-07) period. The estimated demand is 26.69 million ton against the supply of 13.47 million ton. A two pronged strategy was suggested to meet the gap i.e. proper harvesting from forest areas and fresh plantations in 6 m ha of degraded forest lands / wastelands. Later in 2006, Indian Govt. approved National Bamboo Mission which recommended to raise 88,000 ha bamboo plantations each in forest and non-forest areas through a centrally sponsored scheme.

As indicated earlier, the major industrial use of bamboo in the country is paper manufacturing. The paper industry requires about 6 million tons of bamboo for improving its installed manufacturing capacity utilization. Non availability of bamboo is the main reason for low consumption which offers scope for increased utilization of bamboo by paper mills which are currently operating at 41% of installed capacity. Paper mills should therefore enter into buy-back arrangements with bamboo growers outside forest areas to ensure sustained supply of raw material. It is significant to note that the import of pulp costs about Rs. 38000 million annually (1US$ = INR 50).One of the characteristic features of bamboo is its suitability for cultivation in wastelands. Farming in Assam is mostly rainfed and the farmers are not technologically well -equipped. Also input application is minimal. Bamboo, with its wide adaptability, hardy nature, therefore, best suits cultivation in this situation. The project being implemented in the districts of Nagaon, Morigaon and Kamrup have available wastelands of more than 20,000 hectares; hence bamboo development in 1800 acres will not pose any problem so far as availability of land is concerned.

The project

It envisages commercial cultivation of bamboo in about 5400 bighas (1800 acre) of wastelands in Nagaon, Morigaon and Kamrup districts of Assam, through financial support from 3 Banks viz. Assam Gramin Vikas Bank, United Bank of India, and State Bank of India in these districts through their branches in the respective blocks. The total financial outlay of the project is Rs.46.20 million involving a bank loan of Rs.41.58 million. The purpose of bamboo cultivation is to utilize the wastelands in the districts for increasing productivity which are not put to use by farmers. Further, there has been no or negligible credit flow to the Forestry sector in the State for want of viable and bankable projects. The project therefore envisages extension of technology besides financial assistance by Banks. There is a big local market for bamboo in the districts. In fact the Nagaon Paper Mill is located nearby. Besides, new industries like Koson’s Forest Products has come up in Amingao near Guwahati which requires large number of desired variety of bamboos. Thus marketing will not be any problem for the bamboo produced under the project, especially because the project will produce Jati bamboo (***Bambusa tulda***) which is not only favored by the farmers but also by the industries.

The project objectives are :

I. To encourage bamboo cultivation in small holder’s waste lands in possession of farmers in three districts of Assam viz. Nagaon, Morigaon and Kamrup for ecorestoration, economic development, employment generation and livelihood security.

II. To encourage flow of bank finance to the hitherto neglected but potential sector of forestry in Assam

III. To augment raw material requirements of new generation bamboo based industries.

IV. To increase green forests in the non-forest areas of the state

The partners

The implementation of the project involves the active participation of the farmers, banks and NABARD. These agencies are expected to work in close coordination for effective implementation of the project. The responsibilities of each of these agencies are explained in the following paragraphs.

Farmers:

The number of farmers identified under the project is approximately 2500 to cover an area of 5400 bighas (1800 acres, 1 bigha = 1/3 acre) in three years. The land holding of these farmers ranges from 1 bigha to 10 bighas. However, for the project, a minimum unit of one bigha wasteland is required for raising bamboo. As it will be too ambitious to convert agricultural lands for bamboo cultivation due to food security concerns, available waste lands in possession of the farmers only were selected. The obligations on the part of the farmers are : (i) agree to raise bamboo in his plot with rhizomes which are available in plenty in the locality,(ii) the farmers agree to meet necessary input costs of labour, manures, fertilizers, insecticides, fencing etc on his own through bank loan and (iii) repay the bank loan after moratorium period. A few progressive bamboo farmers were identified to arrange for supply of healthy rhizomes for selected farmers of the project.

Banks :

The major banks i.e Assam Gramin Vikas Bank (AGVB), State Bank of India (SBI) and United Bank of India (UBI) were considered under the project although other banks could participate if they are interested in the project. This was done after undertaking field visits with the bank officials in all the three districts. The obligation on the part of the bank will be to encourage the farmers to take up bamboo plantations, extend financial assistance to the identified borrowers and ensure repayment through the proceeds of sale of bamboo by proper vigil from time to time. However, only Assam Gramin Vikas Bank participated in funding the scheme.

NABARD:

It identified wasteland development as a thrust area for rural development. NABARD, as an apex institution in rural credit structure will act as a facilitator for credit flow by way of preparation of project, educating the bankers for bamboo plantations by arranging workshops, advising the bankers for extending finance for bamboo cultivation and creating awareness among all concerned. Apart from the above promotional activity, NABARD will extend refinance support to banks at 100% of bank loan at 6.5 to 7.0 % rate of interest.

Technical aspects

Climate :

A majority of the bamboo thrive at temperature ranging from 8 to 36^{0}C. Rainfall is an important factor and the minimum threshold precipitation required is 1200 per annum. The rainfall range for bamboo cultivation is very wide ranging from 1200 to 4050 mm per annum. Assam is a high rainfall zone with normal rainfall being more than 1772 mm per annum, hence is suitable for commercial cultivation of bamboos.

Soil :

Most bamboos are found in sandy loam to loamy clay soil, derived form river alluvium or underlying rock. Although bamboo, like other commercial crops prefer a well drained soil, it is observed even in swampy soils and wet stream beds. The soils of the districts vary from clay to clay loam to sandy loam and soil reaction is acidic with pH of 4.5 to 7.0. A luxurious growth of bamboo is a common feature in the districts and therefore the soil and climatic conditions are best suited for cultivation of bamboo.

Species:

Among many indigenous bamboo species growing in Assam, only 2 species are cultivated by farmers viz, ***B. tulda*** and ***B. balcooa***. However, the most common bamboo available in the districts and most favored by the farmers is jati bamboo ***B. tulda***. So it is proposed to plant only jati bamboo for the present project.

Planting Material:

There are various methods of propagating bamboo viz. through seed and vegetative methods including tissue culture. The vegetative method i.e mainly rhizomes have been considered under the project because this is not only the traditional method of bamboo cultivation, but also most favored by the farmers because of quick yields. Besides, the progressive bamboo farmers have been identified for supplying rhizomes to the farmers. It has also been observed that plenty of rhizomes are available in the project areas.

Raising of the plantations:

The planting will be taken up during the period January to March. Pits of 60 cm3 will be dug and FYM will be put inside the pits before the Rhizomes are planted at a spacing of 4m x 4 m. The number of plants per bigha is estimated at 85. A provision has been made for casualty replacement in the second year to the extent of 10%.

Fencing :

Live hedge fencing has been recommended as it is essential to protect Bamboos in initial years from grazing by stray cows and goats, because bamboo leaves are fodder and voraciously eaten by the animals.

Fertilization :

Bamboo is a heavy feeder and therefore, even rich soils might becomes depleted after a few years if no fertilizer is added. Although fertilizers may be applied at any time in the year, it is preferred to apply fertilizer after harvest and before irrigation. It should be noted that rhizomes continue to be active (growing) except during the coldest part of the year. It is therefore proper to apply small quantities of fertilizer round the year rather than in one/two large doses. Bamboo responds well to nitrogen and potassium which are found in compost, green manure, wood ash and chemical fertilizers. Lime is often applied to neutralise soil acidity.

Irrigation :

The area receives adequate precipitation for successful bamboo plantation hence no irrigation is proposed except protective irrigation during the dry months in initial years. It would be desirable if irrigation is given at least once in a month during dry period.

Plant protection :

Bamboo is generally free from pest and diseases, however, diseases such as rhizome rot, bamboo blister, shoot and culm borer, are observed sporadically. Timely application of systemic fungicides and pesticides will control the problems.

Weeding :

Bamboo plantations receive more sun because of the relatively wide separation of the culms. Sunlight encourages the growth of weeds which consume nutrients intended for bamboo and shade the ground, lower the soil temperature and thus retard shoot emergence. Regular weeding during the 1st three years is a necessity for vigorous growth of bamboo.

Pruning :

Bamboo grows vigorously and many branches develop on the culms along with thorns. It is therefore necessary to prune the undesirable branches to maintain the healthy growth of the harvestable culms.

Intercropping :

The gestation period in bamboo plantation (through rhizome) is 4 years. During the first two to three years, it is possible to cultivate intercrops such as turmeric, ginger, chilli etc.

Harvesting and yield :

The annual yield of a bamboo clump depends on the number of new culms produced each year. This in turn is related to the production of young rhizomes. Culms mature after two to three years. To maximise production some shoots must be left each year to develop into leafy young culms. On an average bamboo produces 10-20 culms in a year under good growing conditions. Considering a 30 year life cycle, one clump may produce 300-600 culms.

The harvesting can be done from the fourth year onwards, however, for commercial production, harvesting will start from the fifth year under the project on a rotational basis every alternate year from each clump. So in the 5th year it is proposed to harvest bamboos from 40 clumps and the remaining 40 clumps will be harvested next year. In the first year of harvest i.e., fifth year, 8 culms per clump will be harvested followed by 10 culms in sixth year, 12 in seventh year, 15 in eighth year, 18 in the ninth year followed by 20 culms from tenth year onwards.

Financial aspects:

Unit cost-

The unit cost for raising small holder's bamboo plantation (1 bigha) is Rs.9,050 spread over a period of four years. The various assumptions for arriving at the unit cost are given in Table no. 1.

Table-1: Unit cost for intensive cultivation of bamboo in one bigha (1/3 acre) wastelands of Assam

Sl. No.	Particulars of Work	Unit	Cost (Rs.) in Years			
			1	2	3	4
1	Clearing of Jungle, land preparation etc. (MDs)	10	600	-	-	-
2	Digging of Pits (60 cm3) MDs	10	600	-	-	-
3	Live hedge fencing including maintenance	Lumpsum	300	100	100	100
4	Application of Organic manure and Fertiliser	Lumpsum	250	250	250	250
5	Cost of Rhizome including transport (85+10)	Rs.30	2550	300	-	-
6	Cost of Planting rhizome (MDs)	5	300	-	-	-
7	Weeding cum Soil Working (MDs)	6	360	360	300	300
8	Protective Irrigation	Lumpsum	250	250	-	-
9	Plant protection measures	Lumpsum	100	100	100	100
10	Prunning-tending/cleaning (MDs)	2	120	120	120	120
11	Cost of intercropping	Lumpsum	200	200	-	-
	Total		5630	1680	870	870
	Unit Cost	9050				

Labour rate = Rs.60 per MD Espacement = 4m X4 m = 85 rhizomes / unit

Survival = 80 rhizomes / unit of 1 bigha Cost of rhizome= Rs. 30

Income: Harvesting commences from the 5th year onwards which will be done every alternate year with 50% survival of clumps i.e. 40 clumps per year. The sale price per bamboo is considered at Rs. 20 which is a conservative estimate. The income details are given in the Table no.2

Table-2: Income estimates for intensive bamboo cultivation in one bigha(1/3 acre) wastelands of Assam

Year	No of harvestable culm /clump	Total culms per bigha	Income @ Rs. 20 per culm	Yield in ADMT(@15 kg/culm)	Income @ Rs 1200/ADMT)
V	8	320	6,400	4.8	5,760
VI	10	400	8,000	6	7,200
VII	12	480	9,600	7.2	8,640
VIII	15	600	12,000	9	10,800
IX	18	720	14,400	10.8	12,960
X onwards	20	800	16,000	12	14,400

Financial analysis

The project is technically feasible and financially viable with the above cultivation practices, expenditure and income levels. The financial indicators for one bigha bamboo plantation are provided in Table no.3

Table-3: Economics / Financial Analysis for intensive cultivation of bamboo in one bigha (1/3 acre) wastelands of Assam

Yeas	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Total Income	0	0	0	0	6400	8000	9600	12000	14400	16000
Total Cost	5630	1680	870	870	870	870	870	870	870	870
Net Income	-5630	-1680	-870	-870	5530	7130	8730	11130	13530	15130

Financial Indicators

Discount Factor	15%
NPV of Cost	9118
NPV of benefits	22221
NPV of net benefits	13103
BCR	2044
IRR	37%

Repayment period

The bank loan was considered at 90% of the unit cost i.e. Rs. 8,145/-. Income generation from the activity will commence from the 5th year onwards. The interest accrued during the gestation period will be deferred. The repayment of principal with deferred interest will be for four years i.e., 5-8th year of plantation, the details are provided in Table no.4

Table-4: Amount of Bank loan and Repayment schedule for intensive cultivation of bamboo in one bigha (1/3 acre) wastelands of Assam

Years	Unit Cost	Bank Loan @ 90%	Rate of Interest
1	5630	5067	8 %
2	1680	1512	
3	870	783	
4	870	783	
	9050	**8145**	

Years	Loan disbursed during the year	Total loan outstanding at the end of the year	Interest accrued during the year	Cumulative interest	Loan repayment				Income	Surplus
					Principal	Accrued interest	Interest	Total		
1	5067	5067	507	507	0			0		
2	1512	6579	658	1165	0			0		
3	783	7362	736	1901	0			0		
4	783	8145	815	2715	0			0		
5		8145	815	3530	1500	882	815	2315	5530	3216
6		6645	665	2647	2000	882	665	3547	7130	3583
7		4645	465	1765	2500	882	465	3847	8730	4883
8		2145	215	882	2145	882	215	3242	11130	7888
	8145				**8145**					

Discussion

Because of their very fast growth, bamboos fit well in the bank's lending systems. Returns on bamboo investments are comparable with any other method of farming systems. Annual income from bamboos after a short period of gestation, makes them suited for Farm / agroforestry on small land holdings of small and marginal farmers. Within such bamboo plantations, intercrops like soybean, zinger, turmeric, mustard & various medicinal plants can be successfully cultivated at least for two years, which also gives substantial income to the farmers. In fact, with ***Bambusa vulgaris***, a family continues to get a steady annual income for several decades (Chaturvedi 1986). With little planning and efforts, the bamboo poles can be converted into several bamboo products, fetching better price, thus assisting the poor families in improving their economic status. The present scheme promoted by NABARD aims at commercialization of Bamboo in an area where, so far, no commercial Forestry projects have been successful. As there is a demand for bamboo among farmers and paper mills, the project showed positive results. Bamboo in India is not cultivated under any organised system and sometimes farmers face difficulty in marketing; on the other hand, the artisans face problems in procuring bamboo easily. These aspects have been taken into consideration in the scheme. Overall, there is a good scope of raising bamboo through institutional credit in India **(**Haque 1997, 2002; Karmakar and Haque 2004). The bamboo plantation technology is now well established, therefore, the introduction and cultivation of desired bamboo species in the pattern of agroforestry is the need of the hour. *Bamboo* **-** *the poor man's timber,* has the capacity to improve the economic condition of vast members of the rural poor of India **(** Haque 2004). As the supply diminishes, there is a need for a major thrust to restore and enlarge the production base **(**Karki "et. al" 1997). During the past 50 years of India's independence, bamboo received little attention compared to other timber yielding trees **(**Biswas 1997).Hopefully, the potential of bamboo in poverty alleviation is being reassessed and its cultivation and proper utilization can make rural communities of India and the country self sufficient and economically strong on wood front, as it has been achieved on the food front with the Green Revolution.It has been observed that bamboo based agroforestry models provide economic returns much faster and higher than Poplar ***(Populus sp***.) and ***Eucalyptus sp***. **(**Rawat "et al" 2002***).*** In addition, it provides ancillary benefits due to improvement of environment, flood control, soil and water conservation etc.

The Planning Commission, Govt.of India (2001) had identified Bamboo as one of the 6 species for agroforestry plantations. It advocated the use of Clonally Propagated Cutting (CPC) of ***D. strictus, B. tulda*** and ***B. vulgaris*** besides those of ***B. nutans*** for cultivation. It also recommended the research work for selection of plus culms for quality pulp, early and every year flowering, good height and diameter growth including high biomass production per unit basis. The National Mission on Bamboo Technology and Trade Developmentnt (2002) had also recommended identification of potential bamboo for plantation in different agroecological regions, technology upgradation including mass production by tissue culture, plantation technology standardization for afforestation of wastelands, and establishment of primary and secondary processing units of bamboo for value addition, employment generation and poverty alleviation. NABARD supports all bamboo based activities that improve the economic condition of the rural poor in the North Eastern Regions (Haque 2004).The North East has a special significance with respect to bamboo, as about 60% of the bamboo resources of India and 20% of the world are available in the region **(** Salam 2006). Victor Brias (2005) had recommended that since North East India has the highest concentration of bamboo in the world, by blending modern technology and by cutting across boundaries, bamboo can be used as a universal assets. NABARD is also exploring the possibilities of promoting new bamboo projects through Forest Development Corporations(FDC) .It has already sanctioned a major bamboo project to the Andhra Pradesh FDC for raising bamboo plantations on 5400 ha degraded forest lands. The major problem faced by NABARD in this venture is the non-availability of quality planting stocks. Bachpai (2005) undertook growth studies on 15 clones of ***B. tulda*** selected from Assam and Meghalaya States. It was indicated that there were significant differences among genotypes for all the parameters viz. height, diameter at breast height (dbh) and age. The authors concluded that there is an opportunity to select the best plus clumps for further production of improved planting stocks for afforestation and other plantation programmes.

Conclusion:

The scheme faced difficulties in implementation stage, because Govt. of India announced simultaneously a subsidy based bamboo plantation scheme on farmer's land under National Bamboo Mission (NBM), which remained a total non-starter for non-forest land development. Because of wide variations in costs of cultivation in NBM scheme, the author and his team prepared three models and sent to NBM for implementation (Karmakar, Haque and Kumar, 2008). The present paper proved beyond doubt that there are possibilities of channeling credit to small farmers for intensive bamboo cultivation under homestead farming system.

Acknowledgements

The authors thank Mr. S. Das, District officer, NABARD, Nagaon for coordinating the implementation programme with farmers, NGOs and Banks and to the officials of Assam Gramin Vikas Bank for advancing bank loan to the small farmers.

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Genetic Improvement and Conservation of Bamboos in India

Ombir Singh
Forest Research Institute, P.O. New Forest, Dehradun, Uttarakhand, India

Abstract

Bamboo is woody grass belonging to the sub-family *Bambusoideae* of the family *Poacae*. There are more than 1,250 species under 75 genera of bamboo worldwide, which are unevenly distributed in the various parts of the humid tropical, sub-tropical and temperate regions of the earth. India has the largest area and the second largest reserve of bamboo in the world today. There are 124 indigenous and exotic species, under 23 genera, found naturally and/or under cultivation. In spite of rich diversity, the productivity of bamboo forests in India is very low i.e. 4.5 million tones per year. Bamboo today is a major non-wood forest product and wood substitute and also important from socioeconomic and cultural point of view. Quickly changing its image from the "poor man's tree" to a high-tech industrial raw material and wood substitute, bamboo is globally recognized now as an increasingly important economic asset in poverty eradication and economic & environmental development. The ever-increasing demand for bamboo due to various reasons is not commensurate with the current demand of bamboo materials. The main reasons for the gap are: low productivity of bamboo forests and plantations, inadequate supply of quality planting stock and lack of scientific advancement in plantation technology. Hitherto there is a need of raising improved bamboo planting stock to enhance the productivity of the species for which a systematic approach for bamboo improvement starting from exploration, collection, preservation and evaluation of the germ-plasm is essential. A bamboo improvement programme consisting of selection of bamboo plus clumps, collection and conservation of plus clumps in germ-plasm bank, standardization of mass multiplication techniques of improved propagules, standardization of silvicultural & plantation management practices, and multi-location trial of the selected germ-plasm to test the genetic worth of superior bamboo germ-plasm are in progress at various research Institutes all over India to meet the ever increasing demand of bamboo raw material. The results of the bamboo improvement programme are very encouraging, however, results of multi-location trials are still awaited, the outcome of which can be used in further deployment of productive clones in specific areas of the country.

Introduction

Bamboo is woody grass belonging to the sub-family *Bambusoideae* of the family *Poacae*. There are more than 1,250 species under 75 genera of bamboo worldwide, which are unevenly distributed in the various parts of the humid tropical, sub-tropical and temperate regions of the earth. 'Bamboo' the poor man's timber is one of the most important forestry species with wide distribution throughout the India. India has the largest area and the second largest reserve of bamboo in the world today. A very large standing resource is found mostly in moist and deciduous forests in all the states except Jammu & Kashmir. Of India's total forest area of 67.7 million hectares; bamboo (both natural and planted) occupies around 11.4 million hectares. This represents 16.7 percent of the total forest area of the country and 3.4 percent of the total geographical are (329 million hectares) of India (FSI 2003). Bamboo constitutes important species occurring widely in the Indian forests and forms the under-storey in the natural forests. It is found to grow practically all over the country, particularly in the tropical, sub-tropical and temperate regions where the annual rainfall ranges between 1,200 mm to 4,000 mm and the temperature varies between 16^{o}C and 38^{o}C. The most suitable conditions for the occurrence of bamboo are found in between 770-1,080 meter above sea level. However, two-thirds of the growing stock of bamboo in the country is available in the north-eastern states. Bamboo forms a part of a wide variety of forest types in Indian forests. It may constitute a separate forest type or sub-type or occur as brakes. The forest types/sub types in India are listed in Table 1 (Champion and Seth 1968).

Table 1. Distribution of Bamboo in different Forest types

S.N.	Forest Type No.	Forest type/Sub type	Dominant Species
1.	1/E2	West Bamboo Brakes	*Ochlandra sp*, *Bambusa sp*.
2.	2/E2	West Bamboo Brakes	*Ochlandra sp*, *Bambusa sp*.
3.	3/E2	Moist Bamboo Brakes	*Bambusa bambos, Schizostachyum kurzii.*
4.	3/2S1	Dry Bamboo Brakes	*Dendrocalamus strictus.*
5.	5/E9	Dry Bamboo Brakes	*Dendrocalamus strictus.*
6.	8/E1	Reed Brakes	*Ochlandra sp.*
7.	12/DS1	Montane Bamboo Brakes	*Sinarundinaria sp*.

There are 124 indigenous and exotic species under 23 genera, found naturally and/or under cultivation (Naithani 1993). Clump forming bamboo constitute over 67% of the total growing stock, of which *Dendrocalamus strictus* is 45%, *Bambusa bambos* 13%, *D. hamiltonii* 7%, *B. tulda* 5% and *B. pallida* 4%. All other species put together are 6%. *Melocanna baccifera*, a non-clump forming bamboo, accounts for 20% of the growing stock and is found in the north-eastern states of India. Bamboo falls into two main categories according to growth pattern, (i) sympodial or clump forming, (ii) monopodial or non-clump forming, runner bamboo. North-east India supports about 50% of the total genetic resources followed by peninsular India (Eastern & Western Ghats), which accounts for about 23% of the genetic resources occurring naturally. North-western India, Indo-Gangetic plains and the Andaman & Nicobar Islands account for the remaining bamboo diversity in India.

Bamboo today is a major non-wood forest product and wood substitute and also important from socioeconomic & cultural point of view. Quickly changing its image from the “poor man’s tree” to a high-tech industrial raw material and wood substitute, bamboo is globally recognized now as an increasingly important economic asset in poverty eradication and economic & environmental development. Bamboo has always played an important economic and cultural role across Asia and its usage is growing rapidly in Latin America and Africa as well. Since the beginning of civilization bamboo has played an important part in daily lives of people in India. Bamboo craft is one of the oldest cottage industries primarily due to versatility, strength, lightness, easy workability of bamboo with simple hand tools. Bamboo has been put to use for various applications ranging from construction to household utilities and have more than 1,000 documented uses including an important use in paper and pulp manufacturing (Anon 2008). It is an important species for landscape as it provides shade and acts as windbreak & acoustical barrier (INBAR 1997). Bamboo grows fast and matures early; the output of bamboo plantation is great and the use of bamboo stem is wide. Once successfully planted, bamboo plants keep on rhizoming, shooting and maturing every year. The annual selective cutting and sustainable utilization can be implemented without damaging ecological environment (Singh 2008).

The ever-increasing demand for bamboo due to various reasons is not commensurate with the current demand of bamboo materials. The main reasons for the gap are: low productivity of bamboo forests and plantations, inadequate supply of quality planting stock and lack of scientific advancement in plantation technology. In spite of rich diversity, the productivity of bamboo forests in India is very low i.e. 4.5 million tones per year because of many factors mentioned above and for this reason, various research institutes including National Bamboo Mission (NBM) are engaged to remove multiple constraints in bamboo sector. The shortfall in requirements can be met by improving the productivity of plantations using genetic improvement programmes and scientific management of natural bamboo growing areas & plantations. Though, research work on collection and evaluation of genetic resources of bamboos started way back during 1970's in India, but the pace of work was rather slow. A provenance trial on *Dendrocalamus strictus* was laid at Forest Research Institute, Dehra Dun. This was followed by the work on selection, evaluation and *ex-situ* conservation of several economically important bamboos of north-eastern region at State Forest Research Institute, Itanagar in the state of Arunachal Pradesh. In the era of bamboo development there is a need for raising improved bamboo planting stock to enhance productivity for which country wide bamboo improvement starting from exploration, collection, preservation and evaluation of the germ-plasm is required. Accordingly, a bamboo improvement programme consisting of the following is in progress at various research Institutes in India:

1. Selection of bamboo plus clumps
2. Collection and conservation of plus clumps in germ-plasm bank
3. Standardization of mass multiplication techniques of improved propagules
4. Standardization of silvicultural and plantation management practices
5. Multi-location trial of the selected germ-plasm

Selection of Bamboo Plus Clumps

The bamboo productivity can be enhanced manifolds by selection of superior clumps and multiplying them for use in plantations. Lot of variability exists in bamboos in phenotypic characters which can be exploited using suitable methods of quantitative genetics for improving the productivity of bamboos in the country. For the selection of bamboo plus clumps, the point grading method/selection index method (Banik 1995; Singh 2008) is to be followed, in which different points have been awarded to different traits as per the weightage in end uses e.g. more weightage should be given to internode length, being an important trait in consideration for long as well as short internode bamboo. Singh (2008) has drawn scientific guidelines for selecting plus clumps of bamboos which include survey of potential areas, selection criteria, number awarded for different traits e.g.

internode length, height, girth, straightness, number of culms/clump and disease resistance of the culms. The maximum and minimum scores of these characters are decided on the basis of the phenotypic average value of base population of the species. The total score while evaluating the candidate plus clump is fixed to 100. The candidate clump, if attains the pre decided score and more would be declared as plus clump. After that, the rhizomes/culms will be taken from the selected plus clumps for establishment of germ-plasm bank and further multiplication using various proliferation techniques for supplying improved planting stock in plantation activities. Selection of high yielding clones coupled with suitable agro techniques for raising bamboo plantation can improve bamboo productivity substantially.

Keeping such rational approach in view and using selection index method (Banik 1995) as discussed above, the superior genotypes of the priority bamboo species in Northeast India were selected and conserved in bambusetum at Rain Forest Research Institute (RFRI), Jorhat, Assam (Table 2). These plus clumps are under genetic testing in multi-location trials at different places for further recommendations and deployment in the country.

Table 2. Superior Genotypes of Bamboo at Bambusetum - RFRI

S.N.	Species	No. of Plus Clumps
1.	*Bambusa tulda*	50
2.	*B. bambos*	50
3.	*Dendrocalamus hamiltonii*	50
4.	*Bambusa balcooa*	49
5.	*B. nutans*	25
6.	*B. pallida*	25

Collection and Conservation of Plus Plumps in Germ-plasm banks

Both i*n-situ* and *ex-situ* conservation measures are being adopted to preserve the genetic resources of bamboos in India. *In-situ* conservation measures include establishment of preservation plots in every state, where the biodiversity is being periodically monitored. In addition, there are 10 biosphere reserves (Maikhuri et al. 1998), 85 national parks and 450 wildlife sanctuaries (Anon 1997), which include the natural habitat of bamboo also. The bamboos are also protected by the local people in sacred groves. The major limitations of *in-situ* conservation are that natural stands of bamboo are scattered in pockets over large areas making it difficult to declare several bamboo reserves.

Ex-situ conservation activities for preservation of important genetic resources of bamboo need more emphasis. So far these activities are limited to establishment of bambusetum and germ-plasm banks. Clumps with higher scores (as discussed in Selection of Bamboo Plus Clumps) designated as plus clumps are used for germ-plasm conservation. Germ-plasm of selected clumps in the form of off-sets/rhizomes from 1-2 years old clumps should be collected in replicates and planted in the germ-plasm banks/bambusetums. Rhizomes are dug out from the soil preferably during February to May each year. Special care must be taken during collection so that the buds of the rhizome should not be damaged. The culms of the offsets are cut without any split in internodes above 2 nodes especially in case of *Bambusa nutans, B. pallida, B. tulda* and *Dendrocalamus hamiltonii* and above 3-4 nodes in case of *Bambusa balcooa* and *B. bambos*. To avoid desiccation, the extracted rhizomes should be covered with wet gunny bags and transported to the germ-plasm bank/bambusetum without any delay. The time between collection and plantation should be as short as possible to avoid the withering of the collected offsets and thereby to reduce mortality rate. The live collections of bamboos are now available in bambusetums at various places in India (Table 3).

Table. 3. Bambusetums in India

S.N.	Place	State	Species/Live Collections
1.	Forest Research Institute, Dehra Dun	Uttarakhand	63
2.	Rain Forest Research Institute, Jorhat	Assam	34
3.	Institute of Forest Genetics and Tree Breeding, Coimbatore	Tamilnadu	26
4.	Van Vigyan Kendra, Chessa	Arunachal Pradesh	35
5.	Arunachal Pradesh Centre Bamborium, Bashar, Siang district	Arunachal Pradesh	31
6.	Kerala Forest Research Institute, Peech, (Sub-centre at Nilambur)	Kerala	21
7.	Kerala Forest Research Institute, Peechi, (Sub-centre at Palappilly)	Kerala	51
8.	Kerala Forest Research Institute Campus, Peechi	Kerala	13
9.	Tropical Botanical Garden and Research Institute, Palode	Kerala	32
10.	State Forest Department, Begur, Wynaad Division	Kerala	12
11.	Botanical Garden, Punjab University, Chandigarh	Chandigarh	20

Recently, some more bambusetums including three by National Bamboo Mission (Anon 2008) each at Guwahati (Assam), Hyderabad (Andhra Pradesh) and Pantnagar (Uttarakhand) are planned to be set up with superior clumps and provenances of various bamboo species.

Standardization of Mass multiplication Techniques of Improved propagules

Bamboo can be propagated by conventional (seeds/rhizome/off-set planting) and non-conventional (culm/branch cuttings and macro-proliferation techniques) methods.

Seeds

Availability of seed is limited to certain specific periods only as bamboos flower only once in life time. Most of the bamboo flower in long cycles ranging from 10 years to over 60 years depending upon the species. Usually the cyclic flowering is gregarious and after flowering, the entire flowered bamboo population dies. The huge quantity of seed produced are either washed out in hill slopes during rains, or eaten by rodents (rats). The remaining seeds fallen in ideal conditions germinate to seedlings for regeneration.

Rhizome Planting

This is the most common propagation method of bamboo. The bulky rhizomes of bamboos are dug out in the rainy season and planted in the field. The use of rhizomes for propagating bamboo has been limited to non-clump forming species. However, following are some limitations of rhizome planting:

- Not easy to transport
- Meagre development of roots
- Decay of rhizomes and
- Slowness of rhizomes buds to break dormancy.

Off-set Planting

The term off-set is described for bamboo propagules each composed of the lower part of a single culm with the rhizome axis basal to it. The age of off-set should not be more than 2 years at the time of planting for better results. Propagation of bamboos by off-set planting is very common method in villages of Assam. Both age of the off-sets and their collection time have significant effect on their survival and growth after field plantation (Banik 1991). More success is obtained when off-sets are collected and planted in the month of April before rainy season. Two nodes of the culm with rhizome are sufficient for better survival of the off-sets in field. These should be planted immediately after the excavation from mother clump and should be kept in moist gunny bags during transport.

Culm or Stem Cutting

Propagation of bamboo through culm or stem segments is known as culm cutting or stem cutting technique. Generally culm segment of bamboos of 1 or 2-3 nodes bearing healthy buds or branches used for propagation. Culm cutting should be taken from 1.5-2 years old healthy mother culms during February- April. The thin walled top one third portions of the segments should be discarded for better results. Rest of the culm is used to make either single nodded or two-noded cuttings depending on species (two- nodded in *Bambusa tulda, B. nutans,, Dendrocalamus hamiltonii* and one nodded in *Bambusa balcooa*). The clums are cut in such a way that about 5 cm culm length is retained on either side of the node/nodes. The leafy branch lets are trimmed to about five cm length. Cuttings with dried and damaged buds must be discarded. After 200 ppm IBA treatment, cuttings will be planted in raised beds under partial shade (Pathak et al. 2008).

Branch cutting

In thick walled bamboo species having prominent primary branches, branch cutting is the ideal planting material. The small size of cutting and extraction of more cuttings without damaging the mother clump, make this method more advantageous. Branch age should be 0.5-1year for better results. The planting practice is the same as for culm cuttings as discussed above.

Macro-proliferation (Seedling Multiplication)

The multiplication of bamboo seedlings to smaller size planting material is known as macro-proliferation. A bamboo propagule must possess a well established root system, rhizome and shoots for successful establishment. In order to increase planting stock before transfer to the field, macro-proliferation is practiced. A bamboo seedling, at the age of 30-40 days, produces new culms and start developing rhizome. In a period of four to five months, these plantlets develop five to six culms (tillers). These tillers may be separated into as many units with a small piece of rhizome and roots. The separated seedlings should be kept in shade and watered regularly for better results. These propagules attain the field planting height within four months, or they can be further multiplied through macro-proliferation. Banik (1985) reported that five to nine months old seedlings of *B. tulda* can be multiplied 3-5 times in number through this technique. The survival rate of these multiplied seedlings is well within 90 to 100%. A large number of identified planting stocks could be produced and continued for a number of years through this method, however, the seedling multiplication in this way should not be continued for a very long time.

Micro-propagation (In-vitro propagation)

In-vitro methods offer an attractive alternative method of mass propagation of bamboos. So far, tissue culture protocols have been developed for important species required for plantation in different parts of the country by different agencies. Micro-propagation techniques passed through four stages, viz. collection and sterilization of explants, culture establishment, shoot multiplication and root initiation and finally hardening & acclimatization before field planting preferably in rainy season. The protocols of the following species have been developed using explants from nodal segments and somatic embryogenesis as well (Anon 2008):

- *Bambusa balcooa*
- *B. nutans*
- *B. tulda*
- *B. vulgaris*
- *B. polymorpha*
- *B. nana*
- *B. pallida*
- *Dendrocalamus stictus*
- *D. hamiltonii*
- *D. membraneous*
- *D. asper*
- *D. giganteus*
- *Guadua angustifolia*

- *Oxytenanthera stocksii*
- *Pleoblastus variegata*
- *P. green*
- *Pseudosasa japonica*
- *Drepanostachyum falcatum*

The bamboo planting stock is now being produced through tissue culture on a large scale in various parts of the country. The planting material has been tested in multi-locational trials. A national certification system is in place and it is imperative that any large-scale plantation of bamboo should necessarily source its material from superior genotypes identified and to the extent possible only certified tissue culture raised material should be used for obtaining best performance in field.

Standardization of Silvicultural and Plantation Management practices

Raising of Plantations

Bamboo plantations should be raised with intensive management and planed planting schemes like cultivation of any other cash crops to enhance the yield per annum to a predetermined level. Usually bamboo prefers well-drained soils of sandy loams to loamy clay type, however, individual species have well defined habitats. Maintenance activities should be concentrated on protecting the young plants from competition for the first two years after that clump management operations are required. The bamboo plantation achieves its optimum productive stage generally by 4 -7 year as in case of sympodial bamboo and continued till the stand attains an age of around 20-25 years. After that the uprooting of entire plantation is suggested in phased manner for raising new plantations.

Management Practices

Management of bamboo stands is relatively simple and closely related to the striking generic and cultural features. In general, the mature culms are cut and regeneration obtained from new culms produced annually from underground rhizomes, and this practice followed everywhere regardless of the species and type of forest. However, some more points are as:

Soil working around the Clumps: New rhizomes of bamboo emerge at an upwardly inclined angle from the base of clump. During the period of emergence and growth any exposure to sunlight stops the rhizome development. Hence, it is advisable to raise the soil (make mounds) around the clumps every year before the new culms emergence. Such soil working also increases the number of new culms emergence.

Pruning: This is practiced only in those species which produce thorny branches like *Bambusa bamboos*. This should be started in the third year after planting. Pruning prevents congestion and helps in keeping the clump in working condition. All the branches up to 1.5 m height should be pruned leaving one node on the branch stalk.

Thinning/ Improvement cutting: This practice should be started in the second year after planting and continued every year before the onset of rains. All malformed and damaged culms should be removed. Culms causing congestion should be cut to make the remaining culms equally spaced. Thinning operations during establishment period ensures that the clumps reach their productive age without any congestion. This practice also provides space for new culms to grow vigorously.

Harvesting and Harvesting Schedule: Once the clumps are established and reach productive stage, proper harvesting technique and schedule should be followed to ensure sustained production over long time. Usually the culm selection system is followed in harvesting bamboo culms. This system involves:

- 3 years old or above culms should be removed as they have no role in the new culm emergence. Only one and two year old culms give rise to new shoots.
- The cut should be given above the first prominent node (about 15 cm from the ground level) with a sharp instrument.
- Felling of bamboo should be avoided from October to December as during this period the young shoots are in growing process. The new shoots become mature enough to resist any damage by March – May, so felling operations should be completed between May-October each year.

Method of working large clumps: If the clumps are not thinned from the very beginning, they become congested at the time of productive age. There are special techniques of opening such congested clumps in plantations as well as in natural forests (Pathak et al. 2008), which are as:

1. Perpendicular Tunnel method
2. Horse Shoe method.

In the first method two tunnels are made right angles to each other so that the clump is divided into four quadrants. In the second method the clump is converted into a horseshoe shape by thinning the inner culms.

Multi-location Trials of the Selected Germ-plasm

To analyze the genetic worth of plus clumps/superior genotypes of bamboo, multi-location trils are needed to evaluate the stability performance of various quantitative and qualitative traits for:

1. Intensity of inheritance expression
2. Stability of the characters in different environmental conditions
3. Prioritization of the plus clumps for different end users
4. Geographical deployment of suitable plus clumps

Such type of multi-location trials are in progress at various research institutes in India under all India coordinated projects funded by Department of Biotechnology (DBT) and National Bamboo Mission (NBM). The results of these multi-location trials – being long-term experiments are still awaited. These trials will definitely come out with some productive clones of bamboo for further deployment in specific agro-climatic zones of the country, thereby, to meet the ever increasing demand of bamboo raw material.

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Challenges on Climbing Bamboo Utilization and R&D Directions[1/]

R. A. Navitidad

Abstract

In general bamboo can be classified into erect or climbing type based on the growth habit of their culms. A climbing bamboo has crooked or zigzag culm 1-5 cm in diameter with branches at the nodal portions. The main culm and branches grow to a considerable length with almost the same diameter forming a ramified crown structure which cannot stand upwards. Thus, they climb nearby trees for mechanical support above the ground or scramble over sloping ground or up rocky slopes and along creek embankments in the forests.

Climbing bamboos in the Philippines grow gregariously whenever found from low altitudes up to 800m asl. Recent botanical studies reported 16 species of climbing bamboos in the Philippines belonging to three genera: *Dinochloa* (8 spp.); *Cyrtochloa* (7 spp); and *Cephalostachyum* (1 sp.).

The DENR forest inventory in 1988 estimated the standing stock of climbing bamboos at 8.32 B lineal meters. This is greater than the combined standing stocks during that year for erect bamboos (2.44 B lineal meters) and rattan (4.57 B lineal meters).

Presently only a few climbing bamboos species have been commercially utilized i.e. puser (*Cyrtochloa fenexii*) for folding chairs and tables, woven plates, trays and hats; and bagtok (*Cephalostachyum mindorense*) for basketry.

Completed and on-going R & D projects at FPRDI indicate the huge potential of climbing bamboos as an alternative resource for furniture and handicrafts. Some *Dinochloa spp.* have solid culms. These resemble the diameter sizes and bending quality of rattan and can be used for steam-bent articles. The strips or thin splits from culm internodes are pliable with high folding endurance for weaving purposes. Preliminary data also revealed favorable results of preservative treatment, drying, bleaching and dyeing.

With the bright prospects for the utilization of climbing bamboos for furniture and handicrafts, R&D on proper processing, product design and development should be given priority. Studies geared towards resource conservation to ensure sustainable raw material supply are also imperative. These include updating on the

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[1/] Paper presented in the 8th World Bamboo Conference, Bangkok, Thailand. September 16-18, 2009.

inventory of harvestable volume and distribution of standing stock, appropriate harvesting methods, and on propagation as well as development and management of plantations.

Introduction

Bamboo is one of the most versatile and economically important forest products. It contributes to the subsistence needs of over a billion people in rural communities throughout the world. Among its traditional uses include fuel, wood, medicine, shelter, agricultural tools, and containers, hunting and fishing gear and other items for household purposes. Its processing and utilization for industrial products also play a vital role in livelihood and economic development in rural and urban areas. These include production of pulp and paper, housing and building construction materials as well as furniture and handicrafts. However, such products are processed mainly from erect-type bamboos. Scanty information is available on the domestic or industrial utilization of climbing bamboos.

This paper presents a perspective on the existing status of the resource as well as R&D breakthroughs and needed directions to enhance the utilization of climbing bamboos in the country.

Description Status of the Resource

Based on rhizome structure bamboo is classified as sympodial and monopodial (Rojo et al 2000). The former has several culms per clump while the latter is single-stemmed. Morever, the growth habit of the culms can be classified into erect and climbing type.

A climbing type can be easily distinguished from an erect bamboo by having crooked or zigzag culms with relatively small diameter (1-5 cm) which grow to considerable height and bear many branches at the nodal portion. The dominant branch may grow to the same diameter as the main culm forming ramified crown structures that cannot stand upward (Escobin et al 2005). Thus, they climb nearby trees for mechanical support above the ground or scramble over sloping ground or up rocky slopes and creek embankments in the forests.

Number of species and distribution

Rojo (1996) listed only 14 climbing bamboo species in the Philippines based on available literature. Recent botanizing activities by Escobin et al (as cited) reported the existence of 16 species under three genera: *Dinochloa* (8 spp.); *Cyrtochloa* (7 spp); and *Cephalostachyum* (1 sp).

The *Dinochloa* species are the “true” climbers while *Cyrtochloa* and *Cephalostachyum* species have scrambling, trailing or clambering culms. Two of the 16 identified species are commonly found in the Philippines and Borneo. The rest are endemic or found only in the country (Table 1). They grow gregariously whenever found from low altitude to 800 m above sea level. Most species have restricted distribution or are found only in a particular locality/province. However, *D. luconiae* and *D. acutiflora* occur throughout the Philippines.

Table 1. List of Philippine climbing bamboos: distribution and conservation status

Scientific name	Common Name	Origin and Distribution	Conservation Status
Cyrtochloa toppingii	Bukawe, Topping bikal	Endemic to the Philippines, Rizal	known
C. fenexii	Puser, paua	Endemic, Luzon (Abra, Ilocos)	known
C. luzonica	Luzon bikal	Endemic, Luzon (Zambales)	known
C. puser	Puser	Endemic, Luzon (Abra)	known
C. hirsuta	Baitu	Endemic, Luzon (Bataan)	unknown
C. mindoroensis	Mindoro bikal	Endemic, Mindoro	known
C. major	Bikal baboy	Endemic, Luzon (Bataan)	known
Dinochloa palawanensis	Balikaw, Palawan bikal	Endemic, (Palawan)	known
D. acutiflora	Bikal-baboy, balikau	Endemic, Luzon (Laguna, Tayabas)	known
D. luconiae	Osiu, bikal	Native to Philippines and Borneo	known
D. robusta	Balikaw, Palawan bikal	Endemic, (Palawan)	known
D. oblonga	Palawan bukawe, bikal	Endemic, (Palawan)	known
D. elmeri	Elmer bikal	Endemic	unknown
D. pubiramea	Bukau	Borneo, Philippines	unknown
D. dielsiana	Tagisi	Endemic	unknown
Cephalostachyum mindorense	Bagtok, Mindoro bikal	Endemic (Mindoro and Camarines)	known

Source: Escobin et al 2005.

Volume of standing stock

There is a huge volume of climbing bamboo poles in the Philippines based on the results of the RP-German Forest Resource Inventory Project (1988). The volume of standing stock was estimated at 8.32 B linear meters. This is greater than the combined standing stocks during that year for rattans and erect bamboos with 4.57 B and 2.44 lineal meters, respectively. It is presumed that volume of growing stock have increased in the last 16 years due to limited utilization but reduction of volume is also possible due to forest denudation in some areas of the country or conversion into "kaingin" or agricultural lands, human settlement and other land uses.

Existing and prospective utilization

The huge quantity of hitherto, untapped climbing bamboo poles, pose a big challenge to forest product researchers and the forest-based industries to unravel their appropriate commercial utilization.

Some climbing bamboos are presently utilized in limited quantities in the rural areas for fuel, fencing, trellis, skewer, "kaing"-making and woven novelty items. Other species have no known uses (Table 2). This may be due to lack of information on their technical (strength, durability, working characteristics) and commercial properties (availability and reliability of raw material supply).

Table 2. Uses of Philippine climbing bamboos

Scientific name	Uses
Cyrtochloa toppingii	General purpose
C. fenexii	General purpose, fences
C. luzonica	Trellis of crops, fences
C. puser	Fences
C. hirsuta	Barbicue sticks
C. mindoroensis	Fence, general purpose
C. major	Fence, general purpose
Dinochloa palawanensis	No known uses
D. acutiflora	General purpose
D. luconiae	Fences, basketry
D. robusta	No known uses
D. oblonga	No known uses
D. elmeri	No known uses
D. pubiramea	General purpose
D. dielsiana	General purpose
Cephalostachyum mindorense	Containers, handicrafts, novelty items

Source: Escobin et al 2005.

Bagtok (*Cephalostachyum mindorense*) was reported as a preferred raw material by indigenous tribes in Mindoro and Bukidnon for woven handicrafts such as hats, mats and baskets (PDI 1996). In Santa, Ilocos Sur the author had discovered 4 years ago that Puser (*Cyrtochloa puser*) is used for making woven plates and trimming (rim) of broad baskets (bilao). The same species was observed for the commercial production of handicrafts (woven plates, trays and hats) and furniture (folding tables and chairs) in Bangued, Abra. The manufacturer has been selling the products in other provinces, Metro Manila and to the USA (Balbin 2006).

Considering the above utilization of climbing bamboos they have bright potential as an alternative raw materials for the furniture and handicrafts industries.

R & D Status and Directions

Completed and on-going projects

To date, FPRDI has conducted 9 R &D projects related to climbing bamboos: 5 projects under the Manila Science Program and 4 under the Furniture and Handicrafts Program (Table 3). These cover basic (anatomy, natural durability, physical and mechanical properties, proximate chemical composition, identification of species) and applied R&D (drying, protection and preservation, bleaching and dyeing. steam-bending and development of novelty products.

Table 3. FPRDI on-going and completed R & D projects on climbing bamboos

PROJECTS / SPECIES	MATERIAL SCIENCE PROGRAM					FURNITURE & HANDICRAFTS PROGRAM			
	Natural Durability	Anatomy	Physical-Mechanical	Chemical	Identification Manual	Utilization for novelty products	Bleaching and Dyeing	Drying characteristics	Dev. of Bent F/H components
Cyrtochloa toppingii	XX	XX	XX	XX	XX				
Cyrtochloa fenexii	XX	XX	XX	XX	XX				
Cyrtochloa luzonica	XX	XX	XX	XX	XX				
Cyrtochloa puser	XX	XX	XX	XX	XX	XX	XX	XX	
Cyrtochloa hirsuta	XX	XX	XX	XX	XX				
Cyrtochloa major	XX	XX	XX	XX	XX		XX		
Cyrtochloa mindoroensis					XX				
Dinochloa sp. 1(Zambales)	XX	XX	XX	XX			XX		XX
Dinochloa palawanensis					XX				
Dinochloa acutiflora	XX	XX	XX	XX	XX		XX		
Dinochloa luzoniae					XX				
Dinochloa robusta					XX				
Dinochloa oblonga					XX				
Cephalostachyum mindorense	XX	XX	XX	XX	XX	XX	XX	XX	
STATUS	On-going	On-going	On-going	On-going	Completed	On-going	On-going	On-going	Completed

Research breakthroughs

The pioneer R & D project conducted at FPRDI dealt with steam-bending quality evaluation of climbing bamboo for making curved furniture and handicraft components. Results indicate the suitability of tagisi (*Dinochloa* dielsiana), with 1-2 cm diameter and solid culm, for making steam-bent articles (Natividad 2000). It can be bent to a radii ranging from 4 to 8 cm in green condition (MC > 40%) depending on the diameter class (Fig. 1).

Results of completed projects at FPRDI show that climbing bamboos have almost the same density, durability and anatomical properties (fiber diameter and length) as the erect bamboos. These are easy to dry by air or kiln drying with negligible defects; easy to treat with chemical preservative against fungi and insects; amenable to bleaching and dyeing; and have high folding endurance in strip form for weaving purposes (FPRDI 2005). Fig. 2 shows some of the fabricated prototype woven products.

During the 2006 National Trade fair at SM megamall some prototype products from puser (*C. puser*) and baguisan (*D. pubiramea*) were dislayed. These were fabricated at FPRDI in collaboration with CITC, BDT and PDDCP. These include artificial flowers from diagonally cut culms (Fig. 3).

R & D Directions

R & D gaps on the physico-mechanical, chemical, and processing properties of climbing bamboos should be pursued to establish baseline information and technologies for the development of new products i.e. furniture, handicrafts, home and fashion accessories, composite panels for housing and building construction and other purposes.

To sustain raw material supply it is also imperative to formulate policies for their conservation and R & D should be focused on propagation, plantation development and harvesting techniques for preferred species. An updated inventory of the standing stock is likewise needed together with a map on their geographical distribution to facilitate the collection/sourcing of raw materials.

Summary and Conclusion

Climbing bamboos are not as popularly used for household or industrial purposes as the erect ones but they are promising alternative raw materials for furniture, handicrafts and other related products for the local and export markets. Initial results of R& D projects on their processing and utilization indicate their suitability for woven products and steam-bent articles. However, there are still many R & D gaps which need to be addressed. These include generation of appropriate technologies on product development and management of the resource to ensure sustainable supply of raw materials for specific end-uses.

Generated technologies should be promoted and transferred for the development of community-based enterprises in areas where climbing bamboos are relatively abundant.

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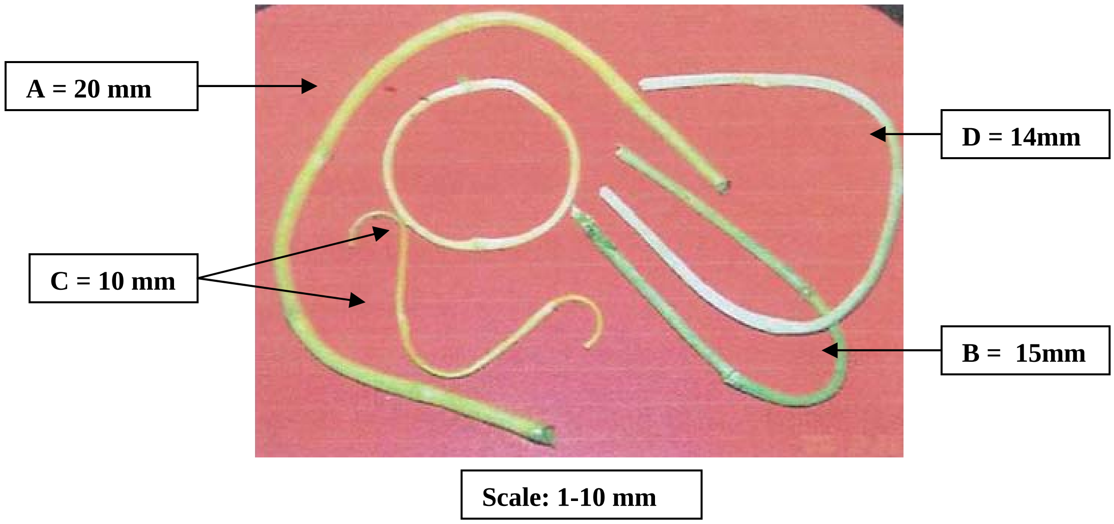


Fig. 1. Samples of Bentworks from tagisi: a) seat frame; b) basket handle; c) ladies bag handles; and d) hair-pin type bent for embellishment of chair back rest.

Fig. 2 Prototype products from Bagtok and Puser

Fig. 3. Artificial flowers from baguisan (left) and puser (right) culms.

Integrated Management of Bamboo Resources in the Colombia Coffee Region

J.C. Camargo[1]; M.A. Dossman[2]; A. Rodriguez[2];L.M. Arias[2]
[1]Associated Professor, Technological University of Pereira, Colombia
[2] Researcher, Technological University of Pereira, Colombia and CIEBREG

Abstract

The silvicultural management and planning of guadua bamboo forests as well as their capability of providing environmental services are analysed in this work. In these sense, the bases for inventory and mensuration are defined as the best way of procuring adequate information. Because of differences on growth and management, silviculture is separately discussed for natural stands and plantations. In addition, an approach to define the effect of site conditions on guadua productivity and quality is proposed. Furthermore, benefits of guadua forest referred to carbon sequestration and soils restoration are remarked. Finally, information was integrated to define the capability of land for guadua production and units of forest management (UFM), which are an instrument that government institutions use for forest planning. Silvicultural practices on natural stands are specially focused to harvesting, thus the possibilities of an adequate management depend on a proper definition of harvest intensity and harvest frequency. For guadua plantations, results on dynamics reveal the significant consequence of fertilisation and weed control, specifically on growth and mortality of culms. As a contribution to elucidate the worth of guadua forest providing environmental services in the coffee region of Colombia, carbon sequestration and soil protection was assessed and quantified. Values up to 900 Tn ha^{-1} of total carbon stock were evidence for guadua stands. Comparisons of soils properties among different land covers evidenced better conditions in soils under guadua stands even under those located on marginal areas. By using geographic information systems and software for modelling productivity of guadua stands, information was integrated and UFM defined. Besides guadua plantations were successfully used in processes of soil restoration, reducing significantly soil erosion. Silvicultural practices, forest planning and the quantification of environmental services, give the bases for an integrated management of this bamboo forest in the coffee region of Colombia.

Introduction

In the Colombian coffee region the woody bamboo species guadua (*Guadua angustifolia* Kunth) represents an important natural resource traditionally used by farmers for many purposes such as construction, furniture and handicrafts (Londoño 1998). Due to the variety of uses the commercial value of guadua culms has recently increased (Held 2005). Therefore, this resource has potential productive and protective functions essential for the sustainable development of this important region of Colombia (Camargo 2006).The species guadua has its natural habitat in Colombia, Ecuador, and Venezuela, but it has also been introduced to other countries in Central and South America, Europe and Asia. Its culms are an ideal construction material with a high percentage of fibres and excellent structural properties such as high resistance to weight-ratio, high capacity to absorb energy and excellent flexibility. As a result, houses made of Guadua are very resistant to earthquakes (Londoño et al. 2002; Gutierrez 2000).

Currently, guadua is the more harvested species to obtain wood for different applications in the coffee region of Colombia. Some reports show that between 2000 and 2004 roughly 2,420,000 culms of guadua was logged from 2,557 ha (Moreno 2006). However, it represents that 91 % of guadua stands were not harvested in this period of time. During a recent inventory study an estimated area of 28,000 ha covered by guadua has been identified in the coffee region alone (Kleinn and Morales 2006).Natural Guadua stands are relatively small and have irregular shape. Most of them have areas smaller than 5 ha and form a highly fragmented pattern and are mainly located along valleys near to rivers (Camargo and Cardona 2005). Even though guadua is adapted to different site conditions, there are special environment which favour its growth and optimal development (Castaño and Moreno 2004). Guadua grows best between 900 and 1600 m above see level, at temperatures between 20 and 26ºC, precipitation between 1500 mm and 2500 mm per year, and in slightly acidic soils (Cruz 1994; Giraldo and Sabogal 1999).

The growth patterns of the Guadua and trees are completely different; therefore bamboo inventory and mensuration should be conducted by using different criterions (Camargo 2006).For reaching an adequate management of this resource basic information on the dendrometric attributes of culms, on stand variables as well as on stand management options is quite relevant. Also aspects such as stand productivity, performance in different environments and interactions between stand management and environmental factors such as site should be considered (Camargo 2006, García 2004; Hincapie & Penagos 1994).

Different response variables have been used to describe the effect of environmental factors. García (2004) i.e., grouped response variables into those that represent growth, such as diameter, height or culm length and those that represent quality (i.e. physical and mechanical properties) such as basic density and strength resistance. Agudelo and Toro (1994) found that the major influence on quality variables lies in the physical properties of the soil as well as in the topography of the site. Culms growing in fine textured soils on steep sites have been shown to possess improved physical and mechanical properties. Also, Londoño and Prieto (1983) observed that the combination of high solar brightness, high precipitation and location of stands on hills produces a positive influence on the growth and development of culms.

In Colombia management of guadua.stands is applied especially to natural stands. A number of studies have pointed out important changes in population dynamics when the stands are under different harvesting schemes in terms of intensity and frequency (Camargo 2006, Morales 2004). Regarding to guadua plantations, studies on growth and population dynamics have given basic information for silvicultural options. As a complement of silvicultural management, planning of guadua bamboo forest is also noteworthy. Forest planning is a priority for government institutions responsible of giving principles for forest management. In this sense, the definition of land capability for guadua plantations and the qualification of guadua stands in terms of productivity as well as to consolidate units of forest management can significantly contribute to the sustainable development and management of guadua in the coffee region of Colombia.

In the other hand, guadua bamboo forests also accomplish important functions contributing to the mitigation of climate change, soil protection and water regulation. Because of population dynamics and biomass of guadua, these forests have a high worth as carbon sink (Riaño et al. 2002). Moreover, the guadua has been often used by government institutions for reforestation programs and important changes can be observed concerning to improvement of soils conditions under reforested areas. For theses reasons, the enhancements of environmental services or ecosystems functions have been attributed to this bamboo species (Cruz 1994, Giraldo and Sabogal 1999).

In order to promote the proper utilisation and management of guadua and the productivity options available to farmers in the Colombian coffee region, information on growth and productivity as well as the bases of silvicultural management are analised in this work . In addition an application of a simple model to integrate spatial information and attributes of land and guadua stands is applied as strategy for planning of guadua forest. Also to elucidate the true meaning of environmental services and ecosystems functions offered by guadua bamboo forest, quantitative information on variables associated to environmental services and ecosystems functions as carbon sequestration and soil protection provided by guadua bamboo forest is presented here.

Silvicultural management

In Colombia and specifically in the coffee region, most of the silvicultural practices have been developed and applied to natural guadua stands. This statement has its main justification because there is considerably more area under natural guadua stands than guadua plantations. According to the most recent guadua inventory in the coffee region there is an estimates of 28,000 ha (Morales and Kleinn 2006). In contrast, have been registered no more than 4000 ha of guadua plantations (CARDER 2000) of which there are not yet official registers of harvests. In addition, practices related to establishing and the dynamics of clumps during the first stage of development are only focused when guadua plantations area managemed. In order to describe silvicultural practices applied to guadua in Colombia, natural guadua stands and guadua plantations should be separately analysed.

Bases of silvicultural management are supported on information on growth, productivity and quality. Consequently, before to describe silvicultural practices and their effect, it would be essential to emphasised on guadua inventory and mensuration.

Guadua inventory and mensuration

Growth pattern of tree and bamboos are wholly different. Hence, bamboo growth and productivity should be measured taking into consideration the best manner to obtain consistent information on dendrometric and stand variables. As in other bamboos, guadua culms are curved in the upper section. It means that the measured height does not correlate with culm growth. For trees, height and length are usually almost identical. In contrast, for this bamboo species culm length and culm height are considerably different. Therefore, the variable of interest is obviously culm length because it is directly related to the commercial product (Figure 1).

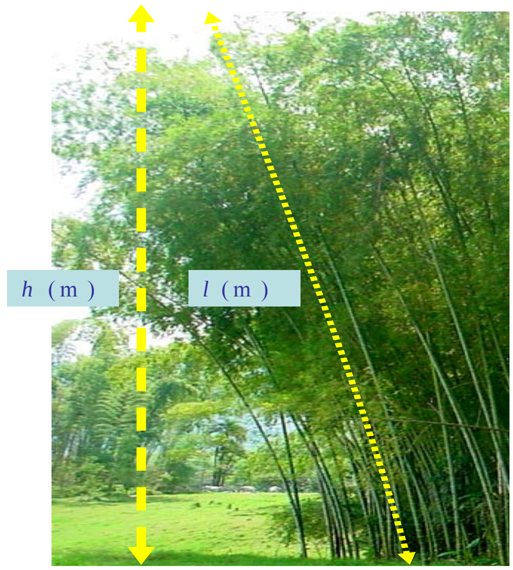


Figure 1. Differences between culm height (h) and culm length (l). Source: Camargo 2006

For trees, diameter is usually measured at breast height, which is fixed at 1.3 m in most countries. This concept is not appropriate for bamboos because diameter varies with the proximity to the nodes. Therefore, it is more appropriate to measure the reference diameter in the middle of the internode (i.e. between the nodes) where conventional breast height (1.3 m) would be. This means that the diameter is actually measured at slightly different heights (Figure 2)

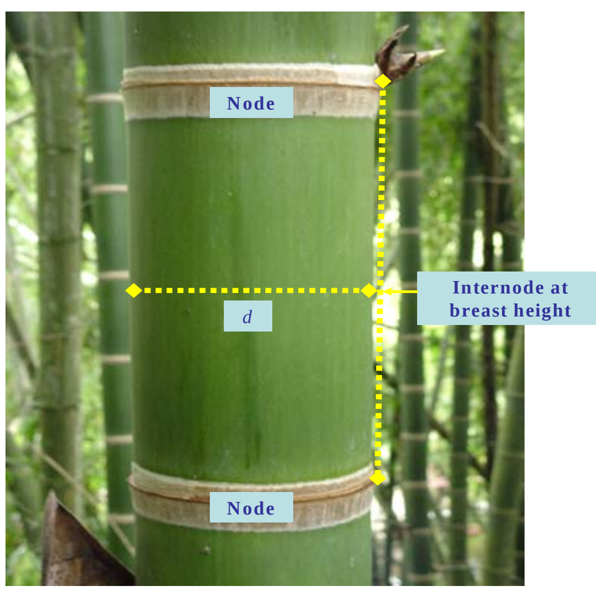


Figure 2. Culm diameter (d) variation between internodes. Source: Camargo 2006

For bamboo species, models for predicting culm height from diameter are not often used (Fu 2001; Watanabe and Oohata 1980). For guadua, a simple model has been used to predict culm length (*L*) from the perimeter at breast height (*C*), including a constant (*K*), which has been determined empirically (Arbelaez 1996, Cruz 1994). For volume, some studies have related it with biomass estimation (Reid et al. 2004) or with physical and mechanical properties of culms (Jamaludin et al. 2000)

Camargo (2006) estimated the relationship between culm diameter, culm length and culm volume by using linear and non-linear regressions. These models were used in regression analyses of culm length, apparent and net culm volumes being the dependent variables. The equations developed for tree mensuration are useful for predicting total culm length and culm volume using a number of independent variables. These models can be used with an adequate precision for estimating both variables. For estimating culm length the modified model of Cox, which includes the stand variable square mean diameter was the best. (R^2_{adj}=0.49, RMSE=2.5). For apparent culm volume the allometric model was the best among the models tested (R^2_{adj}=0.89, RMSE=0.005). A linear regression model was also fitted to estimate net culm volume from apparent culm volume ($R^2_{adj} = 0.94$, *RMSE* = 0.001).

With reference to stand variables, Camargo (2006) and Morales (2004) have defined that the most representative stand variable for gathering in guadua inventories is the total number of culms per hectare. This variable defines the potential productivity of the guadua stands and also is the base to determine harvest. Other variables as basal area and total volume moreover could provide important information on guadua stands. However harvest plans, traditionally have been defined with regard to number of culms to be harvested (Camargo et al. 2008; Camargo 2006).

Studies on plot design conducted within guadua stands permit to conclude that circular plots provide the highest precision in inventories (Rijal 2006). However, plots with this shape are highly demand of sample effort and cost of inventory could increase. In this sense, rectangular and square plots can be more easily established. Among both plots, the rectangular have showed the lowest standard error and consequently the highest precision. However, plots should be arranged with the longer side against the slope. In relation to plot size, Rijal (2006) suggest that plots between 50 m^2 y 200 m^2 have the best precision. These results are also consistent with Camargo (2006) and Schumacher (2006) who tested the precision of different plot sizes within natural guadua stands.

Silviculture of natural guadua stands

Traditionally within natural guadua stands most of the practices are associated to the harvest. These practices are focused in improving the access to stand and include pruning (elimination of lateral branches which are usually thorny) and removal of those culms which have reached the last stage of maturity and during the inventories are found dry, broken or dead. These culms are removed especially within stands with high culms density (over 6000 culms per ha). Only in few cases fertilisation is done. It is due to fact that there is scarce information on benefits of this practice and because of productivity of stands even without fertilisation is adequate, in terms of the amount of culms demanded in the market.

Guadua stands can improve their productivity through silvicultural practices. These practices also may contribute for reaching a sustainable yield. For this reason, it is required to consider different aspects which contribute to an adequate silvicultural management such as the effect of site quality and an adequate definition of harvest regimen.

Site quality

Due to the large number of variables that may influence growth and quality of guadua culms, multivariate seen to be the most appropriate technique to reduce the dimensionality of data (García 2004; Agudelo and Toro 1994; Hincapie and Penagos 1994). Some studies have been useful to identify trends on the variability of growth and quality in relation to site conditions and groups of variables linked to environmental factors which could represent growth or quality have identified (Camargo 2006; García 2004;:Hincapie and Penagos 1994).

To evaluate the effect of environmental factors on growth and productivity the study sites were located in the Colombian coffee region which has a total area of 1,029,524 ha and elevations between 900 and 2000 m.a.s.l. The mean annual temperature is between 20°C and 27°C and precipitation between 950 and 2500 mm per year with a bimodal distribution (García 2004). Soils are principally Andisols, slightly acidic and with good physical properties (Camargo et al. 2001).

Sampling design for data collection was based on a guadua bamboo inventory (Kleinn and Morales 2006) and specific information on site factors and stands characteristics is founded on a research conducted by Camargo (2006). Accordingly data were derivate from a total number of 101 field plots measuring 10 m x 10 m located completely within guadua stands. Response variables were classified into growth, stand and quality variables. Growth variables were the diameter at the internode at breast height, culm length, and wall thickness. Stand variables were basal area, quadratic mean diameter, percentage of shoots, percentage of young culms and total number of culms per hectare. Quality variables were compression strength, shear strength, basic density, curvature, and culm hardness. Independent variables were also recorded from the 101 temporary field plots and used for analyses. Previously, these variables were classified into topographic (i.e. elevation, slope), climatic (i.e. precipitation, temperature), stand (i.e. harvest intensity, distance to edge) and soil (physical and chemical properties).

An analysis of principal components provided information for the identification of key variables responsible for most of the variability between sites. The final set of environmental variables selected for the construction of predictive models was defined considering the high loadings of variables in the principal components and their higher correlation with the respective response variable. These variables were used in multiple regression models.

For fitting multiple regression models the stepwise procedure was performed. The degree of collinearity was evaluated for each model with the variance inflation factor (VIF) and the condition index. Predictors with values of VIF higher than 10, were discarded from the models due to collinearity problems. Within the regression analyses, for components with a high condition index (>30) the corresponding row was examined to see which variables had high values. A condition index of 30 to 100 indicates moderate to strong collinearity. The models selected after the stepwise procedure and the collinearity test, were also assessed by residual analysis. Those that showed higher coefficient of determination (R^2), low root mean square error (RMSE) and low bias were considered to be preferred. Analyses were performed using the PROC REG procedure of the SAS/STAT® statistical programme (SAS INSTITUTE 1999).

Models for predicting culm length, basal area and culm hardness, showed the better performance. However, the variability in the productivity and quality of guadua could not be entirely described by the variables measured and a significant proportion of the variability remains unexplained. The best for growth variables was for culm length which includes 11 variables and explains 54% of total variation ($R^2 = 0.54$, RMSE = 2.3). Most of the variables contained in the model were related to soil properties (especially physical soil properties), however the temperature was the most important independent variable. Residuals analyses did not show any special trend and for all of the classes and the residual variation must be interpreted as random (Figure 3).

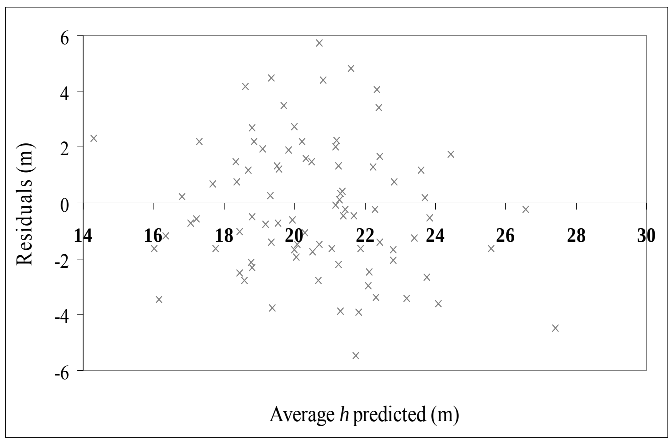


Figure 3. Plot of residuals versus predicted values of average culm length (*h*).

For stand variables the regression model for basal area gave the more reasonable goodness of fit ($R^2 = 0.51$, RMSE = 20.3). It means that 51% of total variation was explicated by the model. Five of the eight variables included in the model are soil properties and the most relevant was apparent density. The residuals analysis did not show any systematic bias when plotted against predicted values (Figure 4).

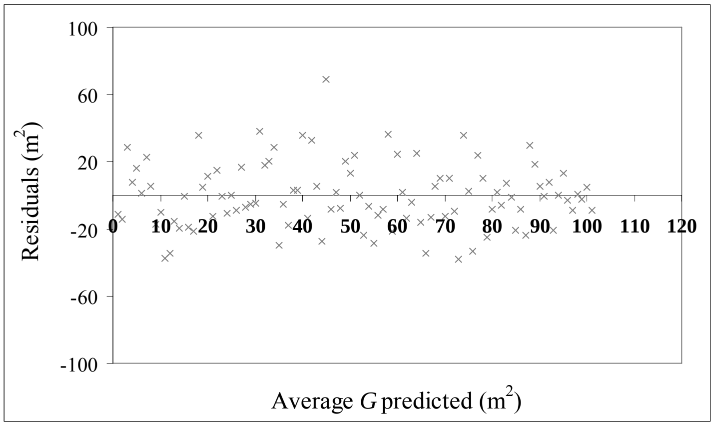


Figure 4. Plot of residuals versus predicted values of basal area (*G*).

The most sensitive quality variable was culm hardness that is explained in 51% by the model (R^2= 0.51, RMSE = 2.7). Being it the mechanical property that best represented the effect of the measured environmental variables on the quality of stands. Residuals analyses for this model did not show any abnormal trends (Figure 5).

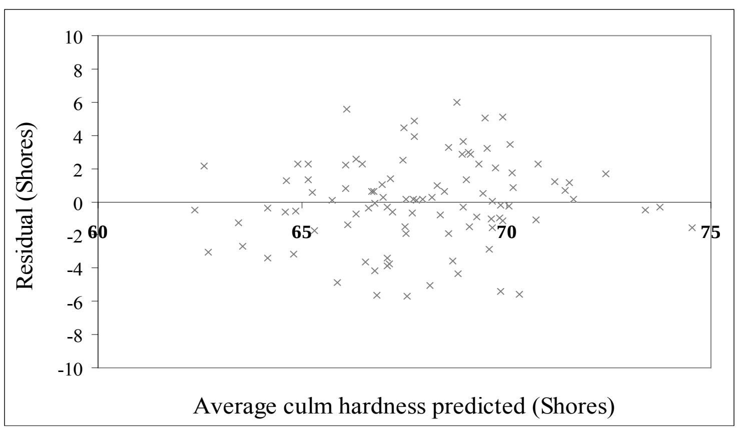


Figure 5. Plot of residuals versus predicted values of average culm hardness.

Effect of silvicultural management

Within Guadua stands individual competition for site factors occurs when the number of culms increases. Consequently, when culms are harvested, vital space is also regulated (Camargo 2006). Hence guadua stands should be harvested at a specific frequency and at an optimal intensity (Castaño 2001). It is suggested that harvesting be carried out during the dry season when the production of shoots and water content of culms are lower. Thus the risk of diseases and pest infestation after harvesting are reduced. The cut should be done 15 to

30 cm above ground level and closely above the node to avoid accumulation of water in the internodes and possible damage by decaying of the rhizome (Judziewicz et al. 1999).

Culms are considered commercial when they are mature, over-mature or dry. Therefore, harvesting should be planned based on the supply of commercial culms (Camargo 2004). Studies on silvicultural management have shown that after a harvest intensity levels between 12 and 50% together with frequencies between 6 and 24 months, stand dynamics and productivity increases (Morales 2004; Castaño 2001). However, when a high level of harvest intensity (50% on commercial culms) is applied continuously, the total number of culms in the stand could be reduced to half and consequently the sustainability of this resource could be endangered (Morales 2004). Different levels of harvest intensity, harvest frequency and fertilisation have been tested to evaluate changes in productivity of guadua stands. The response variable for these trials has been the production of new shoots which is for this study so called productivity.

When the effect of factors (intensity and frequency) is evaluated separately, it is not possible to reveal a tendency in productivity and there are not differences statistically significant. However, according to Morales (2004), when shoot production is simulated considering the combined effect of factors, two important changes can be observed on the dynamics of shoots. First, under any level of harvest intensity the total density of the stand abruptly decreases, especially during the first and second episode of harvest. This decrease on total density of culms, is obviously higher when increase the level of harvest intensity. Second, the total density of the stand tends to be stable only after seven years. In Figure 6, is showed the effect of three levels of harvest intensity with a frequency of six months. Changes in total number of culms per ha are simulated for a period of ten years by using the software SILVCAMARK 1.1 (Morales 2005). The areas enclosed in blue ovals show the two moments above mentioned, the abrupt decrease of total number of culms per ha and their tendency to the stability after seven years.

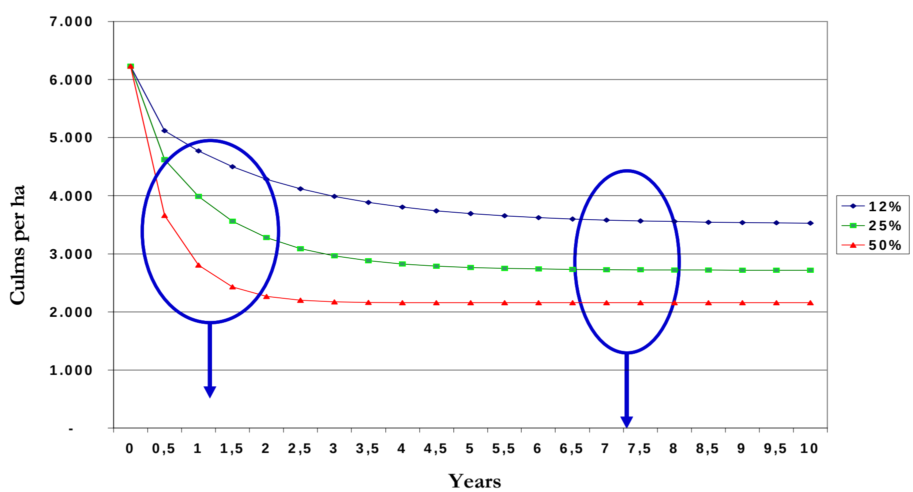


Figure 6. Effect of harvest intensity on the total number of culms per ha. Harvest was done every 6 months with intensities of 12%, 25% and 50% of commercial culms. Source: Morales 2004

Respect to the effect of fertilisation, this factor has been especially important reducing the level of shoot mortality and also increasing productivity. In this case, about 950 shoots per ha emerge every year with fertilisation while without fertilisation just 750. Regarding to mortality, it is of 12% with fertilisation and of 20 % without fertilisation (Morales 2004).

Silviculture of guadua plantations

In Colombia there are few guadua plantations and information on growth, population dynamics and silviculture is still quite general and recommendations are focused in how improve clump conditions and growth space during the phase of establishment (Camargo 2006). Requirements of weed control to improve the availability of light to guadua culms, as well as the possibility of intercropping by considering spacing and maintenance have been mentioned by Judziewicz et al. (1999), but have not been studied in detail. Riaño et al. (2002) have gathered data about growth and culm productivity in guadua plantations for up to six years. In their study, the authors also proposed models to describe clump growth and population dynamics.

Camargo (2006) shows results on the effect of fertilisation and weed control on growth. In this case, growth is expressed as the number of culms per clump, the estimated number of dead culms per clump, culm length and culm diameter at the lowest internode (basal diameter). Measurements of these variables were made on the three central clumps located in the effective area of each plot. Analysis of variance was used to determine differences between treatments and the Tukey test for comparison of the main effects of treatments.

The highest average values for the response variables were observed under chemical fertilisation and weed control done with herbicide. For the number of culms per clump the highest average was of 38 in the first 24 months which is equivalent to 23,750 culms per ha (Figure 7). The maximum number of dead culms per clump for the same period of time was 19 culms, which corresponds to 11,875 culms per ha and a monthly increment rate of 0.8 culms per clump or 500 culms per ha (Figure 8).

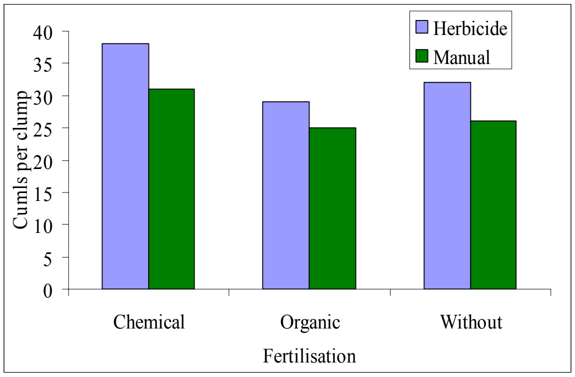


Figure 7. Effect of weed control at different levels of fertilisation on the average total number of culms per clump; 24 months after establishment. Source: Camargo, 2006.

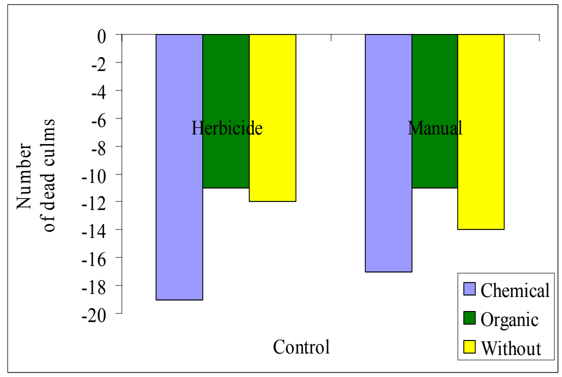


Figure 8. Effect of fertilisation at different levels of weed control on the total of estimated dead culms per clump; 24 months after establishment. Source: Camargo, 2006.

For treatments with chemical fertilisation and weed control with herbicide, the average culm diameter was of 3 cm and average culm length of 6 m, with increments for both variables being considerably higher than with other treatments (Figures 9 and 10).

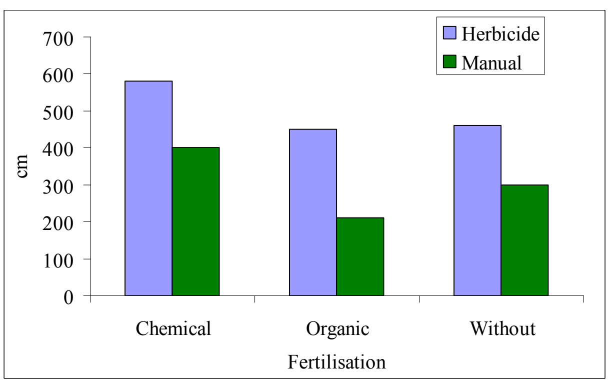


Figure 9. Effect of weed control at different levels of factor fertilisation on the average culm length; 24 months after establishment. Source: Camargo, 2006.

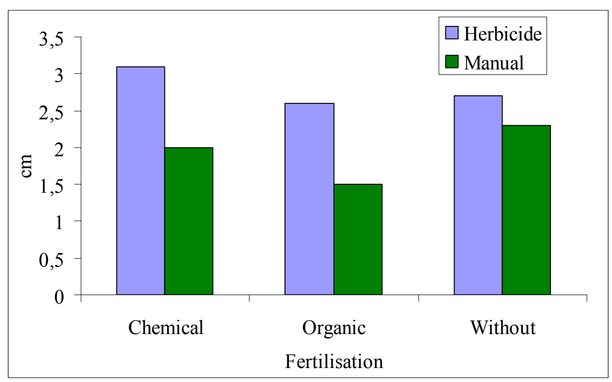


Figure 10. Effect of weed control at different levels of fertilisation on the average culm basal diameter; 24 months after establishment. Source: Camargo, 2006.

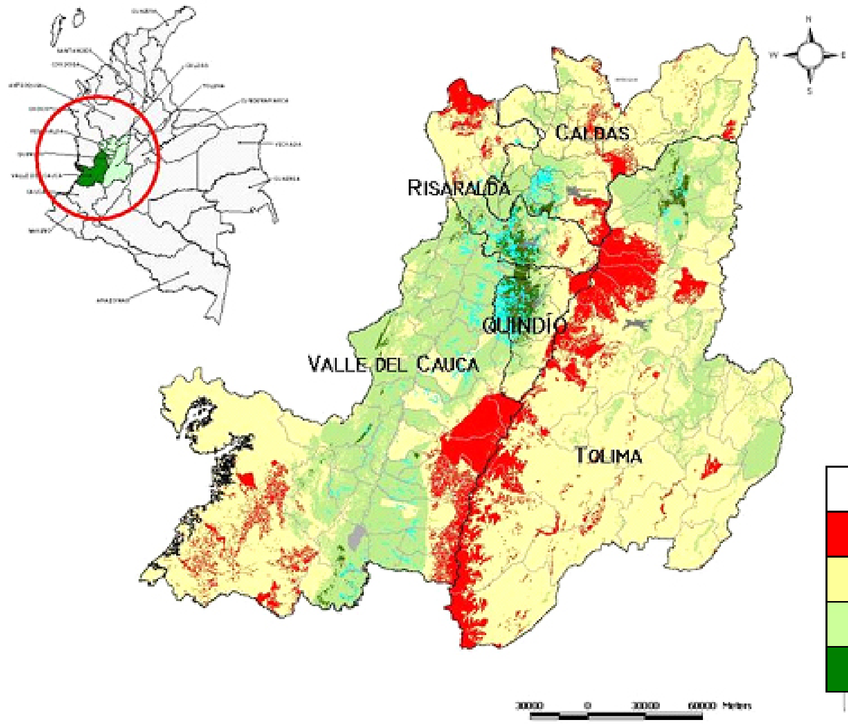
Thus it is observed that fertilisation and reduction of interspecific competition with herbicides are converted by this efficient plant into high biomass values in correspondence with high productivity expressed by increasing shoots production and culms growth.

Planning of guadua forest

The definition of land capability and potential areas for establishing guadua plantations in the coffee region of Colombia was carried out for five states in an approximate area of 5.766.397. A total of 24 variables were used in analyses to develop the model. These variables were included within five factors which represent site conditions: topography, climate, soils, landscape ecology and socioeconomics. By using a simple decision model based on the above mentioned five factors, it was feasible to define four classes of land capability: low, marginal, moderate and high.

In order to consolidate units of forest management (UFM) only 17 municipalities (470.328 ha) were incorporated in analyses. Additional information on volume of harvesting and characteristic of guadua stands related to site quality was included in the model. As a complement information on guadua forest inventories and baseline information on soils, climate conditions, geomorphology, environmental services and socioeconomic aspects, also was integrated. Thus, three classes of UFM were identified according of productivity level low, moderate and high. The software *Arc View 3.3* and its extensions *spatial analyst* and *3D analyst* were used. Also the extension *Model Builder* included within *spatial analyst 2.0* provided tools to develop the model.

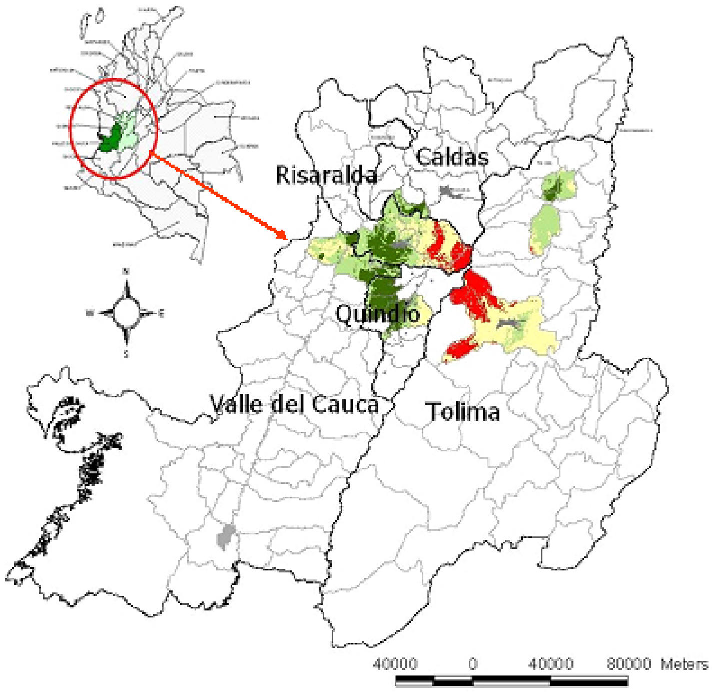
Only 2% of the evaluated total area resulted with high capability for guadua production. This area is located close to urban centers where are sited most of guadua stands (Figure 1). The main limitation for guadua production was the lack of roads (to access) and the absence of places for marketing. Also areas over 2000 m of elevation were immediately excluded, because of guadua does not grow well under these conditions.



Land Unit	Area (ha)	%
Low Capability	67281	12
Marginal Capability	3345448	58
Moderate Capability	1614691	28
High Capability	**124515**	**2**

Figure 11. Capability of land for guadua production. Coffee region of Colombia.

Regarding to UFM, those defined at the category of high productivity represent 19 % of the total area of municipalities analysed (Figure 11). Due to the characteristics of UFM in this category, it is feasible to develop intensive programs of forest management, since all aspects confirm a favorable level. Other UFM at the categories of moderate and marginal productivity could potentially become of high productivity. It is workable only if the volume of harvest increase and some conditions as access are improved (Figure 12).



Units of Forest Management	Area (ha)	%
Other	83529	16
Low productivity	162057	35
Moderate Productivity	137097	29
High Productivity	**87645**	**19**

Figure 12.Units of forest management for 17 municipalities in the coffee region of Colombia.

Guadua stands located within UFM were qualified in terms of productivity, quality and as potential protected areas. Consequently the conformation of UFM is significant as strategy to promote the management of small guadua stands. The fragmented pattern and small size of guadua stands could be a drawback. However, these forest areas included as a part of UFM can be an opportunity to integrate them to forest management and a reasonable strategy of forest planning. Moreover, management and market of guadua culms are incorporated within a UFM plan and not separately. Plans of management and strategies of marketing might now be done according to the specifics characteristics of UFM. The worth of the issues is because provided a tool for planning Guadua forest. Consequently, contribute to an adequate management of this natural resource in the Colombian coffee region and could be replied in tropical areas with fragmented forests.

Environmental services provided by guadua forest

Carbon sequestration within guadua stands

Aerial biomass was estimated with values of culm volume and wood density (Camargo 2006). Thereafter the carbon content was calculated by using a constant of 0.5 (Marquez 2000). Total amount of carbon dioxide in tons per ha was estimated from carbon content per culm and the average number of culms per ha. This information was associated to units of forest management (UFM) classified according to different levels of culm productivity (Camargo et al. 2007).Information on altitude, slope and precipitation were employed in correlation analyses with carbon in soil under guadua stands.

A total of 812.2 Tn CO_2 ha^{-1} were estimated in average for guadua stands in the coffee region of Colombia. Aerial carbon was estimated in 251.3 Tn CO_2 ha^{-1} (31 %) for 6284 culms per ha, whereas 560.9 Tn CO_2 ha^{-1} (69 %) at 0.5 m of depth were calculated as stored in soils. Similar values have been registered for primary and secondary forests in Colombia with 99.2 Tn ha^{-1} and 93.6 Tn ha^{-1} respectively, at 30 cm of depth (Orrego and Del Valle 2001). The proportion of soil carbon regarded to biomass carbon, has been defined as higher for different authors. Lal et al. (1995) mentioned that carbon content in soils could be up to three times more than in living organisms. In the same way, within forest the soil carbon is 1.5 times more than in biomass (Brown 1997).

Correlation analysis showed positive and statistically significant relationships ($P<0.05$) among variables altitude, slope and precipitation with soil carbon stock. Regarding to altitude, it is important to highlight that, as altitude increases temperature decreases. Hence the percentage of organic matter accumulated in the soil tends to be higher, affecting carbon stock. In the other hand, precipitation eases the accumulation of soil organic matter. According to Fassbender (1986) precipitation influences the development of vegetation and therefore the production of organic matter in soils.

For the UFM with high productivity with an average of 5914 culms ha^{-1} the equivalence in CO_2 was of 868.7 Tn ha^{-1} (581.7 Tn CO_2 ha^{-1} in soil and 287 Tn CO_2 ha^{-1} in the aerial compartment). For the UFM with moderate productivity with 6313 culm ha^{-1} in average were estimated a total of 790.4 Tn CO_2 ha^{-1} (553.7 Tn in soils and 236.7 Tn in the aerial compartment). Finally, for the UFM with low productivity were estimated in average 7967 culms ha^{-1} which represent 234.7 Tn CO_2 ha^{-1} in the aerial compartment and 633.7 Tn CO_2 ha^{-1} in soils, for a total of 868.4 Tn CO_2 ha^{-1}).The distribution of carbon stocked was of 70% in soils and 30% in biomass (aerial compartment).

Guadua stands and soil protection

In the La Vieja watershed river (coffee region of Colombia) a total of forty sites were selected for soil assessment. Sampling was conducted in two stages. The first stage consisted to define on maps of land cover, transformed (mixed crops, crops, pastures and silvopastoral systems) and untransformed systems (guadua forest and forest[1]). In the second stage, a total of 40 sites were randomly located within transformed and untransformed covers for soil sampling. Finally, in each selected site three samples of soil were collected.

For each sample point were measured physical soil variables as soil stability, total porosity and texture. Soil stability (Average diameter of soil aggregates ADSA) was used as a reference variable to determine resistance to erosion or susceptibility to erosion. Whereas total porosity and texture, were employed to estimate the capability of soil for water storing (CWS), which is directly related to water regulation. Values for the variables evaluated

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[1] This cover correspond to patches of forest where is not present the species *Guadua angustifolia*

were weighted at depth of 50 cm. Thereafter, the Kruskall Wallis test was performed for comparing the capability of soil for water storing and resistance to erosion among the different land uses and land covers

Comparisons of soils properties among different land use and cover evidenced values of CWS (water regulation) of 530 m^3 ha^{-1}. The higher value, although statistically not significant was for covers of forest with 572 m^3 ha^{-1}. Whereas the lower value was found under crops and pasture (Figure 13). The similar values of CWS obtained are explained because soils in the coffee region are highly homogeneous. Most of them are Andisols originated from volcanic ash; consequently have special physical properties as low bulk density and high effective depth (Malagon et al. 1995). While soil properties as those above mentioned do not change strongly, values of CWS will tend to be similar among covers. Previously, Sadeghian et al. (2001) found lower values of bulk density and soil compacting under guadua stands than those simplified land cover as crops and pastures. In this study it was evidenced that low values of bulk density and soil compaction contributed to a better balance between water and air within soils. It is important to remark that covers of forest and guadua forest are usually located in marginal areas where agriculture and cattle are not feasible. It means that natural soil conditions for these areas are limited by factors as slope and effective depth. Nevertheless, the value of CWS was higher under forest and similar to the other covers under guadua forest. It shows that even on limited soils, forest cover (guadua included) can maintain proper physical characteristics or improve them.

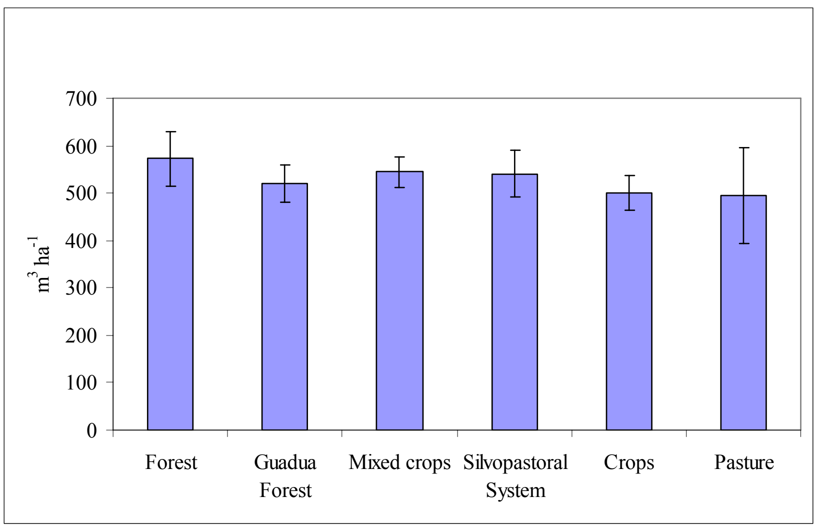

Figure 13. Capability of water storing in soils under different land use and land cover. La Vieja, watershed river. Vertical lines on the bars indicate the standard deviation.

The resistance to erosion showed significant ($P<0.05$) differences among the land use and land cover evaluated. Soils under guadua forest were significantly more resistant to erosion with a better structure represented by aggregates of 5.47 mm in average. Even though values under crops resulted very similar that those registered under guadua their variability was higher and the average was affected for extreme values, whereas mixed crops and pastures exhibited the lower values (Figure 14). Soil structure is related to different properties in soils. Changes on this variable are the result of land use practice and the type of material returned as organic matter in residues (Deuchars et al. 1999). Soil structure is associated to vegetal residues (Douglas et al. 1986) and probably fallen leaves of guadua are contributing to improve it. With the results obtained it is not possible make general conclusions because there is a high natural variability associated to variables assessed. This variability can not be explained simply with the effect of covers, therefore is only feasible to elucidate trends. In this sense, to improve the basic information could be an interesting task for further research.

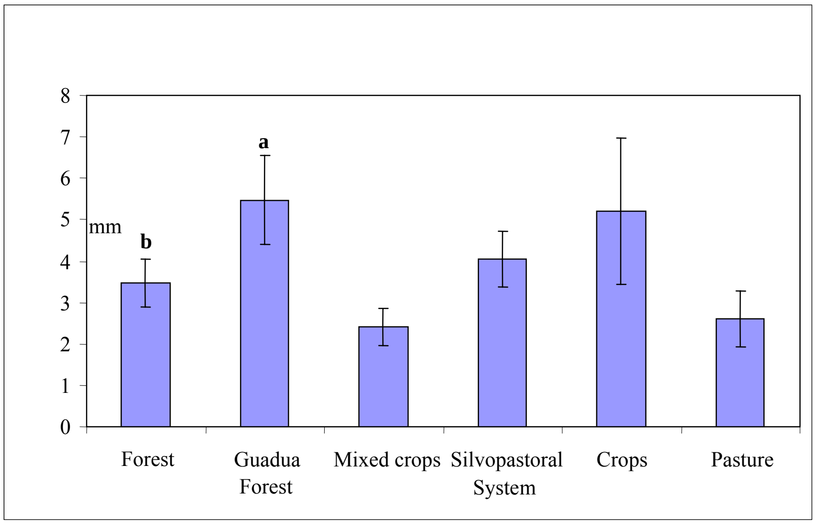

Figure 14. Resistance to erosion evaluated through average diameter of soil aggregates (ADSA). La Vieja, watershed river. Vertical lines on the bars indicate the standard deviation. Different letters indicate statistical significant differences (P<0.05).

The lowest values of ADSA could indicate a poor soil structure, however others factors different to currently cover could have a higher influence on soils properties. The history of land management (i.e. the preceding cover) can have a big influence on the present characteristics of soils. Deuchars et al. (1999) found that soil properties under pasture were negatively affected by cattle trampling even in areas where pastures were abandoned and regeneration forest was achieved, there problems in soil compaction and low porosity were evidenced after 15 years.

Guadua stands and soil restoration

An experiment were conducted to evaluate the short-term efficiency of guadua plantation for soil restoration and avoiding soil loss. Five treatments with three replications were randomly assigned within three blocks and in ffifteen plots of 9 x 12 m (108 m^2) which were adapted with lateral drains for conducting runoff and sediments toward a tank.The treatments evaluated were natural regeneration (T1), tree plantation (T2), guadua plantation (T3), temporary crops (beans) (T4) and pastures (T5). The experimental area was a hill with a slope of 36% in average that during three decades was covered by pastures. As a consequence the soils were eroded and compacted due to intensive livestock activities and especially by cattle tramping.

The soil loss was assessed during a period of seven months. The sediments collected in the tank have been dried and weighted daily to estimate soil loss (erosion) per each treatment. Precipitation has been also measured every day in a conventional rain-gauge. Variance analyses have been conducted to determine statistical differences in soil loss among the treatments evaluated. The post ANOVA test of Tukey was performed to determine differences among means.

Erosion was lower under treatment with guadua with 0.11 Tn ha^{-1} per seven months. Whereas soil loss in the treatments with crops was strikingly high with 0.26 Tn ha^{-1} per seven months. It is important to remark that the only treatment with significant ($P<0.05$) differences was temporary crops (Figure 15). Monthly evaluation of soil loss showed a high correspondence with values of precipitation. Being it an important evidence of the influence of this variable on soils loss. The results observed in this research are highly coincident with a research previously carried out with guadua by Rodríguez and Sepúlveda (2004) whom found low levels of soil loss under guadua stands when were compared with other land and use cover. Overall, erosion can be attributed to high rainfall erosivity and landform (slope). It increases as the level of cover decreased. In addition, on treatment T4 the soil is exposed to rainfall and readily transportable particles can augment the amount of sediments loss.

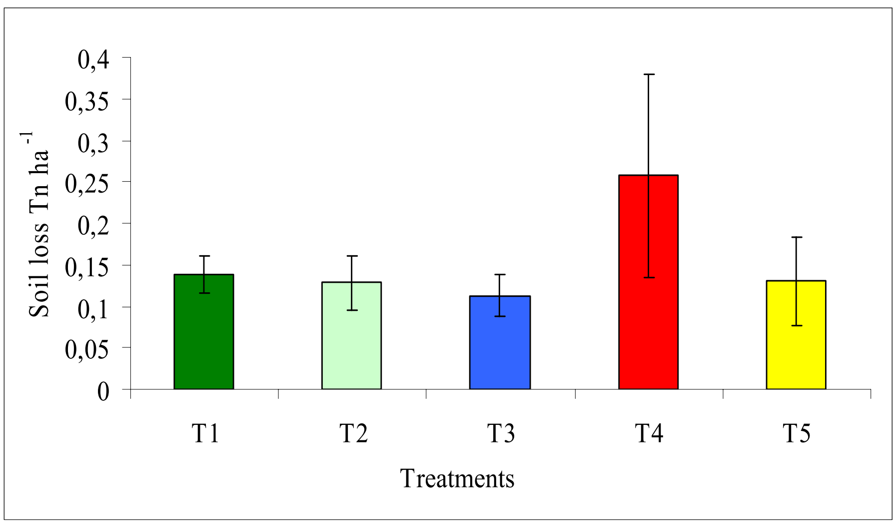

Figure 15. Soil loss (Tn ha^{-1} per seven months) under different treatments: natural regeneration (T1), tree plantation (T2), guadua plantation (T3), temporary crops (beans) (T4) and pastures (T5). Finca Nápoles, Montenegro, Quindío, Colombia. Vertical lines on the bars indicate the standard deviation. Different letters indicate statistical significant differences ($P<0.05$).

Conclusions and recommendations

Forest mensuration methods are adequate for determining the growth pattern and the explicit dendrometric and stand characteristics of guadua. Though these methods should be applied considering adjustments that depend on specific features of this bamboo resource. Thus information from inventories will be reliable and useful for making decisions.

For determining the effect of site conditions on guadua is necessary to define previously which variables could be used to evaluate the response to factors associated to site. In this sense predictive models for culm length, basal area and culm hardness show a reasonable goodness of fit and might be considered as response variables to determine the effect of environmental factors on guadua productivity and quality. Thus, average culm length and stand basal area can serve as indices of guadua stand productivity. Whereas average culm hardness is useful to determine culm quality within guadua stands. Although, the variability in productivity and quality of guadua could not be entirely described by the environmental set of independent variables measured, these results are a significant contribution to know on the potential use of this natural resource in the coffee region of Colombia.

Combining harvest intensity and frequency is possible for establishing the best level of silvicultural management, maintaining as a reference an adequate number culms per ha. For guadua plantation the fertilisation of Guadua and the reduction of interspecific competition with herbicides, represent high possibilities to increase the yield within guadua plantation. Nevertheless, now is required to study in detail this topic which has been barely studied for guadua.

The implemented model for forest planning was useful to define land capability and also units of forest management. Nowadays, government institutions can lead the planning of guadua stands based on this model. Besides, the units of forest management are an alternative against drawbacks relate to fragmented pattern of guadua stands.

Even though guadua bamboo forest in the coffee region of Colombia are highly fragmented, they fulfill important ecosystems functions and provide environmental services such carbon sequestration and soil protection that contribute to maintain the stability even within transformed areas (agroecosystems). Hence strategies for ecosystems conservation or an adequate management of these forests should be implemented, given that are almost the latter remnants of forest cover in this significant area of Colombia. Ecosystems functions and environmental services are provided by guadua bamboo forest even under harvesting. Thus some incomes and products are directly perceived by farmers and certainly, it could motive them to maintain areas under guadua forest within their farms. Thus it would be an strategy that could contribute to the sustainable development of rural areas upon the base of integrating production and conservation.

Acknowledges

The authors wish to thank to COLCIENCIAS for financing the Projects "Estrategias para el fortalecimiento y conformación de empresas rurales con base en la Guadua (*Guadua angustifolia* Kunth) en la zona cafetera de Colombia" (Contract No. 165-2004) and "Valoración de los bienes y servicios de la biodiversidad para el desarrollo sostenible de paisajes rurales colombianos: Complejo Ecorregional Andes del Norte" (contract RC No. 433 -2004) fulfilled by CIEBREG. Also thanks go to the Technological University of Pereira for financing and supporting the development of this investigation. Finally, we want to express our gratitude to the owners of farms for permitting us to work in their properties.

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Lei Bamboo (*Phyllostachys praecox*) Growth Degradation associated with Soil Properties using an Organic Material Mulching Technique

[1]Renyi Gui, [2*]Shunyao Zhuang, [1]Guodong Li, [3]Yongjun Zhu
[1] Bamboo Research Institute, Zhejiang Forestry University, Lin-an, China
[2] State Key Lab of Soil and Sustainable Agriculture, Institute of Soil Sciences, Chinese Academy of Sciences, Nanjing, China
[3] Lin-an Forestry Bureau, Lin'an, Zhejiang Province, China
*Corresponding author, SY Zhuang, State Key Lab of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China.

Abstract

In the last 20 years, Lei bamboo (*Phyllostachys praecox*) has been extensively planted on former paddy soils for its high economic profit in Southeast China. However, Lei bamboo showed a significant degradation in growth after several years with an organic material mulching technique. Based on the inquiry of the farmers, we speculated that soil basic properties changed with the intensive management may be responsible for the bamboo degradation. Accordingly, an investigation of soil basic properties with the bamboo plantation was made in detail. A series of bamboo soils with various planting times was chosen to analyze the soil basic properties. Results showed that soil pH values decreased significantly from 5.71 to 3.85 with increasing planting time, while soil organic C, total N and P increased dramatically. At the same time, soil active Al which is toxic to plant growth increased dramatically from 3.85 to 197.6 mg kg^{-1} after 15 years of the bamboo plantation. High Al content was found in the degraded bamboo roots that verified the hypothesis that the intensive management made soil nutrients available imbalance and lowered the soil pH greatly that possibly resulted in the bamboo growth impairment. Therefore, the present practice of bamboo management had a great influence on soil quality that affected the bamboo sustainable production. A better or improved practice should be used in the future of the bamboo production.

Keywords: aluminum, bamboo, intensive management, soil properties

Introduction

Lei bamboo (*Phyllostachys praecox*) is a famous kind of bamboos for shoot food production in China. This bamboo has advantages in early shoot supply, long time of shoot production, high yield and delicious taste after tamed from the local nature species. Lei bamboo mainly distributes in the counties of De-qing, Yu-hang and Lin-an of Zhejiang Province, Southeast China. Since from 1990, the bamboo plantation has been obtained a great economic benefit using an organic material mulching technique to increase soil temperature and supply shoot earlier in the winter. Hence, the cultivating area of Lei bamboo has been increasing greatly in the region. However, with the planting time increased, the bamboo stand degradation occurred and shoot yield decreased significantly. In the first year of organic material mulching, the yield of bamboo shoot can reach 35 ton per ha, but it drops to less than 10 ton per hm^2 when the stand degraded after 5 years. Thus, the sustainable bamboo production becomes a practical problem due to the bamboo growth obstacle. Presently, the area of Lei bamboo is about 27,000 hm^2 in Lin-an city, however, 1/4 of which is showing degradation with lower production. Some researchers considered that the main reason of the bamboo degradation was irrational bamboo stand management that resulted in a weak growth of bamboo and finally to the stand degradation (Jin et al. 1999; Yu et al. 2001). However, there was no sufficient evidence to elucidate the bamboo degradation with the intensive fertilization and the organic material mulching technique involved.

The organic material (rice straw and bran) mulching technique was developed by the local agricultural technician of Lin-an city (Jin et al. 1998). Using this technique, the bamboo shoot yield was improved greatly and the harvesting time was brought ahead that greatly increased the profit of the bamboo planting. Accordingly, this technique was extensively used in the region of Lei bamboo plantation and even to other neighboring provinces. According to our preliminary field investigation, the bamboo tended to degradation after 5 years using the mulching technique. However, judged from the bamboo growth, no evidence can support the explanation of bamboo degradation induced by irrational management practices (Yu et al. 2001) because the bamboos with or without the mulching technique showed no significant difference in growth in the field, indicating the farmers' management practices were not greatly different in the field using the technique or not, especially in the harvesting of bamboo shoot. Because of the large inputs of fertilizers and organic materials with high C/N ratio, soil acidification can be expected severe in the bamboo plantation soil.

The changes of soil properties with respect to the organic material mulching technique may be responsible for the bamboo withering. Therefore, the objectives of this study were to investigate the basic physiochemical properties of soils with bamboo plantation using the mulching technique to provide an evidence for a better bamboo management. At the same time, the information obtained from this study may be of benefit for us to understanding the influence of bamboo intensive plantation on soil properties.

Materials and Methods

Study Site Description

The study site is located at Lin-an city, Zhejiang Province of China. This region belongs to the sub-tropical monsoon zone. The landform here is hilly with elevation around 150 m. The annual mean temperature is 15.9 with a maximum of 41.3 and a minimum of -13.3 . The annual rainfall is 1550 mm with 236 free-frost days. In this region, the soil type belongs to ferrosols derived from red sandy rock-bed. Lei bamboo (*Phyllostachys praecox*) is a local species and was tamed to plant on the former rice field for high yield, so we selected the rice field plot as the control.

A technique of organic material mulching was developed and adopted in the Lei bamboo production. The mulching technique uses rice straw and bran, sometimes bamboo leaves as the mulching material. The bamboo soil surface is usually started to mulching during the period from November or December to March of next year to increase soil temperature and keep soil moisture in the winter season. The data showed the ground temperature could raise 4-5   after mulched with organic materials (Fang et al. 1994). During the mulching process, rice straw was firstly mulched to a height of 10-15 cm from the surface and then rice bran was filled onto another height of 10-15 cm. The total rice straw and bran used in one time commonly reached 40 and 55 t hm^{-2}. In the next year, the undecomposed rice bran layer was removed in March or April while the rice straw almost decomposed or mixed into soils. In the next mulching time, the removed rice bran was mixed with new to be used. The fertilizer applications were used for three times, i.e. mid-May, mid-September and the time before the mulching, respectively. The fertilizer application rate was about 2.25 t hm^{-2} (N:P:K=16:16:16) and urea 1.125 t hm^{-2}, sometimes manures with equal nutrient used as well. The use of organic material mulching technique began from the 5th year after the bamboo transplanting.

Soil Sampling

During the bamboo plot selecting, similar soil position, landform, initial soil fertility and soil basic physiochemical properties before bamboo plantation were considered. The selected planting time was 1□5□10 and 15 years, respectively. After 10 years, the bamboo stand became to showing degradation in the field. The rice field was chosen as the control because the bamboo planted on soils shifted from the paddy soils. Each replicate of plot selecting was located at one farmer’s field to keep the same original condition of soils from the influence of field management. The area of each selected bamboo plot is larger than 100 m^2. Due to the shallow root depth of Lei bamboo, the soil profile was separated into 5 layers as 0-5, 5-10, 10-15, 15-20 and 20-25 cm, respectively. Before the collection, litters and mulching materials on the soil surface were removed. We selected three sites for sampling and there replicates were done on the each bamboo plot and paddy plot. Fresh soil samples were air-dried and ground to pass through 2 mm sieve. In order to test the hypothesis of Al toxicity with low pH to Lei bamboo, roots of bamboo were also collected in each plot.

Soil Analysis

Soil basic physicochemical properties, including soil pH, organic matter, nitrogen, cation exchangeable capacity (CEC), were analyzed. Soil pH was determined by electrode method. Soil organic matter was measured with $K_2Cr_2O_7$ oxidation and $FeSO_4$ titration. CEC was extracted by 1 M NH_4Cl and K, Na, Ca and Mg were determined by the atom adsorption system (AAs). Because Al may be one factor influencing bamboo growth in red soil with low soil pH, various Al forms were also measured. These Al forms included exchangeable Al, dissociated Al, amorphous Al, organic bound Al and total Al. The exchangeable Al was extracted by 0.1M KCl (James et al. 1983), dissociated Al (Al_d, dithionate), amorphous Al (Al_o, oxalate) and organic bound Al (Al_p, pyrophosphate) were determined by the method proposed (Odes 1963; McMeague and Day 1966). Bamboo roots were digested with $HClO_4$+HF and Al content was measured by AAs.

Results and Discussion

Effects of Bamboo Plantation on Soil Properties

As shown in Table 1, soil pH value decreased with increasing planting time. After the bamboo planted 15 years soil pH dropped to 3.85 that was almost 2 units lower than that of the paddy soil. Such a result indicated that bamboo plantation accelerated the soil acidification when using this intensive management model. Soil acidification is a naturally occurring phenomenon and is usually the result of long-term additions of protons to the upper layers of the soil profile that effectively results in the displacement of exchangeable bases and their subsequent leaching. However, accelerated acidification of soils associated with export of alkali through product removal, or movement of cations associated with nitrate leaching, has brought into question the long-term sustainability of crop and forage production systems (Helyar 1976). In this study, the accelerated acidification in a short term exerted an important impact on bamboo sustainable production. When using the organic material mulching technique, bamboo soils simultaneously received nitrogen fertilizer with a rate of ca. 800 kg N hm^{-2} annually that accordingly made a direct impact on the soil acidification. Due to acid release in the decomposition, the mulched organic material also had an impact on soil acidification but no evidence was obtained up-to-now in the bamboo plantation.

Soil organic matter content increased greatly from 31.0 to 79.2 g kg^{-1} after 15 years (Table 1). Obviously, the increase of soil C and N (from 2.02 to 4.61 g kg^{-1}) was closely related to the input of fertilizer and organic matter. During the first 5 years, soil organic matter and nitrogen contents were slightly lower than those in the control of paddy soils. In the process of paddy field shifted to upland, easily decomposable organic matter decomposed rapidly due to a better oxidation condition. After the rice straw and bran mulching (from the 5th year), soil organic matter and nitrogen increased with increasing planting time. Usually in the intensive managed moso-bamboo, soil organic matter decreased gradually with planting time (Xu et al. 2003). Because there was no organic matter input to the moso-bamboo only chemical fertilizer applied, soil organic matter oxidized and decomposed rapidly without extra input.

Soil total phosphorus content increased significantly from 0.500 to 2.005 g kg^{-1} with increasing planting time. Since the source of P was derived from the fertilizer application and the movement of P in soils was difficulty especially under the acid soil because P can be bound closely with Fe and Al minerals. Meantime, the bamboo soils were shifted from paddy soils where nutrients are not easily leached through runoff due to a plat landform with ridges. The accumulation of P reached such a high level that may result in bamboo blooming earlier and bamboo degradation. We found some blooming bamboo culms in the field, but the number was few. However, compared with soil P, soil total potassium showed no difference in various blocks (Table 1). This indicated that applied K was balance to the bamboo growth if no significant K leached.

Soil available P and K increased greatly after the bamboo planted for 15 years. Especially, the available P increased from 7.14 mg kg^{-1} in the paddy soil to 475.6 mg kg^{-1} in the bamboo soil of 15 years. The overloaded soil P exerted a great risk to the surface water environment. Available K content increased but the total K content showed no increase even with high fertilizer input, indicating large K leached from the bamboo field.

Effects of Bamboo Plantation on Soil Al Forms

Aluminum in soil includes mineral and aqueous forms, where Al minerals are mainly primary and secondary minerals such as aluminosilicate and non-aluminosilicate Al. According to its bound form with minerals, soil mineral Al can be classified as exchangeable Al, hydroxide bound Al, organic complexed Al, hydroxide Al and non-crystalline aluminosilicate Al. Water soluble Al includes dissociated Al, mono-nuclear hydroxide Al, multi-nucleus hydroxide Al, Al-F, $Al_2(SO_4)_3$ and organic complexed Al. Soil Al chemical forms are comlicate in soils that depends on the environment, especially on soil pH value. When pH is less than 5, Al is mainly present in Al^{3+} form. When pH increases, $Al(OH)^{2+}$ and $Al(OH)_2^+$ occurs. When pH is equal to 7, Al will be present in $Al(OH)_3$ or gibbsite. Under the alkaline condition, $Al(OH)_4^-$ or aluminosilicate is present. Mono Al ion can be complexed with inorganic ligands, such as PO_4^{3-}, SO_4^{2-}, F^-, organic acid, protein or adipose. The toxicity of various Al forms on plant is different. Relatively, the toxicity of various Al forms show an order as: Al^{3+}> $Al(OH)^{2+}$> $Al(OH)_2^+$> F-Al >>organic complexed Al.

Because soil Al form is closely related to soil pH and organic matter, the change of pH and organic matter will result in a great change of soil Al form and distribution pattern. As shown in Table 2, the total soil Al content in the surface layer (0-25 cm) decreased in the bamboo plot significantly but the exchangeable Al content increased greatly from 3.85 mg kg^{-1} to 197.6 mg kg^{-1} compared with the paddy soil. The extracted amorphous Al, dissociation Al and organic bound Al also increased significantly in the bamboo plot. Soil Al dissociation degree (Al_d/Al_T) and activation degree (Al_o/Al_d) both increased as well. Accordingly, the bamboo plantation greatly increased the solubility and movement of Al that exert an extreme toxic risk on bamboo growth. Possibly, the improved soluble Al affected the bamboo shoot and resulted in a yield drop. Due to fixation with soil solid phase or phosphate, the concentration of Al in soil solution is generally very low that has little effect on plant growth. However, when soil pH is lower than 4.5, Al will release substantially from bound form to soluble form and be harmful to plant growth. As pointed out, plant root growth and development is the primary target of Al toxicity (Sivaguru and Horst 1999; Vebelen et al. 2006). When soil soluble Al concentration arranges 10 to 20 mg kg^{-1}, plant will appear obvious harmful diagnosis (Shen and Yan 2002). There is no evidence to indicate the tolerance extent of Lei bamboo. Factually, the bamboo shoot production decreased significantly and inferred that Al toxicity might mainly responsible for the yield decline.

The bamboo plantation greatly influenced soil Al distribution pattern in the profile (Fig. 2). In the paddy soil, soil total Al distributed evenly in the layer of 0-25 cm, while it increased with increasing soil depth in the bamboo soils (the 15^{th} year). As indicated in Table 2, the total Al content is lower in the bamboo plot than that of paddy plot, suggesting the current bamboo plantation management also improved Al leached from the surface layer.

Soil Properties and Al Form Transformation

Soil Al forms are influenced greatly by the other soil basic properties. Al dissolved from the minerals to soluble phase is determined by the system pH. We can find out clearly that the content of exchangeable Al exponential decreased with increasing pH within the pH segment of 3 to 6 (Fig. 3). This result is well consistent to that explained by the physicochemical computation. From the Table 2, no linear relationship existed among the pH and Al_d, Al_p, Al_o and Al_T. However, a good relationship was present between the pH and Al dissociation degree (Al_d/Al_T), indicating pH value also controls soil Al dissociation degree.

Theoretically, the content of organic matter could determine the ratio of organic bound Al (Al_p), but there was no good relationship present between the pH value and ratio of Al_p/Al_T. Possibly, the composition of organic matter was different among the various blocks and pH influenced the effect of organic matter on Al complexation. The combination effect of organic matter and pH on organic bound Al was obvious in the bamboo soils.

Organic Material Mulching Technique and its Implications

Soil acidification is a slower process in the natural environment. Using the rice straw and bran mulching technique, the bamboo soil acidification was accelerated. Namely, soil pH almost dropped 0.12-unit per year. The bamboo soil acidification might result from the fertilizer application, mulching material decomposition and bamboo root acidic secretion. However, we did not have enough evidences to distinguish the acidification contributions from these sources. One point could be confirmed that it was the mulching technique with high fertilizer application accelerated the soil acidification. Additionally, Al content in the bamboo root was measured and the results showed that it increased greatly in the degraded bamboo root (Fig. 4). In the first year after the bamboo transplanting, Al content in the root was about 2000 mg kg^{-1}, but increased dramatically to 8000 mg kg^{-1} after 10 years of bamboo planting. Of course, the accumulation of Al in the bamboo root was related to soil active Al (Fig. 5). Therefore, we inferred that the bamboo degradation with intensive management was mainly resulted from the soil acidification due to the high fertilizer application and mulching technique.

Certainly, the mulching technique was extensively accepted and brought profit for the bamboo farmers. However, the adverse effects of rice mulching on soil quality were not yet been studied in detail. The bamboo withering after 5 to 10 years after the mulching did not obtain enough notes from the soil view by the farmers. Moreover, the effects of mulching technique on the bamboo ecological environment merit further studies.

Conclusions

With the increasing bamboo planting time, the contents of soil organic matter and total nitrogen increased greatly. Total phosphorus accumulated obviously after 15 years of bamboo plantation. The contents of available phosphorus and potassium also increased greatly with the bamboo planting time. However, soil pH value lowered significantly on the contrary. Soil exchangeable, dissociated, organic bound and amorphous Al increased significantly with the bamboo planting time. Soil Al dissociation degree increased with the bamboo planting time as well. The accumulation of Al in the bamboo root was greatly in the degraded bamboo stand that was also closely related to the active Al in soil. It was soil acidification and accordingly high active Al that affected the bamboo shoot growth and finally resulted in the bamboo degradation. The current management of bamboo production should be improved to meet the sustainable Lei bamboo production.

Acknowledgements

The authors thank for the financial supports from National Natural Science Foundation of China (40671109 and 40871116).

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Table 1. Soil properties changed after Lei bamboo plantation with various planting years

Panting time	pH	OC ($g.kg^{-1}$)	TN ($g.kg^{-1}$)	TP ($g.kg^{-1}$)	TK ($g.kg^{-1}$)	AP ($mg.kg^{-1}$)	AK ($mg.kg^{-1}$)	CEC ($cmol.kg^{-1}$)
0	5.71 a	31.0 b	2.02 b	0.500 d	11.11 a	7.14 d	40.5c	13.4 c
1	5.37 a	25.5 c	1.86 b	0.735 c	11.50 a	38.3 cd	62.3 bc	15.7 c
5	4.76 b	25.0 c	1.71 b	0.741 c	12.41 a	54.1 c	75.9 abc	14.3 c
10	4.33 b	33.1 b	2.07 b	1.280 b	11.06 a	171.8 b	110.8 ab	19.2 b
15	3.85 c	79.2 a	4.61 a	2.005 a	11.03 a	457.6 a	131.9 a	32.5 a

*Different letters represent 5% significance with Duncan's test.

Table 2. Soil Al forms in surface layers of paddy and bamboo soils ($mg\ kg^{-1}$)

Time yr	Al_{ex} ($mg\ kg^{-1}$)	Al_d ($mg\ kg^{-1}$)	Al_p ($mg\ kg^{-1}$)	Al_o ($mg\ kg^{-1}$)	Al_T ($g\ kg^{-1}$)	*Dissociation degree* Al_d/Al_T(%)	*Activation degree* Al_o/Al_d(%)
0	*3.85 a*	*1404 a*	*344 b*	*2088 a*	*54.1 b*	*2.60*	*1.49*
1	*4.25 a*	*1583 ab*	*245 a*	*2073 a*	*54.0 b*	*2.93*	*1.31*
5	*86.6 b*	*1870 bc*	*545 c*	*2217 a*	*54.3 b*	*3.45*	*1.19*
10	*91.0 b*	*1860 c*	*612 d*	*2276 a*	*52.5 b*	*3.55*	*1.23*
15	*197.6 c*	*1800 c*	*653 e*	*2210 a*	*49.4 a*	*3.67*	*1.23*

*Different letters represent 5% significance with Duncan's test.

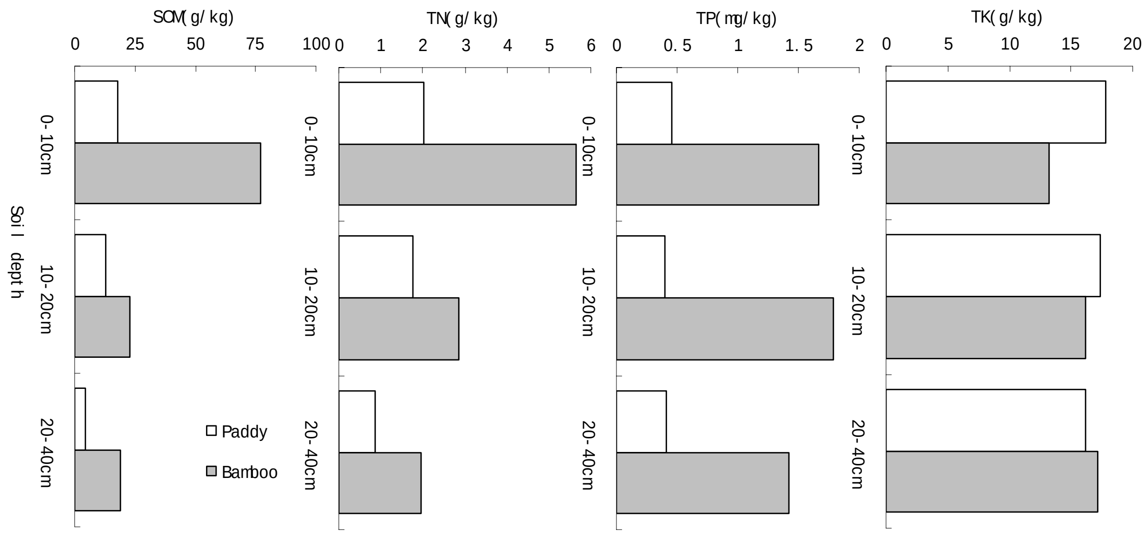

Fig. 1 Soil nutrients of C, N, P, K distribution in profiles of paddy and bamboo soils with 15 years

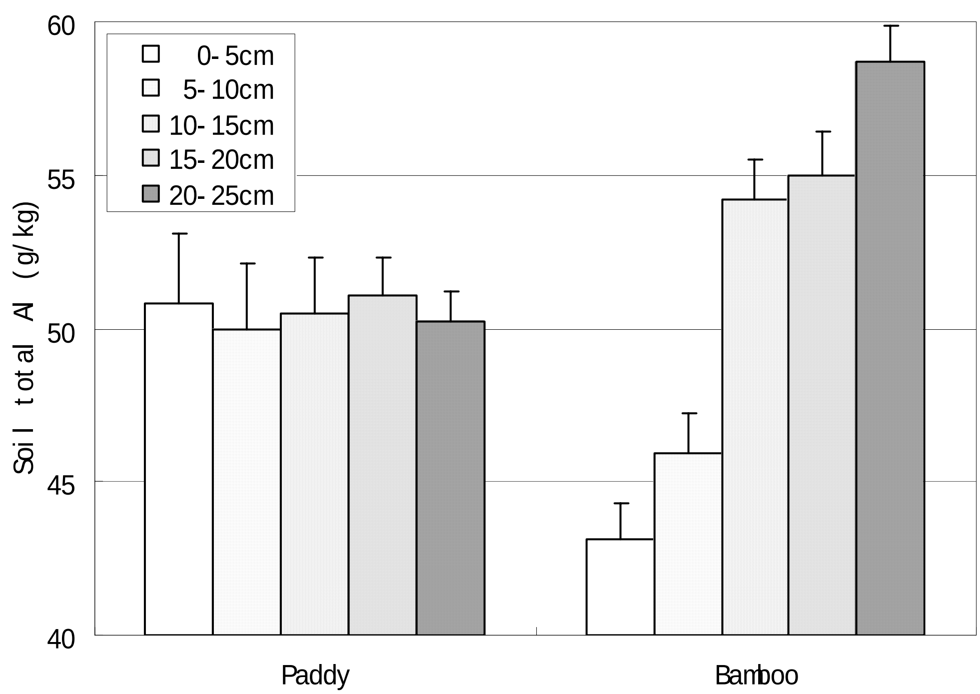

Fig. 2 Total Al content varied with depth in the paddy and bamboo soils with 15 years

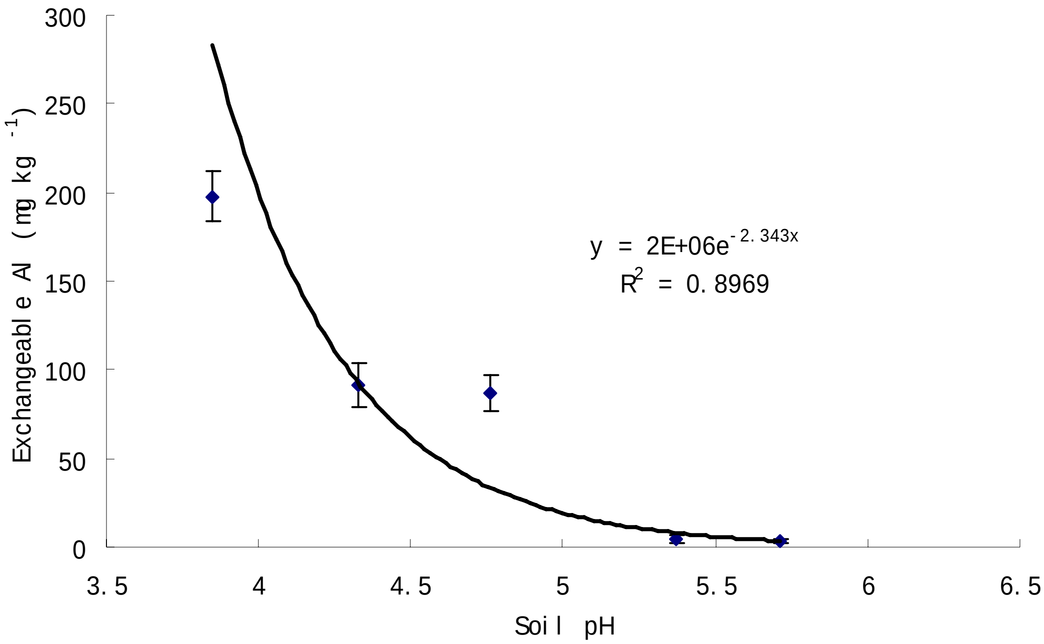

Fig. 3 Soil exchangeable Al content varied with soil pH value

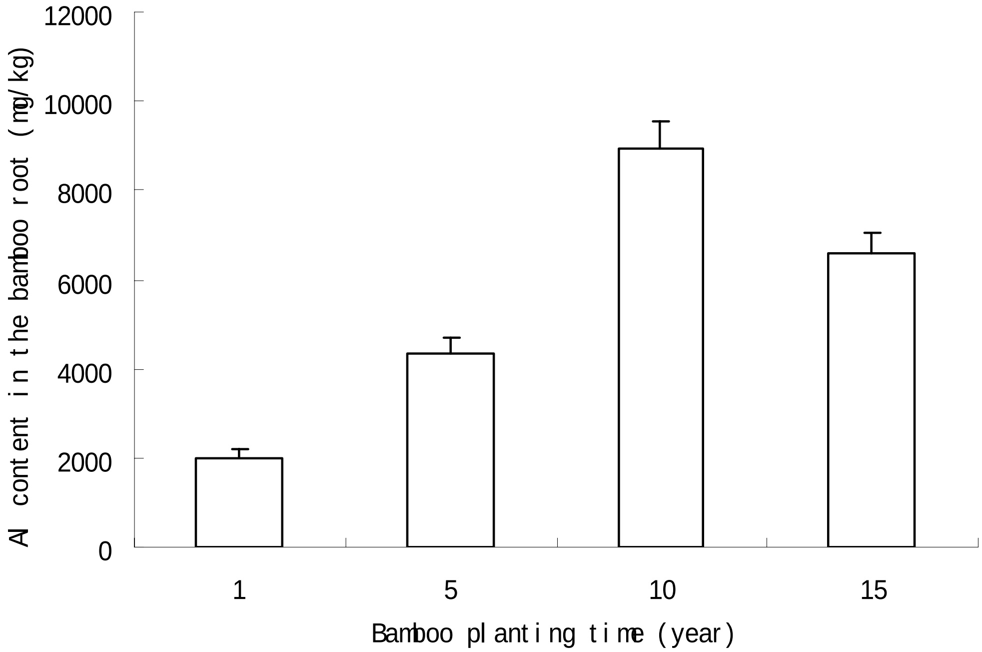

Fig. 4 Al content in the bamboo root varied with planting times

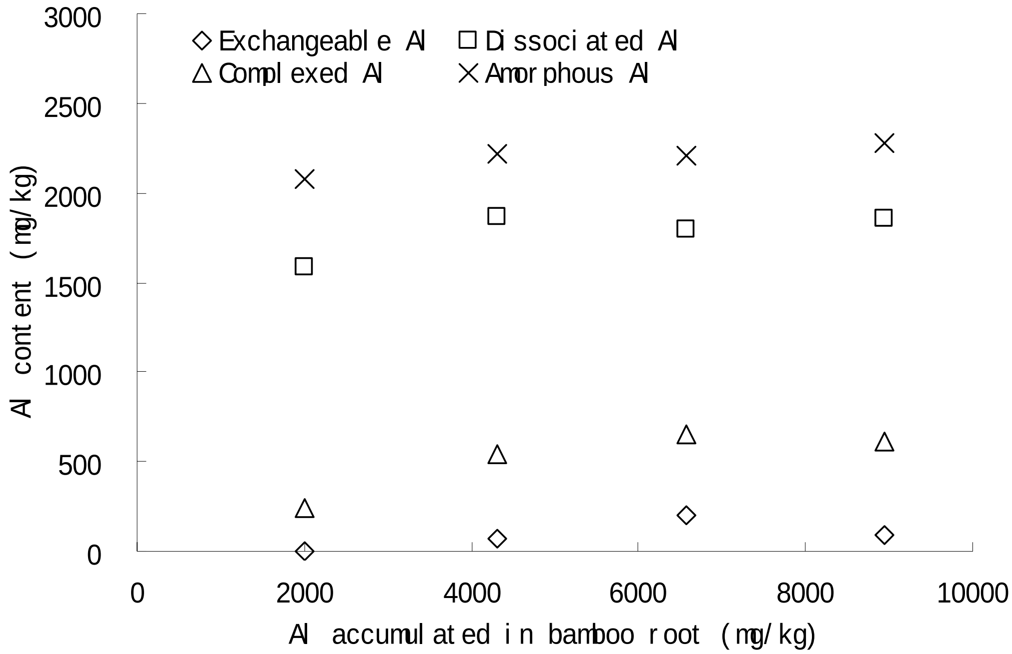

Fig 5. Relationships among the Al accumulation in bamboo root and various Al forms in soil

Optimising Inputs for Production of Bamboo Shoots and timber[2]

David J. Midmore
Central Queensland University, Australia

Abstract

This paper discusses silvicultural management effects on yields of bamboo shoots as a vegetable and for biomass production by bamboo culms. Bamboo yields respond positively to silvicultural practices, both in terms of shoot number and yield and biomass production. Fine-tuning is necessary for optimal input:output relationships. However, data collected on the physical and mechanical properties of culms from different silvicultural practices are important from a practical perspective: managing clumps for sustainable shoot or timber productions does not appear to seriously interfere with the intended use of culms. However, differences between species and treatments that affect the ages of culms at harvest are important considerations when choosing bamboo production practices

Introduction

Bamboo in a natural and plantation context is commonly harvested for its shoots as a vegetable, and for culms (poles) as a wood substitute. Global trade to the extent of US$ 7 billion attests to this. As a non-timber forest product (indeed a misnomer, for it often replaces timber) bamboo does not figure in inventories of forest timber resources, but its sustainable management is equally as important as that of forests, whether it is harvested for shoots, for timber, or for both. Sustainable management should be an important goal for natural and plantation stands of bamboo, yet surprisingly little research has been directed towards defining appropriate guidelines to stakeholders in the bamboo industry, an industry that accesses c. 40 Mha, or 1% of global forest area (FAO 2005). The sustainable management of the bamboo resource is not only relevant to the tangible products of sustained shoot and culm harvests, but also for the sustained provision of important ecosystem services such as carbon sequestration, erosion containment, and local climate regulation (Zhou et al. 2005). Unregulated exploitation of stands is a major reason for degradation of bamboo resources worldwide. Harvesting of very young culms for fiber or timber has jeopardized bamboo growth since ancient times, e.g., in China, but more recently inappropriate harvest has lead to extremely low (when overexploited) and extremely high (when unmanaged) standing-culm densities. If bamboo stands are left undisturbed, biomass production increases until

[2] This draws upon publications by Midmore (2009a) and Kleinhenz and Midmore (2001)

aboveground and belowground competition results in decreasing annual rates of biomass gain. Control of standing-culm density is the most important measure to combat such a decline in productivity.

In order to be sustainable, outputs from production must be at least matched by inputs, and provision of those inputs must not jeopardise the sustainability of the resource pool from which the inputs are drawn.

Four major examples may be cited. Firstly, the pool of carbon dioxide which provides the chemical basis for much of biomass (on average c. 50% by dry weight of biomass is carbon – Scurlock et al. 2000) is to all intents and purposes limitless, and unlikely to diminish because of the photosynthetic demand by bamboo. Within the canopy on still days carbon dioxide may drop to a concentration that does limit photosynthesis, but that is another story. Secondly, the fresh water resource available to bamboo globally is sufficient to satisfy the demand by 40 Mha of bamboo, but locally this may not be so. Spatial heterogeneity in the distribution of water resources for bamboo, whether it simply be rainfall or captured and stored water resources, will influence the biomass production of bamboo, and the choice of plantation set-ups. Inordinate demand on stored water reserves to the detriment of that water use by other industries, especially if the total resources are depleted over time, cannot be considered as sustainable. Practices to increase the efficiency of producing shoots or culms per unit of water uptake and to optimise the use of the water resources should be implemented.

Thirdly, the spatial heterogeneity of mineral nutrients contained with the soil likewise strongly influences bamboo biomass production, and, if not replenished as they are removed in harvested shoots and culms, can limit the sustainability of bamboo stands. As a final example, the availability of labour or mechanical practices that satisfy the high demands for either by the bamboo crop will constrain the sustainability of bamboo production. Excessive costs for mechanical solutions to harvesting and processing of bamboo products, or competition with alternative livelihoods for the normally surplus labour pool, can limit the sustainability of bamboo production. These need to be considered when planning for expansion of the industry. On the positive side, establishment of new bamboo plantations and their intensive management open up new job opportunities and scope for economic growth, regionally and nationally.

In order to address the sustainability of bamboo production, from an input-output perspective, it is necessary firstly to consider potential yield and output data, and then to relate that to known resource availabilities and to resource use efficiency by bamboo stands in the face of varying input availabilities.

Expected bamboo yields

Bamboo is best known for its fast growth rate. It can produce harvestable culms within 4–7 years of planting, which subsequently can be harvested annually. For this reason, it is expected that in the future, the major demand for bamboo will be for timber substitution more than for edible shoots. Recognising this potential, in recent years, there has been increasing documentation of bamboo productivity (Isagi 1994; Isagi et al. 1997; Kleinhenz and Midmore 2001; Hunter and Wu 2002; Wang 2004; Castaneda-Mendoza et al. 2005; Midmore 2009a).

Focusing on the above-ground culm biomass, but excluding data for branches and leaves (and data that appear erroneous), the above-ground culm weight of the highest-yielding bamboo stands (c. 150 t/ha) is similar to that of average forest tree stands (100–160 t/ha), but does not match that of the very high values attained by some tree stands (300–1,700 t/ha; Hunter and Wu 2002). In contrast to trees that can accumulate biomass over long periods through radial and vertical extension of stems (trunks), bamboo culms lay down most of their biomass within their first year of growth, largely from current assimilation but also from redistribution from older culms and rhizomes (Magel et al. 2006), and die off after a maximum of 8–10 years, resulting in a decline in biomass of individual culms over long periods. Isagi (1994) referred to this as the biomass accumulation ratio (biomass/net annual production) and showed it to be 4.66 for a stand of *Phyllostachys bambusoides* in Japan.

Culms on average comprise c. 75-83% of total aboveground biomass, branches *c*. 12-15% and leaves *c*. 5-7%. On an annual basis, above-ground culm growth rates (fresh weight) of 10–30 t/ha/year have been reported (summarised by Kleinhenz and Midmore 2001), which is in line with those of woody species (Hunter and Wu 2002). Although one report with *Bambusa bambos* mentions 47 t/ha/year, productivity of bamboo on an annual basis is generally no greater than that of woody species, and bamboo is no more efficient at sequestering carbon than are woody species. Below the ground, bamboo sequesters carbon in the form of rhizomes, and below-ground biomass is greater proportionately for monopodial (running) species at c. 43% of total biomass compared to c. 31% for sympodial (clumping) species (Kleinhenz and Midmore 2001). The rhizome therefore represents an important sink for sequestered carbon but, according to Hunter and Wu (2002), this sink is no larger than that of woody trees. One advantage of bamboo over trees is that culms can be harvested much sooner than trunks of woody species (Figure 1) and another is that they can be harvested on an annual basis without the environmental consequences of clear-fell. Given that culms can be harvested on an annual basis, inter-culm competition for light is lessened, and younger culms, those with greater photosynthetic efficiency, gain greater access to light, supporting therefore faster growth rates. This is evident in Zhu et al. (2009) who show the drop in light interception by the canopy when older culms are harvested and the capture of that light by younger culms soon thereafter. The effect on biomass is marked. For example, net annual biomass production of 9.3 t/ha per year in 12-15 year old Dendrocalamus asper was raised to 26.3 t/ha per year one year after culms >4 years of age were removed from the clumps (Kao and Chang, 1989).

Removal of all culms at harvest represents removal of c. 150 kg N, 30 kg P and 260 kg K per hectare, leaving between 25 to 70% of those amounts in the rhizomes (Kleinhenz and Midmore 2001). Exceptionally, higher values up to five times these have been reported. On an annual basis, with culm yields of on average 13 t/ha/yr c 36 kg N, 9 kg P and 63 kg K are removed per hectare, but with culm yields possibly four times these values much more would be removed.

Leaf litter annually provides between 13-22% of the total NPK in total biomass, when stands are 6 years or older, and some is taken up for incorporation into new leaves which are the major sinks for nutrients. The resorption efficiency is higher for K (c. 43%) less for P (37%) and least for N (19%) (Embaye et al. 2005). Internal recycling is important for bamboo to make efficient use of nutrients, as is the ability to take up nutrients from a decomposing litter mass (Das and Chaturvedi, 2006). Nevertheless, without nutrient inputs the soil nutrient resource declines, as illustrated by data of Wu et al. (2006) showing that total soil N decreased by 5.2% and available P by 15% following 3 years continuous cropping with *Phyllostachys iridescens*.

Shoot harvests represent a smaller nutrient sink than culm harvests. For example, nutrients removed in fresh shoots (on average 16 t/ha/year yield; 5-10% dry weight; 4.0, 0.6, and 4.0% N, P, and K) average at 49, 7, and 49 kg N, P, and K/ha/year. In stands managed for optimal shoot production a significant amount of biomass and nutrients are removed in shoot and culm harvests – about 85, 16, and 112 kg N, P and K/ha/year are removed when bamboo is grown for average shoot and timber yields Kleinhenz and Midmore 2001). Shoot yields reported to reach 40 t/ha per year (Pan 1986) would considerably increase the demand for nutrients.

A series of field experiments have been conducted in Australia and the Philippines (Midmore et al. 1998; Midmore and Kleinhenz 2000; Kleinhenz and Midmore 2001, 2002) and more recently (Midmore 2009a). In the latter, best practice was imposed as a 'control' treatment, and then in other treatments omitting one or other practice (for example, omit fertiliser and/or irrigation, omit the thinning regime) to study the impacts upon shoot and culm (pole) production. The following section draws heavily on the outcomes of the series of experiments conducted under project activities funded by the Australian Centre for International Agricultural Research, and published recently by Midmore (2009a).

Appropriate management practices for sustainable shoot production

Although a group of species with a long association with Asian cultures, bamboo in Australia was originally planted starting in the 1990s with a view to producing bamboo shoots to offset the importation of canned produce (Midmore 1998), and later to expand into rewarding export markets identified in Asia (Collins and Keiler 2005). In contrast, in the Philippines, bamboo is harvested mainly as a timber substitute, with only localised cultivation and use of shoots as a vegetable—indeed local ordinances often prohibit shoot harvests (Virtucio and Roxas 2003). In other Asian countries it is valued not only for timber, but also for fresh shoots especially in the hot summer monsoon season when other vegetable species are in short supply.

Management factors that influence shoot production (Kleinhenz and Midmore 2001 and many of the >200 cited references contained therein) fall mainly under irrigation, fertiliser, mulch and thinning regimes. Species has an overriding effect on shoot size, number and timing of production and some tentative conclusions are drawn from the experimental data published by Midmore (2009a).

Irrigation and rainfall

Supply of water to bamboo just before and during the shoot season has been recognised as an enhancing factor for the onset and continued production of shoots from running (monopodial, e.g. *Physostachys pubescens*) species of bamboo (Kleinhenz et al. 2003), and data from more recently reported experiments (Zhu et al. 2009; Malab et al. 2009) and others (e.g., Thanarak 1996) confirm this for clumping (sympodial) bamboo species.

For example, in the Philippines, at the two sites where irrigation was an experimental factor (Ilocos Norte and Capiz), irrigation increased the number of emerged shoots,; the effect was greatest if combined with fertiliser application (Malab et al. 2009; Marquez 2009). In an Australian site in Queensland (Zhu et al. 2009), a treatment of withholding irrigation was confounded by a complete absence of clump management and the combined effect of which was to significantly reduce the number and size of shoots that emerged. However, the major irrigation factor under investigation was that of testing the need for irrigation during the dry winter season. In Queensland, the water-use efficiency of shoot production was raised by 28% by omitting irrigation during winter (Zhu et al. 2009), and in the Northern Territory (NT; – Traynor and Midmore 2009) year-round irrigation was also shown not to be important for shoot production, provided it was supplied just before the anticipated shoot season—a 'date' characteristic to each species for reasons which remains a mystery. At one of the sites in the NT, the number of shoots was even greater in the treatment without winter irrigation than in the treatment supplied with irrigation throughout the year.

If winter temperature is low, clumping bamboo will not respond to winter irrigation in terms of shoot production.

Fertiliser

As for many other agricultural and horticultural crops, nutrient application rates, ratios between nutrients, schedules of nutrient application, form of fertilizer, and nutrient placement are equally important considerations in bamboo production. Since bamboo is a perennial crop, however, nutrient management schemes that have been developed for annual crops may not apply to it. Moreover, bamboo is grown for several products, and it is understandable that optimal fertilization will vary with purpose of cultivation. Due to increasing scarcity of resources in the future, there is a need to match efficient fertilizer use to sustained productivity, and to sustain favourable soil conditions over the short and long term.

Based on earlier research (Kleinhenz and Midmore 2002) and the response curves of percentage leaf nitrogen (% leaf N) to N application rate, it has been proposed that fertiliser N be added to ensure that % leaf N is maintained at close to 3%.

Application of fertiliser at these and even higher rates invariably allowed clumps to achieve high shoot yields (Zhu et al. 2009), consistently hastening not only the onset of shoot production (Traynor and Midmore 2009) as already seen by others (e.g., Thanarak 1996; Li et al. 1998), but also the rate of emergence and number of shoots. Even organic fertiliser has shown a small, but consistently positive response.

In Queensland, withholding N fertiliser led to significantly lower % leaf N than in fertilised treatments, the latter receiving an average yet unsustainable 700 kg N/year (Zhu et al. 2009). Leaf N declined during the shoot season, perhaps due to a within-clump dilution effect with the rapid growth of new culms and leaves during that period. Withholding N fertiliser may also lead to smaller (and unmarketable) shoots or reduce shoot number and therefore yield, depending upon species and location. The magnitude of the depressive effect of withholding N fertiliser on shoot production, both number and size, varies between years, especially without irrigation (Decipulo et al. 2009). Mortality was significantly lower in low N treatments than in other treatments (Marquez 2009).

Extensive research looking at the rates of N required to maintain % leaf N at c. 3% show that they are often uneconomic for shoot production and that a lower leaf N concentration is called for, specific to species and grower expectation.

Culm thinning practice

The intensity with which culms are removed from clumps, and reciprocally the number remaining, and the choice of culms harvested, governs the age structure of culms within a clump. To maximise early capture of light energy, some recommend leaving all culms in a clump until 4 years after planting (e.g., for *D. asper* – Thanarak 1996). It has become clear that for high yields of shoots to be harvested as a vegetable a bamboo stand should contain a high number of young culms (ideally only 1 or 2 years of age at the time of the shoot season). Older culms do not support nearly as many shoots per culm as do young culms (Malab et al. 2009). Indeed, in a high rainfall site in the NT of Australia, shoots selected for culm production at the beginning of the shoot season themselves produced edible shoots near the end of the same shoot season (Traynor and Midmore 2009). In a drier environment of Queensland, shoot production was greater when all early shoots were removed for sale, leaving only late-season shoots for culm production—possibly minimising the effect of apical dominance that may inhibit later shoot emergence. Likewise in the Philippine treatments with more young culms raised the productivity index (the number of shoots produced per standing culm – Malab et al. 2009), and in a rainfed site of Bukidnon, the standing culm density (SCD) of 10-10 (ten 1-year-old and ten 2-year-old culms) gave more shoots than the 6-6 treatment (Decipulo et al. 2009).

To be sustainable, the number of culms left to support the next year's shoot harvest must match the number of culms to be harvested on an annual basis – the duration (or lifespan) of culms between shooting and their harvest will depend upon the optimal total number to achieve full canopy cover and capture of light energy. For example, if 15 culms per clump represent the optimal number for such light capture, a clump could equally contain 5 one year old culms, 5 two year old and 5 three year old culms (a total of 15 culms at the time of shoot harvest) or 3 one year old culms, 3 two year, 3 three year, 3 four year and 3 five year old culms (again a total of 15 culms). The former would be preferable for shoot production systems (more younger culms) and the latter for pole or culm production (older culms are preferable for most purposes). Of interest, weight per harvested shoot was not affected by thinning regime in the NT, or by the spatial arrangement of standing culms in Queensland (widely spaced versus narrow spacing within a clump – Midmore 2009a).

Leaving all shoots to grow into culms causes congestion in the clumps, and constrains production of shoots in later years. For this reason, some minimal annual thinning of culms or shoots is necessary if clumps are to continue to produce shoots (and culms) on a sustained basis.

Species

Bamboo species harvested for shoots number less than 50, but even this number represents a great diversity in terms of possible management practices specific to each species. Shoot number per unit area in bamboo with large culm diameters (e.g., *D. asper*) are considerably fewer than in smaller-shoot-producing species *Bambusa oldhamii*. With clumps close to 10 years of age, the latter produce on average over 20 shoots per clump in optimally managed treatments in Queensland (Zhu et al. 2009). In contrast, the mature *Dendrocalamus asper* (giant bamboo) of Bukidnon produces few shoots, on average c. 1 shoot per standing culm (Decipulo et al 2009), but they are large if harvested for consumption (reaching 4.5 kg). Age of the clump also affects shoot number. Young clumps for example of *D. latiflorus* in the NT of Australia, aged between 3.5 and 4 years produced many shoots early on but fewer as the clumps aged (on average *c*. 40 shoots per clump in the first year of measurement, *c*. 30 in the second and *c*. 10 in the third year). However, the proportion of marketable shoots increased over time (Traynor and Midmore 2009).

Appropriate management practices for sustainable culm production

The same production inputs, water, nutrients and management of culm populations influence culm production and as for shoot production, species has an overriding influence on culm production, in terms of both numbers and size.

Irrigation

Withholding irrigation altogether (as compared to satisfying evapotranspiration demand) in an environment with barely 1500 mm of annual rainfall reduces biomass yield by 40% (Zhu et al. 2009), but that is confounded by also withholding fertiliser. The same effect was evident by withholding winter irrigation at another warmer site with similar rainfall – culm yield was reduced by 24% compared to full irrigation (Traynor and Midmore 2009). Irrigation throughout the year at only 50% of pan evaporation reduces culm yield by 15%, not as great as withholding all irrigation during the dry season. At another warmer site, on a lighter soil, the 50% irrigation treatment did not affect culm yield, although culm water use efficiency (WUE – based upon weight of culm per unit of irrigation) was double that of the 100% irrigation treatment (Traynor and Midmore 2009).

In similar trials in the Philippines, in one site in Capiz, neither lack of irrigation nor irrigation supplied only just before and during the shoot season reduced culm yield compared to the fully irrigated treatment (although both treatments had higher culm WUEs than the irrigated control – Marquez 2009). In another site with irrigation treatments, in Ilocos Norte, culms that experienced the reduced irrigation treatments were thinner in diameter and their biomass lower (Malab et al. 2009).

It has been suggested, based upon experimental data, that sympodial bamboos can dissipate up to 3300 mm/year rainfall equivalent (Kleinhenz and Midmore 2000), but c. 2000 mm/year offers the best returns in terms of water use efficiency, both for shoots (if concentrated just prior to and during the shoot season) and for culms.

Fertiliser

As mentioned earlier, nutrient application rates to ensure that leaf nitrogen remains at close to 3% are considered to be excessive, although bamboo has a great capacity to take up much available soil nitrogen – a luxury uptake (Kleinhenz and Midmore 2002). Much focus has been on N fertilizer (the most readily available nutrient, and with the lowest unit cost), but bamboo also responds to potassium, and the nutrient use efficiency if greater than that for nitrogen and phosphorous (Table 1).

In recent trials in the NT of Australia (Traynor and Midmore 2009), culm yield was unaffected by fertiliser application in the first year of measurement, and marginally enhanced in the second year – an indication that perhaps, even for a young plantation at full irrigation, clump water demand was not being met. In Queensland, the withholding of fertiliser reduced culm yield in a mature plantation by 40%, but this was confounded by the concomitant absence of irrigation (Zhu et al. 2009).

Similarly in recent trials in a rainfed site of Bukidnon (Decipulo et al. 2009), withholding fertiliser reduced culm yield considerably. Under irrigated conditions in Capiz, withholding fertiliser reduced culm yields by c. 40%, the effect being greater with application of mulch (Marquez 2009). Lack of fertiliser was also responsible for reduced culm diameter under irrigated conditions at Ilocos Norte, as it was under conditions of no management (i.e. no irrigation, fertiliser, mulch or clump cleaning – Malab et al. 2009).

Timing, placement and form of fertilizer also play an important role in bamboo responses, and these are discussed in detail by Kleinhenz and Midmore (2001). Split applications increase nutrient use efficiency, although no particular timing for application appears to be superior.

Culm thinning and species

The effect of culm thinning treatment on culm biomass is closely related to the effect of species. In small-diameter species such as *B. oldhamii* (Zhu et al. 2009), thinning of culms to leave only a small number (five) from year to year constrains culm yield potential (to c. 24 t/ha/year for 12–16-year-old clumps) compared to leaving all shoots and thinning the resulting less-than-1-year-old culms at the time of harvesting the 2.5–2.8-year-old culms (c. 33 t/ha, with one year reaching 47 t/ha). However, across treatments where shoots are removed during the shoot season, there was only a weak negative relationship between the number of shoots removed and culm biomass production. With younger (3.5–7.0-year-old) clumps of *D. latiflorus* in the NT of Australia, thinning treatments did not affect individual weight of culms; most likely because complete canopy closure had not occurred (Traynor and Midmore 2009). Hence, culm yield was a reflection of the number of culms harvested. Culm yield ranged from 3.5–3.7 to 6.8 t/ha/year for the treatments with SCD of 4-2-2, 2-2-2 and 4-4-4, respectively.

The commonly grown *B. blumeana* in Ilocos Norte in the Philippines only responds to thinning regime in terms of culm diameter; the lowest within-clump population (3-3 SCD) had the highest diameter, but otherwise yields were related to the number of harvested culms. The average culm yields ranged from 7 t/ha/year to slightly more than 10 t/ha/year, and reflected a probable yield constraint due to lack of water (Malab et al. 2009). The same species grown in Capiz, but harvested after 4–8 years from planting had much lower culm biomass yields (averaging 1.8–5.6 t/ha/year over the ages of 6–8 years) and culm yield was depressed when culms were retained to be harvested at 4 years of age (Marquez 2009). Culm numbers harvested were low, and culms were quite thin. Yields were, however, still increasing over time, with yields for 8-year-old clumps ranging across treatments from 7 to 13 t/ha.

With average culm dry weight yields of c. 44 t/ha/year over 3 years, yield of *D. asper* in Bukidnon (Decipulo et al. 2009) was greatest in the treatment that retained the higher number of culms (80 t/ha/year, 10-10 SCD) and least in the treatment with least culms retained (22 t/ha/year, 3-3 SCD). This emphasises the close relationship between annual biomass production and number of culms removed per year. Quite clearly leaving many culms for timber production is at variance with harvesting many shoots as a vegetable. Species with smaller sized shoots are those that lend themselves best for the dual purpose of producing shoots and timber. Our data

(Midmore 2009b) suggest that larger culm diameter species are better suited to timber production only, but such a conclusion maybe confounded with site effects. Definitive large scale experiments maintained for a number of decades are still needed to confirm or otherwise these conclusions.

Sustainable management practices for optimal culm quality

From an economic perspective, in traditional forestry, short rotations are preferred over longer rotations, as are silvicultural practices that favour fast growth, but these may be offset by reductions in physical and mechanical properties of timber and lumber grade recovery. Across two species studied in the Philippines, *D. asper* and *B. blumeana* (Alipon et al. 2009), physical and mechanical properties, such as relative density and moisture content, were not generally significantly affected by the imposition of silvicultural treatments. However, inherent differences between species were marked. Strength properties were still improving in culms older than 3 or 4 years in *B. blumeana*, but in *D. asper* those of 1-2-year-old culms were equivalent to those of 2-3-year-old culms. *D. asper*, if it were to be used for construction purposes, could be harvested at close to 2 years of age, whereas culms of *B. blumeana* should be at least 3 years old and ideally older (Alipon et al. 2009).

For *B. blumeana*, the treatment that led to the oldest culms at harvest (4–5 years of age) overall resulted in the most suitable culms for construction or housing purposes (but that treatment had inferior shoot production compared to the well-managed control treatment with harvest of culms at a younger age).

For *D. asper*, the treatment that gave highest biomass (10-10 SCD) had comparable strength to the untreated clumps but pulping characteristics were inferior.

Conclusions

Bamboo yields respond to silvicultural practices, both in terms of shoot number and yield and biomass production, and fine-tuning is necessary for optimal input:output relationships. However, data collected on the physical and mechanical properties of culms from different silvicultural practices are important from a practical perspective: managing clumps for sustainable shoot or timber productions does not appear to seriously interfere with the intended use of culms. However, differences between species and treatments that affect the ages of culms at harvest are important considerations when choosing bamboo production practices.

Acknowledgements

I thank all of my co-researchers for their input into the experiments and literature reviews that form the basis for this publication.

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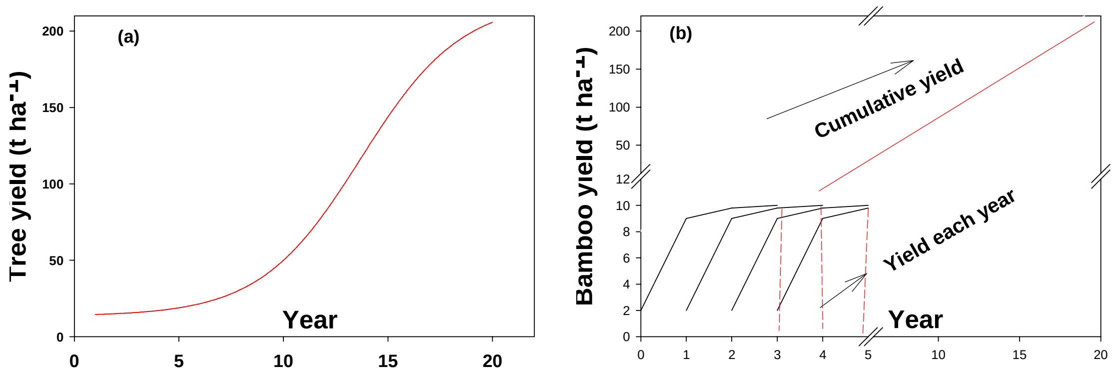

Figure 1. Comparative analysis of (a) one-off harvest of one tree trunk at 20 years and (b) annual harvests of culms from bamboo. From Midmore 2009a [with Permission]

Table 1 Average fertilizer-use efficiency of N, P and K in bamboo production for shoots and timber

	Fertiliser-use efficiency (t yield / kg nutrient)		
	Bamboo product		
Nutrient	Shoots	Timber	Average
N	0.03	0.17	0.13
P	0.04	0.02	0.02
K	0.08	0.54	0.45

Data from Kleinhenz and Midmore (2001)

Bamboo Resource and Policy in Mizoram, India

Mitsuhiro Nose
Research Institute for Humanity and Nature, Kyoto, Japan

Abstract

Bamboo resource is typical renewable and important material for local dwelling people. India is rich in its resource and Mizoram is specific state for growing stock and usage. In this study, the operational system of bamboo policies and administrative organization is examined to use the resources fluently in case bamboo flowering would occur. According to the statistical information, Mizoram was remarkably large amount resources per capita in India. There was so much bamboo area in north east divisions out of state. Two processing plants already established in Mizoram but full operation was the future subject in 2009. Bamboo policies already came into force and invested a large amount of fund as Centrally Sponsored Scheme. It is pointed out that three problems to resolve are left for providing the benefit from bamboo in the near future. Collect and use of statistical information, collaborate with departments of State Government in terms of bamboo use, and incorporate with the results of research activity on governmental policy operation.

Keywords: India, Mizoram, bamboo policy, operation, system

Introduction

The population has integrated to urban area, whereas rural area decreased in population all over the world. It is true the urban area concentrated the materialistic wealth for living people who immigrated from rural area. Various materials brought us convenient life while the wealth supported by large amount of exhausted resources that wouldn't last so long. But though some of local resources used for productive activities and daily life continuously by many local dwellers, they can't be exhausted under considering the carrying capacity. Especially, cyclic resources are important for sustainable development and society that is a key factor of future generation. This concept required the precondition of using renewable resource such as vegetable matter.

Bamboo belongs to the *Gramineae* family and has about 90 genera with over 1,200 species, and is naturally distributed in the tropical and subtropical belt between approximately 46° north and 47° south latitude, commonly found in Africa, Asia and Central and South America (Lobovikov, et al., 2007). India, China and Myanmar have 19.8 million hectares of bamboo reserves which is nearly 80% of the world's bamboo forests; of this India's share's is 45% (Nath, et al., 2008). It was pointed that India was the second richest country in bamboo genetic resources after China (Behari, 2006). However, According to the latest statistics, the major bamboo producing countries are India, followed by China, Indonesia and the Lao People's Democratic Republic (Lobovikov, et al., 2007).

Bamboo has called the poorperson's gift to mankind and the quality and availability both caused and effects in the larger socio-cultural and economic dimensions of a community (Behari, 2006). It has been estimated that the combined value of international and commercial consumption of bamboo is to the tune of US $ 10 billion in the world (Borah, et al., 2008). Such a large number of economic impact on results in important resources for local dwelling people who are easy to approach and use. The over-exploitation of timber also focused research on bamboo production, cultivation and utilization in recent years (Rao, et al., 2008). Therefore, bamboo is worth for thinking the way of usage as a large amount of renewable local resources.

Research purpose and method

Bamboo is used in domestic needs for house construction, fuel, fodder, food, tools, religious ceremony, and previous study already analyze the resource, physical characteristics, utility, market values and propagation success in Manipur, India (Singh, et al., 2003). It is extremely versatile, strong, renewable and environment friendly plant species (Nath, et al., 2008). In order to use this useful resource, it would be needed the financial support of administrative sector and its operation of local people, because the government has the power to tax the primary products or subsidize a process (Chundamannil, 1990), and it is critical problem for local area to accept the related policies. In India, the National Bamboo Mission (NBM) provides for resource creation right from nursery state to high-end value additions and marketing of bamboo products (Gupta, 2008). Mizoram state also established original bamboo policy in 2002 under the rich in bamboo forest (Bamboo Development Cell, 2004). Moreover, as it is predicted before, the gregarious bamboo flowering occurred and has economic impact on the people of this state (Lalnunmawia, et al., 2005). Especially, the people who depend on the bamboo resources will have faced serious problem.

In this paper, the bamboo resource of Mizoram was identified in India through analyzing of bamboo policies and contents of them. The operational system of policies and administrative organization is also examined to use the resources fluently even if bamboo flowering would occur.

Bamboo Resources

The grand total of bamboo area was estimated 96,071km^2 and the percentage share of it was 14.2% compared with forest area (Table 1). As shown in this table, Mizoram was 49.3% relatively larger bamboo area than other states. These states amounted to 84.5% of bamboo area in India and 4 North East states contain this list. It was indicated that bamboo resources were unevenly distributed.

Table 1. Forest and bamboo area in India

States	Bamboo Area (Sq. km)	Forest Area (Sq. km)	Percentage Share (%)	Per Capita (person/hectare)
Maharashtra	14,428	47,476	30.4	0.01
Chhattisgarh	11,521	55,863	20.6	0.05
Madhya Pradesh	9,508	76,013	12.5	0.02
Mizoram	9,210	18,684	49.3	1.04
Assam	8,214	27,645	29.7	0.03
Andohra Pradesh	6,598	44,372	14.9	0.01
Orissa	6,353	48,374	13.1	0.02
Karnataka	5,976	35,251	17.0	0.01
Arunachal Pradesh	5,714	67,777	8.4	0.52
Manipur	3,692	17,086	21.6	0.17
Sub Total	81,214	438,541	18.5	0.02
Grand Total	96,071	677,088	14.2	0.01

Note: The list arranges top ten state of bamboo area.

Source: Rai, et al.(1998), Forest Survey of India (2005)

Table 2 Distribution of bamboo area by Forest Division

Name of Forest Division	Geographical Area (Sq. km)	Bamboo Area (Sq. km)	Bamboo Area as % of Geographical Area
Aizawl	1,635	790	48.3
Champhai	3,496	461	13.2
Darlawn	1,538	871	56.6
Kawrthah	790	515	65.2
Kolasib	1,559	973	62.4
Mamit	1,504	894	59.4
N. Vanlaiphai	1,009	495	49.0
Thenzawl	2,335	1,415	60.6
Northern	13,866	6,413	46.2
Chhimtuipui	3,459	629	18.2
Lunglei	1,623	451	27.8
Tibung	1,139	330	29.0
Southern	6,221	1,409	22.7
Total	20,087	7,822	38.9

Source: Department of Environment & Forests (2002, 2003)

Bamboo area per capita also was shown following table and Mizoram was remarkably large amount that doubled by Arunachal Pradesh of North East.

The inventory work has been taken up for rapid assessment of bamboo resources of Mizoram in 2000 (Department of Environment & Forests, 2002). A joint project has conducted by Environment & Forest

Department and Forest Survey of India in order to collect the resource data. According to the division wise distribution, bamboo area was larger northern part than southern part (Table 2). There was so much bamboo area in north east divisions The data of bamboo area in Mizoram was differed from both tables, because of the difference of indicator and criteria on land use.

Bamboo Use

Bamboo is used for construction materials, charcoal and vinegar, handicraft, paper pulp, and so on. According to the survey in Karnataka, 49% of bamboo is used for making agricultural implements whereas the remaining 51% is used for other purposes (Rao, et al., 2008). There is no statistical data or reliable information of bamboo use in Mirzoram, and the following products of bamboo are amenable to industrial development (Bamboo Development Cell, 2004).

1) Bamboo laminated boards and flooring

2) Bamboo ply board (strip board and mat board and applications)

3) Reconstituted bamboo wood

4) Bamboo charcoal, and vinegar

5) Bamboo shoot

Actually, there are two processing plants established in Sairang and Lengpui. Bamboo flooring board industry in Sairang was jointly developed by Bamboo Development Agency, Venus Bamboo Products Ltd.in West Bengal, and Boarke Machine Company in Taiwan (Department of Industries, 2009). Department of Industry invested the financial support to development of bamboo-based Industries. Though a lot of administrative expenditure had already been expensed, the plant hadn’t operated yet hearing from a staff of government in February 2009.

Bamboo processing plant needed some resources for operating. The bamboo stock has been delineated on map with the help of natural and artificial features (Department of Environment & Forests, 2002). Unfortunately, though there is no information of usage, bamboo resources and annual yield was shown the following table 3. The growing stock ranged 800 to 4,000 thousand tons and average amount of each division were relatively larger southern part than northern part. Distribution of culms and annual yield are also large in southern division statistically. However, the yield was calculated by fixed percentage, and there is little reliability for the information.

Table 3. Division-wise bamboo resources and annual yield

Name of Forest Division	Growing Stock (1,000 tons)	Distribution of Culms (Millions)	Annual Yield (1,000 tons)	Annual Yield by Bamboo area (tons/hectare)
Aizawl	1,515	375	333	4.2
Champhai	805	199	177	3.8
Darlawn	2,063	516	454	5.2
Kawrthah	1,262	316	278	5.4
Kolasib	2,826	706	622	6.4
Mamit	2,711	678	597	6.7
N. Vanlaiphai	1,266	316	279	5.6
Thenzawl	3,821	955	841	5.9
Northern	16,269	4,061	3,580	5.6
Chhimtuipui	3,639	774	910	14.5
Lunglei	3,034	644	759	16.8
Tibung	2,318	438	579	17.6
Southern	8,991	1,856	2,248	15.9
Total	25,260	5,917	5,828	7.5

Source: Department of Environment & Forests (2002, 2003)

Bamboo Policy

In India, recently the potential of bamboo for developing it as one of the sunrise industries resulted in launching of bamboo development program by the Prime Minister in 1999 with a view to focus on the development of bamboo sector (Kerala Bamboo Mission, 2009). National Mission on Bamboo Application (NMBA) under Technology, Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology was established in 2002 to focus on the commercialization of value added applications in the bamboo sector. The National Bamboo Mission (NBM) is fully centrally Sponsored Scheme under the Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India (National Bamboo Mission, 2009).

Based on the activities to be carried out under the provisions of the NBM and depending on the continuance of the NBM beyond the X Plan period, after the detailed peer review to be carried out towards the end of 2007, the following targets are sought to be achieved. India has adopted plan economy since the independent and settled the five year’s finance of governmental sector. Total plantation area in two Plan periods amounts only 3% of bamboo area in India (Table 4). But this scheme will try to prepare for the opportunity from creation of resource, processing, and purchase of production. Though Xth Plan already finished in the fiscal year 2007, there is no information about the results of this scheme yet on website (National Bamboo Mission, 2009).

Table 4. Total target under NBM in whole India

Area Expansion	Xth Plan	XIth Plan	Total
Forest Area	16,000ha	72,000ha	88,000ha
Non-Forest Area	16,000ha	72,000ha	88,000ha
Nurseries - Centralized	160	185	345
Kisan	50	30	80
Mahila	50	30	80
Improvement of existing stock	7,500ha	28,500ha	36,000ha
Tissue Culture Units	1	2	3
Bamboo Bazaars	71	124	195
Retail Outlets (Show-Rooms) in 10 Metropolitan cities	3	7	10

Source: National Bamboo Mission (2009)

As described before, Mizoram has plenty of bamboo resources and gregarious flowering of bamboo (*Melocanna baccifera*) predicted that next cycle would occur in 2007 (Lalnumawia, 2005). Former Chief Minister Zoramthanga named "bamboo Minister" tried to build a new prosperity for Mizoram out of bamboo. Bamboo Policy of Mizoram 2002, which has been formulated the ecological and economic potentials of the bamboo resources. The aim of this policy was to use them as an industrial raw material for ensuring the sustainable development of local people. Specific policy in Forests Department is as follows (Department of Environment & Forests, 2006);

1) Bamboo Flowering and Famine Combat Scheme (BAFFACOS) with fund provision from the Planning Commission and Twelfth Finance Commission Award.

2) Management of gregarious flowering of bamboo in the Northeast which is Centrally Sponsored Scheme from the Ministry of Environment & Forests, Government of India.

3) The National Bamboo Mission which is a Centrally Sponsored Scheme from the Ministry of Agriculture, Government of India.

Two policies were established on the occasion of bamboo flowering and funded by federal government. The system of these schemes was similar to Joint Forest Management (JFM) implemented from the year 1990 (Masuda, et al., 2005). The subsidy of JFM granted directly to Forest Development Agency (FDA) at local area. Bamboo Development Agency also received the grant and the member at district level in Aizawl is shown the following figure 1. Each member has the chance to see the meeting each other irregularly and usually exchange the official document.

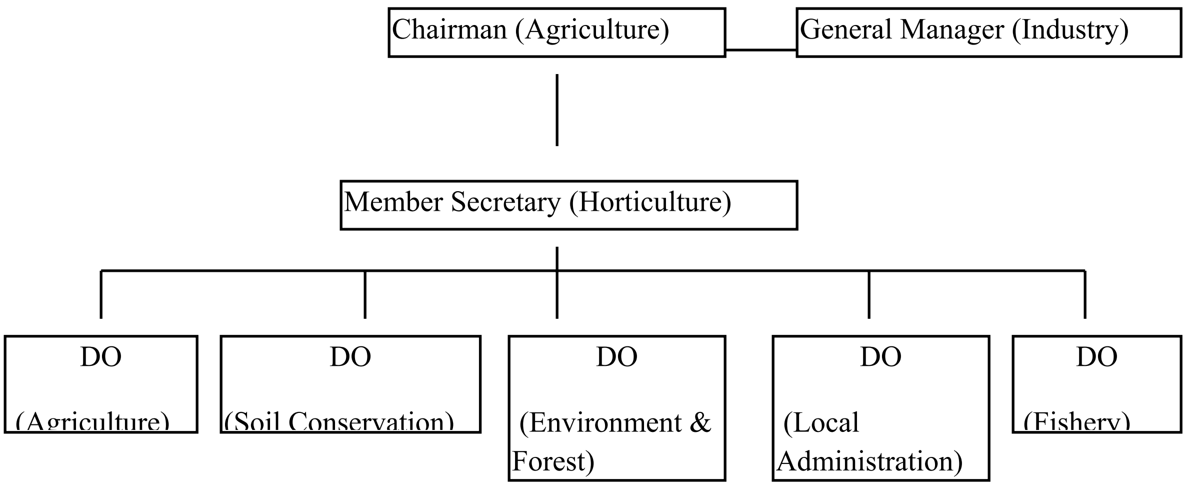

Figure 1. Bamboo Development Agency at Aizawl District

Source: Hearing Survey

Notes: “Do” is the abbreviation of District Officer.

There is no intention to change the bamboo species on NBM. However, introduction of improved varieties of bamboos from outside will be given more importance due to the short term economic benefit. But many bamboo area has been allotted for practice of shifting cultivation (Jhumming) every year. Allocation of land for “Jhumming” is mainly done by village council which is directly controlled by Local Administration Department. Moreover, bamboo flowering is the good opportunity for changing the bamboo species. In fact, part of bamboo area converted to agricultural land by local farmers and the recover of bamboo depends on the timing of farming according to the ecological research. At the same time, the new Government of Mizoram is trying to change the present practice of “Jhumming” by adopting “New Land Use Policy” by providing alternative occupations for cultivators (Das, 2004). The operation of district level NBM should be attracted more considerable attention for economic development.

Conclusions and future problems

This paper reviewed the bamboo resource, use, and policy in India and Mizoram. It was estimated that the bamboo resource was rich in Mizoram and used the growing stocks for some products. Bamboo policies already implemented and invested a large amount of fund from Central Government. But there are three problems to resolve in the near future for providing the benefit from bamboo.

1) Statistical information

Fundamental information is important for governmental staff to operate the policy. It is true that bamboo resources and uses are available, but district wise data calculated by fixed percentage not to reflect the actual situation. A lot of staff related with bamboo policies from state to district level. In fact, according to the hearing survey, each staff usually has collected quantitative information watching the charge of their area.

2) Collaboration of departments

As shown in figure 1, Bamboo Development Agency consists of several departments in Mizoram. From a viewpoint of actual material flow, resource management, processing, and consumption was controlled by each department. Besides, bamboo forest overlapped agricultural and forest area, the former is charged of Agriculture and Horticulture Department, the latter is charged of Environment & Forests Department. However, except for official meeting, it isn't clear that departments collaborate the aim of bamboo use and economic development respectively. The inspection of policy is also needed to check the results of policy because several people estimated the failure of bamboo plantation in 2001-2003. Effective system of bamboo policies is needed to use the resources successfully.

3) Results of study

Some researchers of Mizoram University and Japanese laboratories have conducted the study activities on the occasion of bamboo flowering. The results of these studies already published and reported the fragmentary information of ecological aspect of the phenomenon. Unfortunately, these efforts don't have to connect the actual operation of bamboo policy. Now is the time to provide the useful information of bamboo for researchers as the social responsibility of academic body.

A part of this research was supported by Grant-in-aid for scientific research (A) of Ministry of Education, Culture, Sports, Science and Technology, Japan (No. 17255007, representative: Shibata).

Acknowledgement

I must appreciate Dr. Shozo Shibata (Kyoto University) for inviting me the project and join the conference in this time. Hearing survey was conducted in cooperation with Mr. Lalmuanpuia (Department of Horticulture), Mr. Lalrinmawia (Department of Environment & Forest), Mr. Rosiama Vanchhong (Bamboo Development Cell), and Dr. Lalnunmawia (Mizoram University). The study was financially supported by Grants-in-Aid from the Ministry of Education, Culture, Sports, Science and Technology, Japan (20255011).

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Evaluation of Above Ground Biomass produced by *Dendrocalamus asper* in North Western Himalayan Region of India

Anjuli Agarwal* & J P Purwar
GBPUA&T Agricultural Research Station, Majhera
Garampani (Nainital) 263 135 Uttarakhand, India
*Corresponding Author

Abstract

Bamboos, ubiquitous in there distribution and having high productivity can be the ideal species to establish carbon sinks. Regression model was developed to predict the above ground biomass produced by *Dendrocalamus asper* in the mid hills of North Western Himalayan region of India. Biomass produced by *D. asper* was evaluated on fresh & dry weight basis at two aspects in two year old plantation. Micropropagated plants were used for the plantation. Biomass produced after the plantation was 17% higher at the hill top as compared to river bank on the fresh weight basis and 19.8 per cent higher on dry weight basis. Soil carbon status was also evaluated before and after the plantation. Per cent soil carbon also varied at the hill top and near the river bank. However, increase in soil carbon was noted at both the aspects two years after the plantation.

Introduction

Bamboo, due to its biological characteristic and growth habits, is not only an ideal economic investment but also has enormous potential for alleviating many environmental problems facing the world today. Bamboo, being the fastest growing plant removes more carbon from the atmosphere in any given period. Bamboo accumulates biomass quickly and offers the opportunity to maintain and increase carbon stocks through carbon sequestration. India has an estimated 8.96 million ha of bamboo forests with an annual production of only 4.5 million tones (Rawat & Pal 2004). Though, biomass production and carbon storage estimation has been done in various species of bamboo in India as well as in the world but biomass accumulation varies with environmental, anthropogenic and topographical factors from species to species. In India many studies on biomass production in bamboo have been conducted, in Madhya Pradesh on *Dendrocalamus strictus* (Singh & Singh 1999), Tamilnadu on *Bambusa bambos* (Shanmughavel & Francis 2001), in a dry deciduous forest of Uttar Pradesh on *D. strictus* (Singh et al. 2004) and in the central Himalayan Region on *Thamnocalamus spathiflorus* (Saxena et al. 2001). Himalayas are extremely rich in biodiversity and 'sustaining the Himalayan Ecosystem' is one of the missions under the National Action Plan on Climate Change. In Uttarakhand state of India, very large portion of the area is mountain region and there is a great pressure on the forests in the rural areas for timber and fodder because of which all around the villages there are lots of degraded lands. Bamboo plantations lauded for their ability to sequester carbon, can be an effective, cheaper, and income generating option to face the challenge of climate change and to fulfill the demand of livelihood for the forest dependent people. Out of few big bamboo species, which are able to grow at lower temperature, *Dendrocalamus asper* is one of the economically viable and socially useful species for cultivation in the mid hills of Himalayan region. No reports on biomass produced by *D. asper* are available from the mid hill region of India. The Present study was conducted to estimate the above ground biomass produced in *D. asper* plantation at two aspects (hill slope and river side) in the mid hills of Uttarakhand state of India.

Materials and Methods

The study was conducted during 2006-2008 at Agriculture Research Station, Majhera and Jarmila, Garampani, Nainital, Uttarakhand, India. Altitude, latitude and longitude of the study site are 1000 m (a.s.l.), 29º30.137', 79º28.784', respectively with two aspects i.e. top of hill and side of river bank. Maximum temperature, minimum temperature and maximum relative humidity were recorded 32.1ºC in the month of June, 4.83ºC in the month of January and 97.67 per cent in the month of August, respectively on the basis of mean of three years data. Annual rainfall of this site was 554.30 mm (Fig 1).

Methods as given here pertain to data collection procedure and analysis for biomass using acceptable linear equations for the encountered species in this study. Plants of *D. asper* were produced through micropropagation (Agarwal et al. 2008) and planted at ARS, Majhera at the top of the hill and at Jarmila by the side of the river bank of Kosi (spacing 5m) in the year 2006 (Fig 2). Sampling was done during December 2008 by selecting five plants from each site. Five poles of various diameter and height from each plant were harvested. Fresh weight of each pole with branch & leaves was taken and dry weight was recorded by drying at 70ºC for 72 hrs in an oven after harvesting. On the basis of fresh & dry weight linear regression equation was developed (Singh et al. 2009) to estimate the above ground biomass of *D. asper*. For the estimation of soil carbon, sampling was done according to Jackson (1973) at 0.5m and 1.0 m radial distance from the centre of the plant. Soil sampling for control was done before the bamboo plantation. Estimation of organic carbon was done by Soil testing laboratory (Uttarakhand Tea Development Board), Bhowali, Nainital (UK) India.

Results & Discussion

Model for the prediction of above ground biomass in *D. asper* was developed. With the help of this model, estimation of above ground biomass produced by *D. asper* at two aspects in the mid Himalayan region was done. The results indicated change in the biomass on the basis of fresh and dry weight. For fresh weight, height of the pole, girth to height at 1.0 m and 1.5 m affected the biomass by 99.8 per cent whereas in dry weight it was 97.6 per cent (Table 1).

Table 1: Linear relationship between above ground biomass of bamboo plant components (y Kg pole^{-1}) and height (x_1, m), girth to height at 1m (x_2, m) & girth to height at 1.5m (x_3, m).

S.N.	Biomass (Kg plant^{-1})	Intercept (a)	Slope (b_1)	Slope (b_2)	Slope (b_3)	R^2
1	Fresh weight	-1.30	0.463	-3.74	30.2	0.998
2	Dry Weight	-0.809	0.393	-6.68	18.43	0.976

Above ground biomass produced by *D. asper* at two aspects varied. Biomass produced in two years after the plantation was 17 per cent higher at the hill top as compared to river bank on the fresh weight basis. Average biomass produced was 542.24 kg ha^{-1} and 450.06 kg ha^{-1} at ARS Majhera and Jarmila, respectively. Dry weight was recorded approximately 63 per cent less than the fresh weight (Table 2). Average biomass on the basis of dry weight was 208.43 kg ha^{-1} at ARS Majhera which was 19.8 per cent higher than Jarmila (166.99 kg ha^{-1}).

Table 2: Above ground biomass produced by *D. asper* at two aspects

S.N.	Treatments	Average Biomass (Kg ha^{-1})*	
		ARS, Majhera (Hill Top)	Jarmila (River bank)
1	Fresh weight	542.24	450.06
2	Dry weight	208.43	166.99

* On the basis of one pole/plant

Soil carbon concentration in both the aspects was estimated up to 20 cm depth. Soil carbon of the hill top was found higher than the soil carbon of river bank. Negative correlation was found between the per cent soil carbon and radial distance from the centre of the plant (Table 3). Per cent soil carbon increased by 64-70 at ARS Majhera and 32-60 at Jarmila due to litter deposition (leaf fall) as compared to control.

Table 3: Soil carbon due to plantation of *D. asper*

S.N.	Radial distance from centre of plant	Per cent Organic carbon	
		ARS, Majhera (Hill Top)	Jarmila (River bank)
1	0.5 m	2.57	0.97
2	1.0 m	2.15	0.58
3	Control	0.78	0.39

There are few studies on biomass production by *D. asper*. Mathematical regression models are commonly practiced in determining the biomass of forest all over the world because it does not damage the growth of the measured forest (Lu Yong 1996). Similar model was developed through this study to estimate the above ground biomass production of *D. asper*. Kao & Chang (1989) have reported growth and biomass production in a *D. asper* plantation after establishing a 0.1ha plantation (spacing 5X5 m) for 16 yr in Taiwan in 1972. Maximum net annual production (estimated at 41.4 t/ha) was recorded during the 8th yr after planting. In the present study biomass produced by *D. asper* ranged from 0.17-0.21 t ha^{-1} in the two years of growth period. At the river bank, biomass produced was less as compared to hill top, probably, due to flood, quality of soil and less sunshine hours on per day basis.

Biomass production in the subsequent years would be directly correlated to the existing quantity of biomass in the previous year. Therefore, annual biomass production would increase substantially as the plant grows further. Increase in per cent soil carbon at both the sites, two years after the plantation indicated positive effect of plantation on soil health. More concentration of carbon at 0.5 m radial distance than 1.0 m shows that variation is caused by the smaller size of the canopy. Per cent carbon in the top layer of soil (0-10 cm) reported by Singh et al (2009) in a *Shorea robusta* forest of Central Himalaya varied from 1.79-2.03. Due to *D. asper* plantation per cent increase in carbon as compared to control at ARS Majhera is quite comparable with *Shorea robusta* forest.

Biomass prediction in the subsequent years of growth shall be helpful to measure the rate of carbon sequestration in a *D. asper* stand in the Himalayan region. However, multilocational studies shall be required to confirm the results of the present study.

Acknowledgement

Authors are thankful to Govind Ballabh Pant Himalayan Institute of Environment and Development, Kosi Katarmal, Almora (UK) India for financial assistance and Director Experiment Station, Govind Ballabh Pant University of Ag & Tech, Pantnagar, India for providing the necessary facilities.

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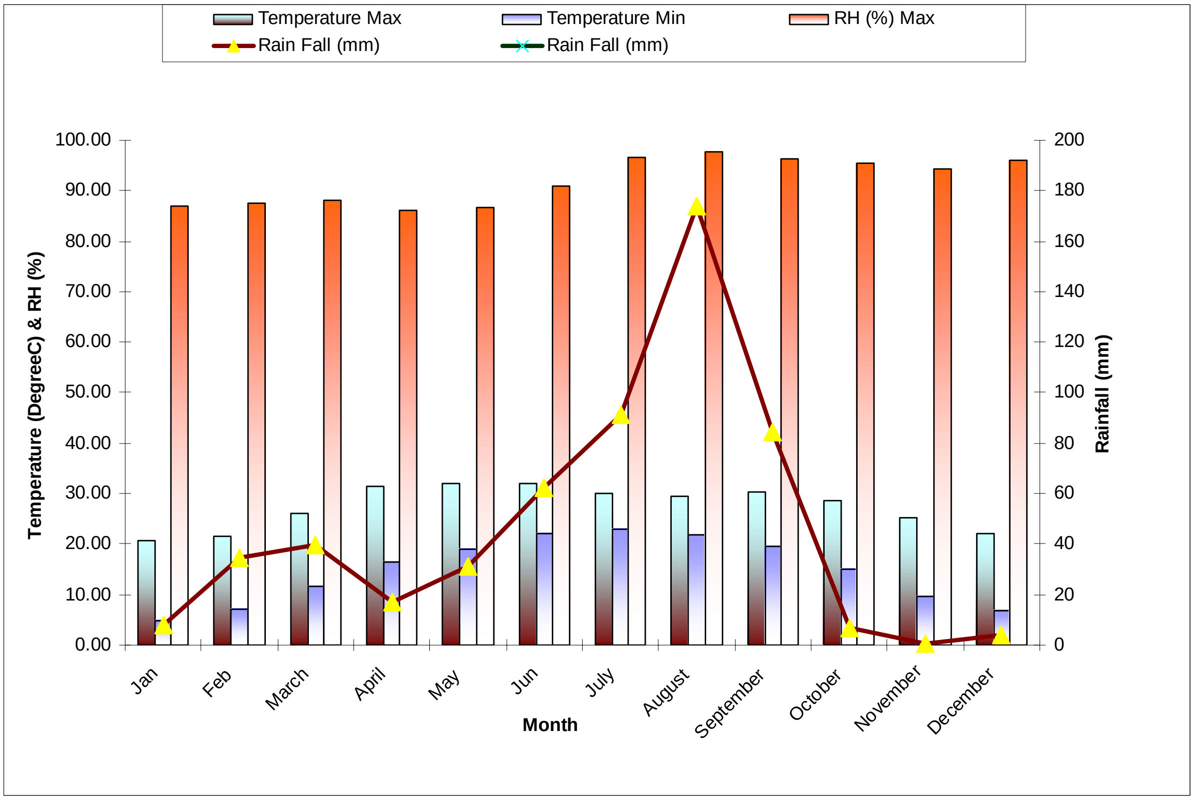

Fig 1. Mean weather parameters for the study site

Fig 2. Bamboo Plantation at hill top (a-b), at river bank (c-d)

Distribution and Assessment of Bamboo in South Kordofan State, Sudan

Ahmed M A Eldoma,[1] Eiman E. E. Diab [2] and Gamal Eldien M Abbakar[3]
[1]Sudan University for Science and Technology, Faculty of Forestry and Range Science, Khartoum, Sudan
[2] Institute of Environment and Natural Recourses, National Centre for Research, Khartoum, Sudan
[3] Forests National Corporation, South Kordofan State, Kadogli, Sudan.

Abstract

An inventory and assessment of bamboo was carried out in eight different sites in South Kordofan State of the Sudan. The common bamboo species growing in the area is *Oxytenanthera abyssinica*. However, Findings of the present study revealed the occurrence of a second bamboo species in some forest sites inventoried viz. *Sinarundinaria alpina.* It has not been commonly known before to be indigenous to South Kordofan. Results obtained indicate significant differences between the forest sites in stocking and other growth characteristics. In this connection, stocking ranged from 305 to 1100 clumps/ha. These differences may be attributed to over exploitation as related to proximity or remoteness from populated areas. The study emphasized the importance of further research work and development of the country's bamboo resource at large and particularly South Kordofan, the Blue Nile and South Darfur States where bamboos are naturally growing.

Introduction

Sudan is one of the largest African countries. It covers approximately 2.5 million km^2. It is located between latitude 4 - 22^0 N and Longitude 22 - 36^0 E. (Fig 1). The forest resources endowment of the country is highly diverse ranging from mere desert scrub at the northern frontiers to very rich savannah and pockets of tropical rain forest in the southern parts of the country. Even though Sudan is not rich in its forest resources but the fact remains that it is one of the African countries having potentialities of diversified forest products. Bamboo is one of several forest resources of the country that has received only very meager attention. Only very little and fragmented efforts were made to assess the bamboo resources of the country. The problem of proper management and maintenance of the remaining bamboo forest resource has been strongly emphasized in conjunction with the present day deterioration of the natural forests of the country as a result of over exploitation and desertification (Elhouri *et al*. 2001). Vast areas of natural forests of South Kordofan include bamboo as an integral part of them. Consequently, information is needed on the bamboo resource as a prerequisite for proper planning, sustainable management, maintenance and protection. Andrews (1950) and Khan (1966) have reported that *Oxytenathera abyssinica* is the only bamboo species that grows in the Sudan as indigenous species. This has been further supported by Kigomgo (1988), Elamin (1990) and Hashim (1997). However they reported that another bamboo species viz. *Sinarundinaria alpina* which was formerly known as (*Arundinaria alpina*) is naturally growing in the upper reaches of the Imatong mountains in Sothern Sudan. Phytogegraphically, bamboo in northern Sudan stretches from east to west covering vast areas of the Blue Nile, South Kordofan (Nuba Mountains) and parts of Sothern Dar fur. However its actual extent of distribution has not been documented as no substantial inventory of bamboo resources has been carried out.

The present work is the first attempt ever to assess the bamboo resource of this area using a planned inventory. Southern Kordofan state is considered one of the main production areas of bamboo in the Sudan and is reputed for its sizable production of bamboo according to official forest royalty records of the Forests National Corporation FNC, 2008).

Therefore the main objective of the present work was to assess the status of bamboo and define its geographical distribution within Southern Kordofan state.

The specific objectives were:

1. To undertake an inventory of the bamboo and delineate its occurrences in Southern Kordofan state in the Sudan.

2. To quantify the bamboo resource stocking and variations in eight different sites in Southern Kordofan state.

3. To identify the associated forest tree species within the bamboo occurrences.

Materials and Methods

Southern Kordofan State lies between latitude 9^{o} 13'- 12^{o} 38' N and longitude. 27^{o} 05' - 32^{o} E. (Fig.2.) Total land area amounts for about 13200 Km^2.

Eight sites were selected based on representation of the various parts of the state and according the past records, results of a pilot survey which was conducted before the actual inventory and primary data collected from the FNC and other sources.

The bamboo inventory was carried out in all the eight different forest sites within South Kordofan State using a random sampling procedure. Two base lines perpendicular to the contour were maintained in each inventoried site. Sample plots of 20 x100 m were laid down along each line at 50 m distance. Sample plots were replicated three times. Within each sample plot measurements were recoded for the number of clumps, clump circumference, culm height, culm diameter, and number of culms in the clump. In addition a count and listing of all forest tree species associated with bamboo in the sample plots were carried out.

Data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis Systems (SAS) Version 6.12 SAS (1996). Duncan New Multiple Range Test procedure was used to separate means (Duncan 1951; 1955).

Results

Analysis of variance showed significant differences ($p > 0.05$) between the sites for all measured variables. Table (1) depicts the differences between the eight studied sites in Southern Kordofan with respect to number of clumps, culm height, culm diameter, clump circumference and number of culms.

Table (1): Variation in number of clumps, culm height, culm diameter, clump circumference and number of culms at the different studied sites (per sample plot) in Southern Kordofan State, Sudan.

Forest Site	Number of Clumps	Culm height (m)	Culm diameter (cm)	Clump circumference (m)	Number of culms
Bonjae	97^{cd}	4.34^{cd}	1.93^{b}	3.891^{ab}	92^{a}
Omjamena	22^{e}	6.501^{a}	2.50^{a}	4.29^{ab}	81^{ab}
Caw	84^{d}	4.43^{cd}	1.17^{de}	4.27^{ab}	60^{bc}
Abu faida	161^{b}	4.75^{c}	1.31^{de}	4.29^{ab}	55^{c}
Amsharmot	134^{bc}	4.90^{bc}	1.47^{cd}	5.06^{a}	50^{c}
Eltogola	61^{d}	5.48^{b}	1.71^{bc}	4.45^{ab}	41^{c}
Alfras	123^{c}	3.16^{e}	1.22^{de}	3.08^{b}	37^{c}
Kokaya	220^{a}	4.03^{d}	1.06^{e}	3.60^{ab}	35^{c}

Means with the same letter in a column are not significantly different at $p > 0.05$ using Duncan New Multiple Range Test.

Number of Clumps

The eight forest sites in Southern Kordofan showed significant variability between them in the number of clumps per unit area. However, the number of clumps ranged from 22 to 220. The biggest number of clumps was recorded by Kokaya forest site (220) and the least number was recorded by Omjamaena forest site (22). Abufaida forest site ranked second with (161) but it is significantly smaller than Kokaya forest site which showed no significant differences with Amsharmot forest site (123). Further more, Caw forest site (84) and Eltogola forest site that recorded (61) showed no significant difference between them. In addition Bonjae forest site (97) and caw forest site (84) together with Eltogola forest site showed no significant differences between them.

Clump circumference

This characteristic showed the least variation between the studied sites. Amsharmot forest site recoded a significantly bigger circumference (5.06) m than only Alfras forest site (3.08) m but not the rest of the sites (Table 1.).

Culm Height

Omjamena forest site recorded significantly taller culms (6.50) m compared to the other sites and was followed by Eltogola forest site which recorded a significantly taller culms (5.48) m than the rest of the sites. However, Bonjae and Caw forest sites showed no significant difference between them recoding (4.34) and (4.43) m respectively. Generally, Alfaras forest site produced significantly shorter culms (3.16) m compared to the rest of the studied sites.

Culm diameter

The biggest culm diameter (2.5) cm was recorded in Omjamena forest site while the smallest culm diameter was produced by the Kokaya forest site (1.06) cm with significant differences between them. Bonjae forest site ranked second to omjamena forest site and it recorded (1.97) cm which was significantly different from the remainder of sites with the exception of Eltogola forest site (1.71) cm. However, the rest of the sites showed no significant differences between them in culm diameter.

Number of Culms

Bonjae and omjamena forest sites produced significantly bigger number of culms (92) and (81) respectively and were not significantly different from each other. These were followed by Caw forest site (60) with no significant difference with Omjamena but significantly different compared to Bonjae. The remainder of the sites did not show significant differences between them in the number of culms including Caw forest site as shown in Table (1)

Table (2). Approximate stocking of bamboo in the selected forest sites of South Kordofan, Sudan.

Forest Name	Approximate area/ha	Mean number of clumps/ 0.2 ha	Number of clumps/ha
Bonjae	607	97	485
Eltogola	485	22	305
Abu faida	10117	84	805
Amsharmot	8000	161	500
Caw	12000	134	420
Alfras	3600	61	615
Omjamena	4500	123	110
Kokaya	2800	220	1100
Total /average	42109	88	543

Table (2) shows the approximate areas of the forests sites where the bamboos inventory was conducted. The total area of the eight forest sites amounts approximately 42109 ha. The density of bamboo clumps ranged from

305 clumps /ha at Eltogola forest site to 1100 clumps /ha at Kokaya forest site. However, the average number of clumps for all studied sites of South Kordofan was estimated at around 543 clumps /ha.

Discussion

The present work showed that bamboo is naturally distributed in a disjuncted manner in South Kordofan State. The inventory covered eight forest sites but only two of them were reserved forests. The management plans of these forests excluded bamboo despite its clear importance as a commonly used market item. Variations between the eight sites in stocking may be attributed to proximity of some of the studied sites to highly populated areas which exerted heavy pressure and over exploitation of bamboo resource. This was shown clearly by the fact that the remotely located forest sites like Kokaya (1100), Abu Faida (850) and Alfaras (615) were better stocked compared to the sites located near towns and highly populated villages like Omjamena and Eltogola forest sites with (110) and (310) clumps/ha respectively. The prominent bamboo species in the areas is *Oxytenanthera abyssinica* according to Andrews (1950), but however, the present work have identified a new bamboo species growing naturally in some forest sites viz. *Sinarundinaria alpina.* Bamboo in some sites form almost pure stands, but generally found mixed with different forest tree associates. The most frequent associates of bamboo in all its ocurrencies in these sites are *Combretum* species and *Diospyrus messpiliformis*.

Tree species like *Anogeissus leiocarpus, Commiphora abyssinica Sclerocarya birrea* and *Dichrostachys cinerea* were found growing with bamboos in some of the inventoried sites but not as frequent as the combretum and diospyrus species mentioned above. These results are in agreement with the reports outlined by Mooney (1963), Williamson (1974), Jiping (1987) and Diab (2002) on tree species associated with bamboo in some tropical areas of Africa.

Results of this works indicate that the average stocking of the bamboo is 543 clumps/ha. This stocking seems to be quite reasonable compared to other naturally growing bamboo stands else where (297-325) clumps/ha. If these forest sites were carefully managed and protected for sustainable culm production they will certainly contribute to the welfare of rural people as an income generating activity and employment. In addition, research and development is timely needed to quantify and assess the bamboo resource, develop silvicultural and appropriate harvesting techniques and marketing opportunities. This work is recommended to be replicated at the national level especially at the Blue Nile and South Dar fur states where bamboos grow naturally at different sites but were not inventoried yet.

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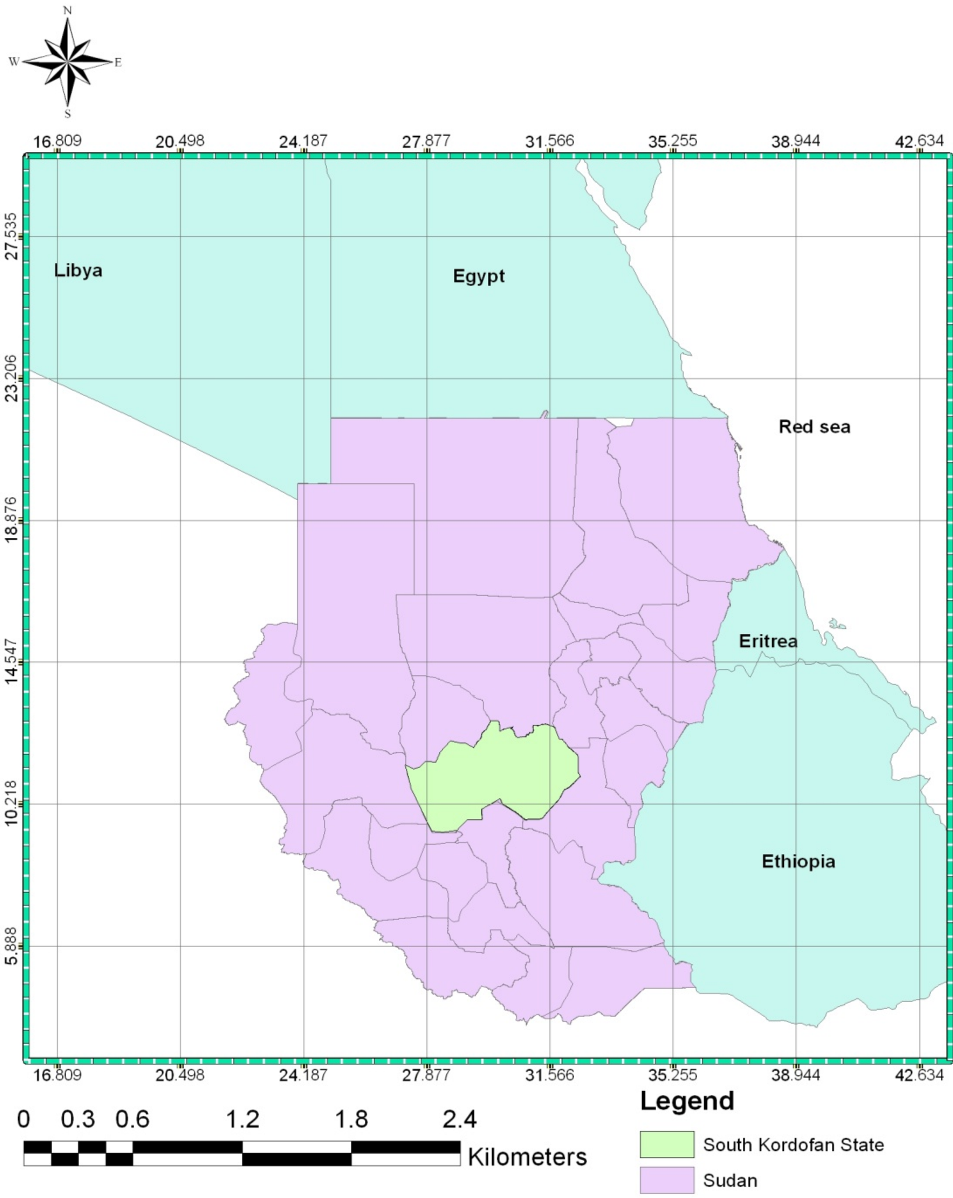

Figure 1. Map of the Sudan

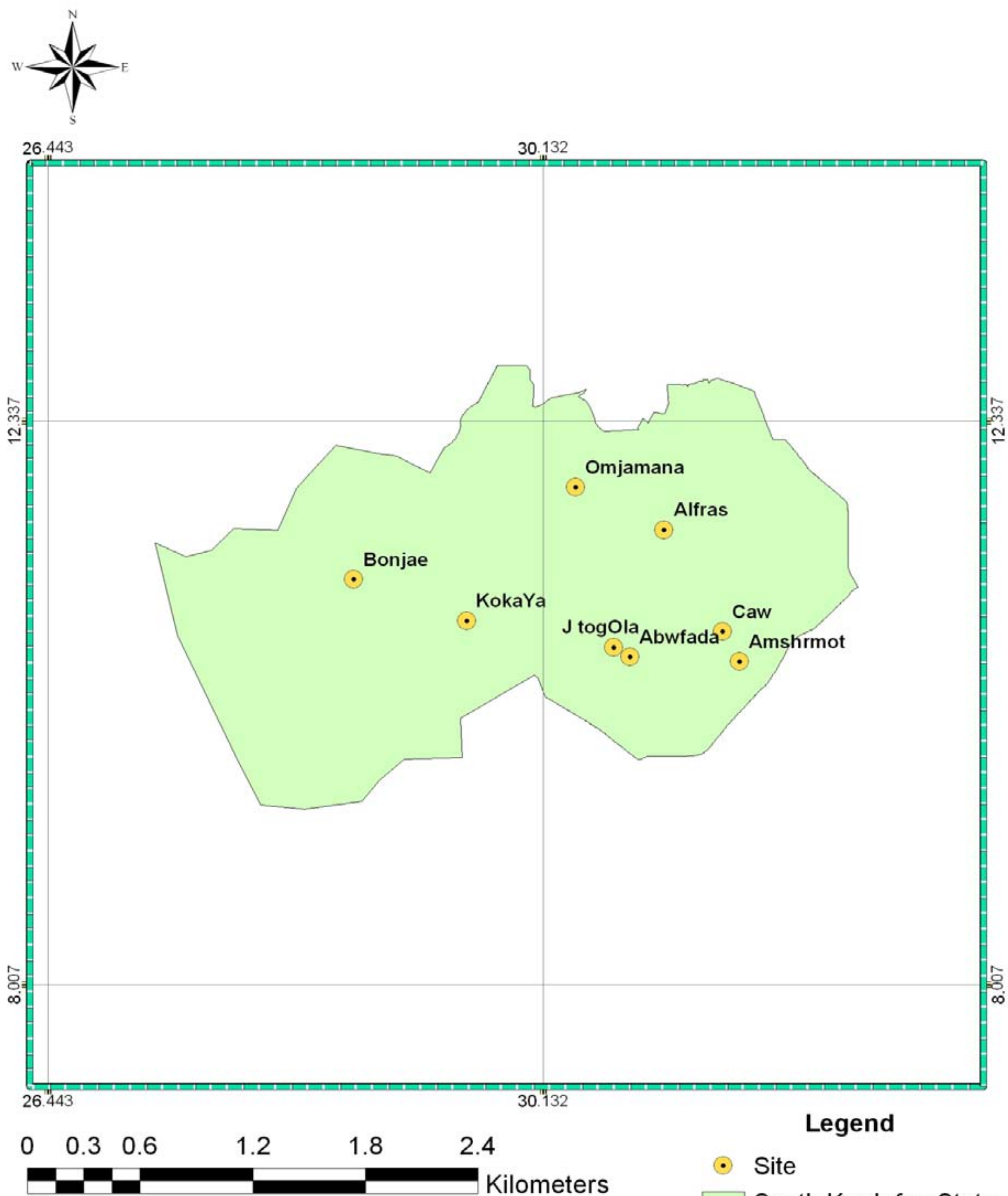

Figure 2. The Studied Bamboo Forest Sites in South Kordofan Sudan

The Preservation of Bamboo Forests undertaken by NPO Kitakyushu Biotope Network Group in Kitakyushu, Japan

Bart DEWANCKER[1], Toshiichi KUSABA[2]

[1] Associate Professor, The University of Kitakyushu, Faculty of Environmental Engineering

[2] Engineering Advisor, The University of Kitakyushu Faculty of Environmental Engineering

Abstract

In Japan, nearly all the bamboo forests are not maintained any longer, and because bamboos are very fast growing, this result in a rapid expanding spread of large bamboo forests. There are now devastating problems occurring for the bamboo forests, which are invading the adjacent forests and surrounding areas. Bamboo forest thinning had always been the solution to prevent damage of such spread of bamboo forests to other tree varieties and the surrounding fields. Especially since there is no longer a large demand for bamboo material, as well as the high loan costs in Japan, bamboo forest thinning is quite difficult to undertake. In Kitakyushu (Japan), the NPO Kitakyushu Biotope Network Group undertakes thinning of bamboo forests through participation of citizens, company employees, all of them are volunteers. Since November 2001, several environmental preservation activities were organized with the goal of preserving the bamboo forests in danger. Some of the main purposes of these activities were to make the citizens and the local government aware of the aggravating and severe problems and try to find also ways for the use of bamboo material. Already more than 2000 citizens have participated in these activities, and several hectares of bamboo forest are being maintained. Most of the bamboo material was chipped and the chipped bamboo material had been used for making of soil products.

Introduction - Problems which are facing the bamboo forests

In former times, bamboo has played a crucial role in the daily life of many Japanese people. Bamboo was used as building material, in fishery and agriculture, and as a basic material for making daily life tools and utensils. Moreover, bamboo sprouts were and still are a much loved food in Japan. Most probably, bamboo charcoal was used as energy resource as well. The change from an agricultural society into an industrial society, which means changes in life style, resulted in the fact that there was less need for bamboo material. Above that, the very high loan costs in Japan are another main reason for the import of cheaper bamboo sprouts and with bamboo prefabricated building material and other tools, mainly from China and other Asian countries, resulting in less demand for local bamboo. Since there is no longer any market for the local bamboo material, the bamboo forests cannot be maintained any longer (figure 1 and figure 2).

Figure 1: A not maintained bamboo forest

Figure 2: A maintained bamboo forest

Situation of the Bamboo Forests in Kitakyushu

The city of Kitakyushu is located in the western part of Japan on the island of Kyushu. Kitakyushu has one of the largest bamboo forest areas in Japan (city area: about 480 km^2); the total bamboo forest area is not exactly known but is estimated to cover about 1500 ha. In the south of Kitakyushu is located a place which is called Ouma, an area well-known in Japan for its bamboo sprouts. The Ouma bamboo sprouts are distributed all over Japan. Because there is still a large demand for the Ouma bamboo sprouts, the bamboo forest in this area are rather well maintained compared to bamboo forests in other parts of Kitakyushu which are not maintained at all.

Another part of the city, located in the northwest of Kitakyushu is the Wakamatsu ward. The Wakamatsu ward is a very rural not densely inhabited area, and an area with large bamboo forests. In Wakamatsu, most of the bamboo forests are not maintained. In former times, the Wakamatsu ward was an island. Still these days Wakamatsu ward is surrounded by water; in the north by the Hibiki Nada Sea, in the south and east by the Dokai bay, in the west by the Onga River, and in the southwest by the Egawa River. The Wakamatsu ward can be divided into 5 zones, as is shown on the map (figure 3).

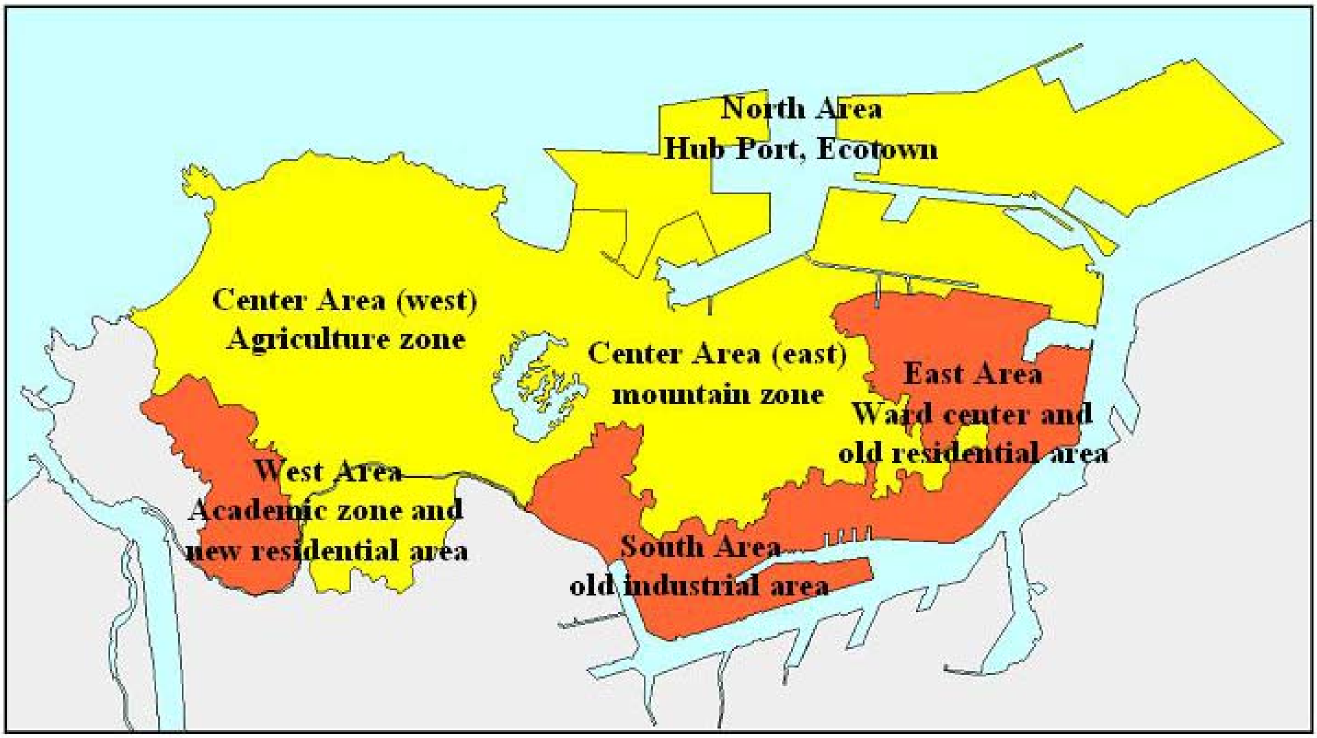

Figure . Map of the Wakamatsu Ward

The 5 zones are;

Zone 1: The old ward center, which is located in the eastern part of Wakamatsu. In this part of the ward are left many old buildings, some of them do have a high historical value.

Zone 2: In the south, an old industrial area along the northern shore of the Dokai bay.

Zone 3: In the west, a new residential area and academic zone, within the center of it the Kitakyushu Science and Research Park.

Zone 4: In the north, the Wakamatsu seashore area, with a new hub port and the so-called Ecotown, an industrial area where industries related to recycle techniques are located.

Zone 5: The most central part of the Wakamatsu ward has a rich abundant nature. This area can be split up in a western and eastern part. The western part is mainly occupied by agricultural land. The eastern part has plenty of beautiful mountains with the Ishimine Mountain and Takato Mountain as the one with the highest peaks. The bamboo forests are mainly situated in the zones 3 and 5 (figure 4).

Figure 4: the Ishimine Mountain and Takato Mountain

Bamboo Preservation through participation of local citizens in Kitakyushu

In recent years, the role and participation of local citizens in sustainable community planning has become more and more important because the improvement of our environment cannot any longer be realized only on a scientific level, but through participation of local government, local industries, research institutes and local grassroots organizations. Also the problem of thinning out and maintaining the bamboo forests must be undertaken through a good collaboration between bamboo forest owners, local government, local industry and the local citizens.

NPO Kitakyushu Biotope Network Group

The Kitakyushu Biotope Network Group has been created in July 2001. Members of the group consist of academics, company people, local government people, local citizens, students, etc. There are about 25 core members. Since June 2003, the Kitakyushu Biotope Network Group has become a Non Profit Organization (NPO). The main goal of the Kitakyushu Biotope Network Group is to work on issues of environmental protection, mainly dealing with preservation of nature in the urban and suburban area as well as dealing with topics of environmental education. The sustainable community planning activities undertaken by the NPO Kitakyushu Biotope Network Group can be divided into environmental preservation activities related to;

1) forest and bamboo forest preservation
2) river and seashore preservation
3) agriculture activities for children

Since 2001, the Kitakyushu Biotope Network Group has organized over 100 sustainable community planning activities. In this report only the activities related to bamboo forest preservations will be mentioned as is shown in table 1.

Table 1 List of bamboo related activities

Date	Name of the bamboo related event
10 Nov. 2001	2nd EPA: Bamboo Forest Preservation Project
29 April 2002	3rd EPA: Clean Up the Egawa River by use of a bamboo raft
19-22 Aug. 2002	5th EPA: First Bamboo Design Workshop
14 Sept. 2002	Junior Meister Course: Making of Bamboo Charcoal Part 1
12 Oct. 2002	Junior Meister Course: Making of Bamboo Charcoal Part 2
23 Nov. 2002	6th EPA: Bamboo Forest Preservation - International Collaboration
9 March 2003	9th EPA: Satoyama Preservation
29 Nov. 2003	Dream Cupid: Making of Bamboo Charcoal
12-14 Nov. 2004	17th EPA: Green Town Planning Workshop in the Kitakyushu Science and Research Park
20 Aug. 2005	Bamboo Craft Course for children
11 Sept. 2005	21st EPA: Fishing with bamboo pole in the Egawa river
3-6 Nov. 2005	23rd EPA: Second Bamboo Design Workshop [Shelter 3X3X3]
18 Feb. 2006	26th EPA: Egawa River and Dokai Bay Project Part 9: Water Purification of the Dokai Bay by using of bamboo
9 July 2006	28th EPA: 5 year Commemoration Project Part 1: Cooking Papa
17 July 2006	28th EPA: 5 year Commemoration Project Part 2: Cross the Dokai Bay with a bamboo raft
5, 6 Aug. 2006	28th EPA: 5 year Commemoration Project Part 3: Nagasaki Historical Road Bamboo Lantern Event
27 Aug. 2006	Bamboo Craft Course for children
14 Oct. 2006	Bamboo Craft Course for children
23 Nov. 2006	Bamboo Craft Course for children
10 Feb. 2007	31st EPA: Bamboo Preservation Event

2,3 June 2007	Bamboo Craft Course for children
18 Aug. 2007	Bamboo Craft Course for children
7,8 June 2008	Bamboo Craft Course for children
23 Aug. 2008	Bamboo Craft Course for children
29, 30 Nov. 2008	Bamboo Craft Course for foreign students

Note 1: EPA = Environmental Preservation Activities

Besides the environmental preservation activities (EPA) and other activities mentioned in table 1, bamboo forest maintenance activities are undertaken every second Saturday of each month. Since January 2004, except for the month of August, on every second Saturday of the month, a small group of citizens has started to preserve the bamboo forests in the area around the Kitakyushu Science and Research Park. The cut bamboos are chipped and these chips are used for soil making products, as well as for the making of bamboo charcoal. The cut bamboo material is also used in all the activities mentioned in table 1. A part of the bamboo material was also used for bamboo objects, small artistic objects made by the students of the University of Kitakyushu.

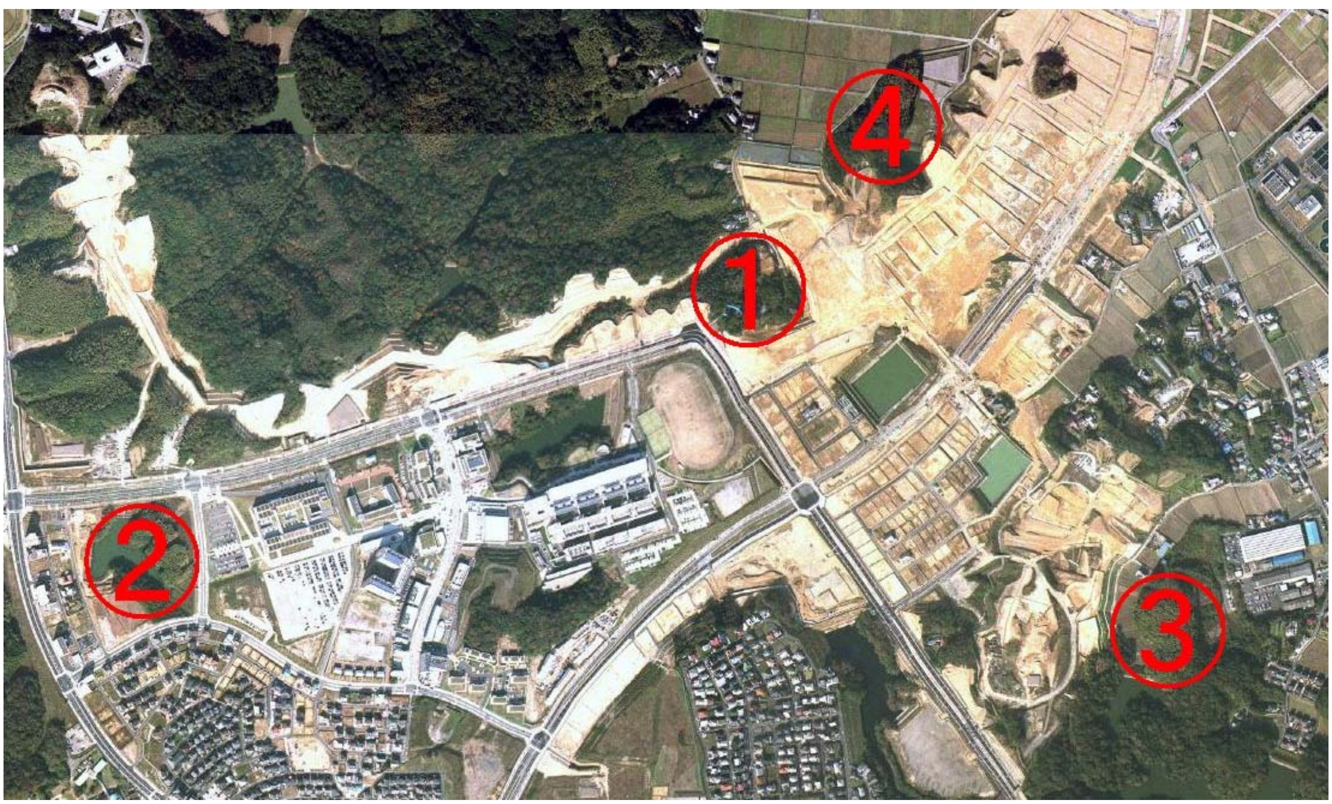

Figure 5: Area map of the Kitakyushu Science and Research Park

(Aerial photograph reference: Google Map)

In the area around the Kitakyushu Science and Research Park there are four forests which are maintained as is shown in table 2 and figure 5 and 6 (figure 5 and figure 6).

Forest 1; the Yatsurugi Shrine, a small shrine surrounded by a small forest, in this forest nearly all the bamboo has been cut away because in a shrine forest there was originally no bamboo.

Forest 2; the Hibikino South Park, a 4 ha large park, in the middle is a pond and around the pond is a forest and bamboo forests.

Forest 3; the Honji Conservation Area

Forest 4; the Hibikino North Park

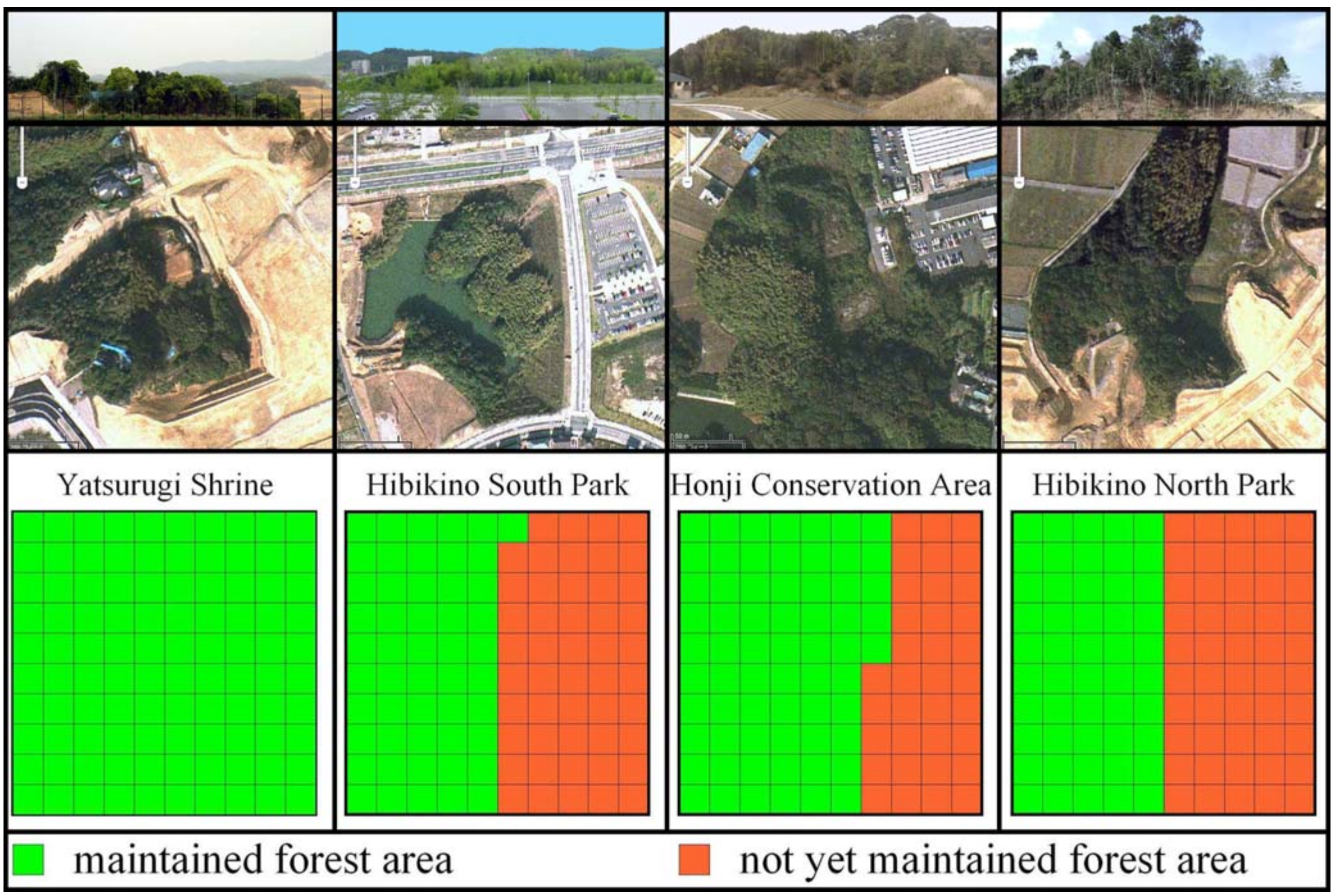

Figure 6: Yatsurugi Shrine, Hibikino South Park, Honji Conservation Area, Hibikino North Park

Table 2 Bamboo forest maintenance

	forest area (A)	bamboo forest area (B)	maintained area (C)	bamboo forest maintenance ratio (C/Bx100)
Yatsurugi Shrine	19,600 m^2	-	19,600m2	100%
Hibikino South Park	28,000 m^2	11,400m2	6,200 m2	54%
Honji Conservation Area	25,000 m^2	13,300m2	8,600 m2	65%
Hibikino North Park	21,000 m^2	7,800m2	3,900 m2	50%

There are three cases for the preservation of bamboo forests and adjacent forests;

Case 1: In case 1 the bamboos have invaded the adjacent forests. In that case all the bamboos are cut down. The main reason for that is because most of the trees died or nearly died because no sunlight infiltrates any longer the forest once bamboos have reached their full grown height.

Case 2: The zones with only bamboo are preserved the following way. First of all, the older bamboos are cut away. Afterwards thinning of the bamboo forest occurs, until a well balanced density has been reached. Depended on the place, 2 or 3, up to 10 and more bamboos are left on 3.3 m^2 (1 tsubo corresponds to 3.3 m^2, a Japanese area unit).

Case 3: The third way of preservation is keeping bamboos and normal trees together. The density of trees and bamboos vary from place to place. The infiltration of sunlight is one of the most important elements to decide the density of thinning the forest.

Due to the fact that all participants are non-professionals, these preservation and thinning methods cannot always be seen as the most appropriate ones (figure 7).

Figure 7: Cutting and carrying of the bamboos

Number of participants

The bamboo forest activities have started in 2001, and since January 2004, with a monthly average of about 37 people, 52 regularly organized maintenance activities were undertaken with a total of about 2000 participants as is shown in figure 8 (figure 8).

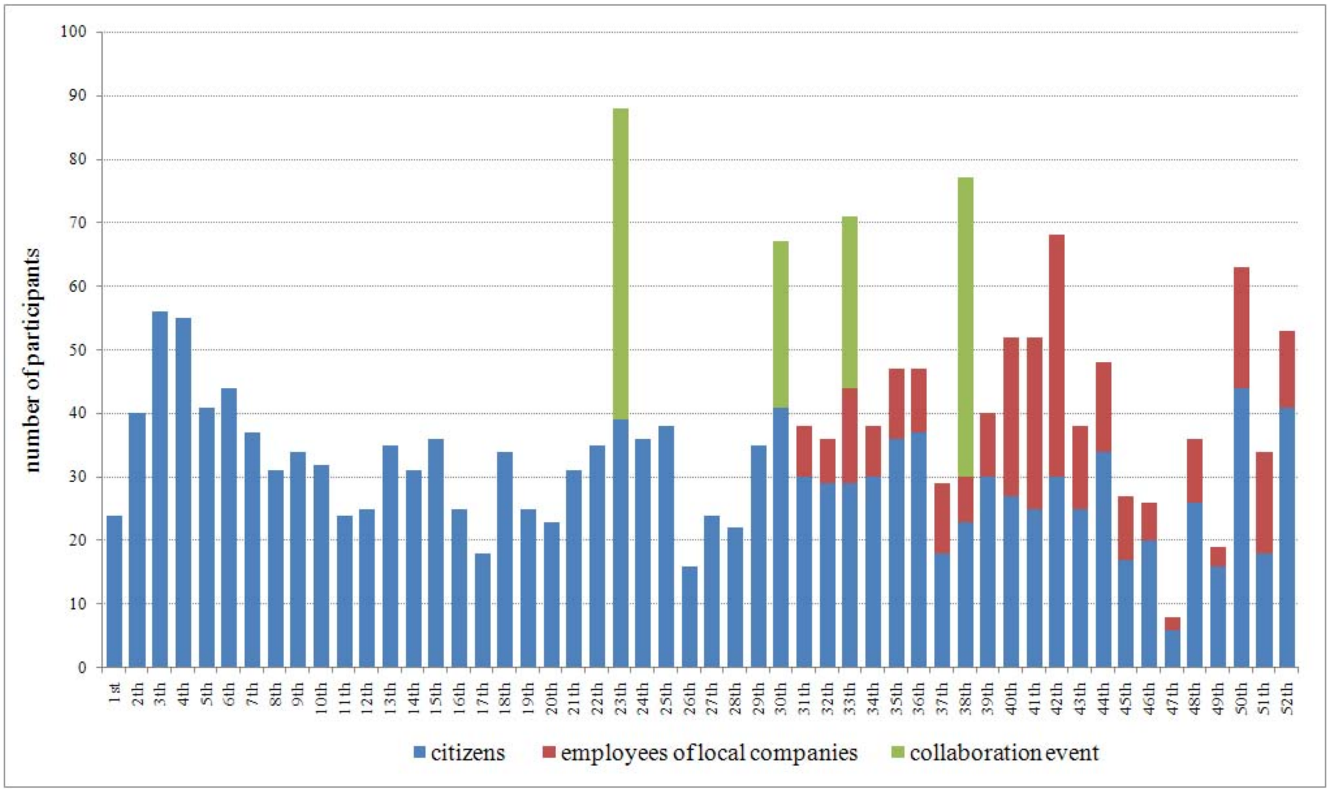

Figure 8: Number of participants

The first months of 2004, when the activities started, more than 50 participants attended the events, many people were interested but due to the hard labor work of cutting and carrying the bamboos, many participants attended only once or twice. The peak moments are events with more than 70 participants, events which are organized in collaboration with events organized by the city or by other organizations. Due to long lasting bad weather in 2006, the number of participants decreased. At the end of 2006, the employees of four local companies joined the group of volunteers. In Japan, Corporate Social Responsibility (CSR) has become very important and local companies are starting to join the bamboo forest preservation activities. Participating companies are; 1) Kowa Seiko Corporation, 2) Yaskawa Electric Corporation, 3) Duskin Corporation, 4) Hibikinada Development Corporation.

The age of the participants is not investigated, but we can see that there is a shift from mostly elderly participants in the beginning, to a more mixed age structure of participants. This can be explained by the fact that people working in the companies have joined. Moreover, nearly all participants were males, and since companies have joined the number of female participants has increased.

Conclusion

In this report the role of the NPO Kitakyushu Biotope Network Group in the preservation of bamboo forests has been explained. It can be said that the preservation of bamboo forest in Japan only can be solved through intense participation of local government, industries (companies CSR program), research institutes, local grassroots organizations, and NPO's etc. With over 100 activities, the NPO Kitakyushu Biotope Network Group has elaborated a lasting bamboo preservation project, these activities show a solution to let local citizens take part in solving bamboo forest problems. All activities attracted many participants, which mean that the citizens of Kitakyushu are concerned about the bamboo forests. In the future, it will be important to establish several bamboo preservation key areas, and make a network of these areas, so that the local citizens not only participate in one-day events but become members of these organized preservations projects and take more initiative in their own local area.

Performance of Exotic Bamboo Species in Kenya

Victor Brias

Abstract

During the period 7 August to 6 September 2006 the author analyzed the performance of trial plantations of exotic bamboo species that were established by the Kenya Forestry Research Institute (KEFRI) between 1988 to 1990. The objective of studying the KEFRI trial plantations was to analyze the trial plantations in various regions Kenya in order to provide up to date information on species to site matching, with specific focus on identifying suitable species for developing bamboo plantations in the Lake Region, Highlands and coastal regions of Kenya.

Observations and analyses of species performance and were made in 4 bamboo plantation trial plots located in Kakamega, Muguga, Gede and Jilore. Measurements and estimations of culm size, height, and clump density were made by selecting samples of various clumps of each species on each of the ‘ sites.

Since the climatic conditions of the trial sites differ significantly from the native habitat of the species, a strict methodology was needed for analyzing the data. A benchmarking system was used for gauging the relative performance of the species on the sites in relation to the known characteristics of the same species in their natural range in Asia. Since there was no record of culm weight of the various species planted, the author employed a mathematical method of calculation, which provides a rough estimation of the dry weight of culms.

The analytic results of the trial sites provides a rough assessment of the potential performance of the exotic bamboo species in selected areas of Kenya. Information on species to site matching was provided based on the observations and analyses.

Acknowledgements

The present study was originally conducted as part of the author’s assignment as a technical expert in bamboo plantations for the Eastern Africa Bamboo Project (EABP) funded by the Common Fund for Commodities (CFC), executed by the United Nations Industrial Development Organization (UNIDO), and supervised by the International Network for Bamboo and Rattan (INBAR). The author expresses his thanks to CFC, UNIDO, and INBAR for their permission to publish the study in this revised form.

The author also expresses his gratitude to Mr. Gordon Sigu of the Kenya Forestry Research Institute for his assistance in data collection and measurements on the field.

Background: KEFRI Trial Plantations

In 1988 the Kenya Forest Research Institute (KEFRI), through the initiative of Dr. Bernard Kigomo, started a bamboo research program that involved the establishment of trial plantations of exotic bamboo species in six locations within three regions of Kenya. The 6 trial plantations sites of KEFRI are located in (i) Kakamega and (ii) Siaya in the Lake Region, (iii) Muguga and (iv) Penon in the Highlands, and (v) Gede and (iv) Jilore in the coastal region.

Some of the bamboo planting materials that were used in the trials were obtained in Kenya but most of the germplasm was imported from Rwanda, Tanzania, Zimbabwe, India, Thailand, and Japan in the form of seeds and vegetative material. The germplasm was mass propagated at the KEFRI nursery in Muguga and subsequently planted in the trial sites between 1988 and 1990.

An initial study of the trials was made by KEFRI in 1995 and published by Dr. B. N. Kigomo and Mr. G. O. Sigu (1996). Their study provides details of the characteristics of the planting sites, the form (i.e., seeds, rhizomes, offsets, or cuttings) and provenance of the germplasm, the species planted in each site, as well as success or failure, and growth performance of each species per site.

Objectives and Expected Results of the Plantation Analyses

The objective of studying the KEFRI trial plantations was to analyze the trial plantations in various regions Kenya in order to provide up to date information on species to site matching, with specific focus on identifying suitable species for developing bamboo plantations in the Lake Region, Highlands and coastal regions of Kenya.

Due to time limitations and logistical constraints, only 4 out of the 6 KEFRI trials sites were studied, namely: Kakamega, Muguga, Gede and Jilore.

Since the trial sites at Siaya in the Lake Region and Penon in the Highlands were not visited, it was therefore not possible to analyze and compare the results of the trials plots in Penon to those of Muguga, nor to compare the results of the Kakamega trials to those of Siaya.

The characteristics of these sites included in this study are shown in Table 1.

Table 1: Characteristics of KEFRI Bamboo Trial Sites

Site	**KAKAMEGA**	**MUGUGA**	**GEDE**	**JILORE**
Region	Lake Region	Highlands	Coastal (Malindi)	Coastal (Malindi)
Coordinates	0°14'S / 36°38'E	1°54'S / 34°15'E	3°20'S / 40°5'E	3°12'S / 39°55'E
Altitude	1,675 m asl	2,050 m asl	50 m asl	80 m asl
Temperature (min)	17°C	11°C	22°C	24°C
Temperature (max)	33°C	28°C	33°C	34°C
Annual Rainfall	1100-1950 mm	900-1500 mm	900-1400 mm	550-1000 mm
Soils	Dark Brown Loams	Deep Dark Red Clay Loams	Sandy White Loams	Sandy-red compact sandy soils

Source: Kigomo & Sigu, 1996.

The trial sites of Kakamega and Muguga both have very fertile soils and high annual rainfall and are suitable for agriculture. The performance of bamboo species in Kakamega can be used as a basis for species selection in the Lake Region.

At at elevation of just over 2000 m above sea level, Muguga lies in the lower elevation range of Kenya's highlands. In areas located between 2,500-3,400m above sea level, the only bamboo species observed in Kenya is the indigenous species *Yushania alpina*. At an altitude of up to 2,400m (e.g. Olenguruone) the species *Bambusa vulgaris* 'Vitatta' is cultivated and grows vigorously. No other exotic species have been observed in Kenya above this altitude. The performance of exotic bamboo species in Muguga therefore provides an indication of suitable species in the lower elevation range of Kenya's highlands.

The trial sites in Kenya's coastal region, namely Gede and Jilore, have a much lower rainfall, but they are nevertheless suitable for several tropical bamboos. Some bamboos that performed poorly at Kakamega and Muguga, showed much better results at the coast. Despite the fact that there are no natural bamboo resources in the coast, there are initiatives to plant bamboo, especially to meet demands by the tourism industry. The analysis of the performance of bamboo species under the conditions in Gede and Jilore may therefore be useful for private farmers in the area.

General Observations and Species Planted

The KEFRI trial plantations have been neglected for many years. Lack of management, clump maintenance and harvesting and is evident in the weeds between the rows of clumps, the abundance of old or rotting culms within clumps, the absence of any fertilizer and mulching regime. Each site appears more like a wild bamboo forest than what is properly called a 'trial plantation'. The 5m x 5m spacing of clumps provided clear evidence of the plantation structure, but the deficiency of management made the assessment and analysis of each site extremely difficult. The sites have not been systematically harvested to measure yield. Instead the sites have mainly been used as sources of germplasm for further propagation at KEFRI nurseries. Because of the conditions of the site, the analyses-and especially the assessments of potential yield-were made using conservative assumptions.

The following species and varieties were observed in the trial sites: (1) *Bambusa vulgaris*; (2) *Bambusa vulgaris* 'Vitatta'; (3) *Bambusa bambos*; (4) *Bambusa tulda*; (4) *Cephalostachyum pergracile*; (5) *Dendrocalamus asper*; (6) *Dendrocalamus brandisii*; (6) *Dendrocalamus giganteus*; (7) *Dendrocalamus hamiltonii*; (8) *Dendrocalamus membranaceus*; (9) *Dendrocalamus strictus*; (10) *Thyrsostachys siamensis;* (11) *Phyllostachys species.*

There is confusion about the identity of some species planted in the trials, especially in Muguga and Kakamega. There were in several cases clear differences between the plants in particular species plots. The author later learned from Dr. Bernard Kigomo that, at the time of establishing the trials, there was a mix of some plants during transport and planting. This is why plants differ significantly from the typical form of the species in some plots, which raised serious doubts regarding the identity of some species. A particular case in point is the plant referred to as "*Phyllostachys pubescens"* planted in Kakamega. The plants were grown from seeds obtained in Japan. Although the plants certainly belong to the Phyllostachys genus, they are extremely smaller in both height and diameter and do not resemble the species *Phyllostachys pubescens*. Due to doubts about identification, apparent unsuitability of the species for the area, and the fact that this species was only planted in Kakamega, the species is not included in this analysis. Another case is that of *Dendrocalamus. asper*. The relatively good performance of this species under cultivation in Nairobi suggests that this species may be interesting for plantations. *D. asper* was planted in the Muguga trials but the species was not identified at the site, so no data was recorded for analysis. It is possible that *D. asper* was mixed up with *D. brandisii*. In Kakamega, a clump resembling *D. asper* was observed in the plot of *D. brandisii*. *D. asper* was however not originally included in the Kakamega trial site. Some elements of doubt therefore remain in the analyses and taxonomical clarifications are required.

Methodology

The method of analyzing the sites involved the following steps:

1) Observations were made on various clumps of each species and the number of culms and new shoots per clump was counted or estimated. In very dense clumps it was not possible to count the number of culms and therefore an estimate of the number of culms was made based on the number of culms counted for a particular area of the clump. Based on the counted and/or estimated number of culms of the sampled clumps of each species, average numbers of culms per clump per species was calculated.
2) The observation of the clumps involved visually identifying small, medium, and large culms and measuring the circumference of selected samples using a measuring tape. Based on the measured samples of various sizes of culms of each species, and taking into account the fact bamboo culms are tapered from the base towards the tip of the culm, an average culm diameter was calculated for each species.
3) The average height of the culms of each species was determined in many cases, roughly by observation, as well as accurately, by felling culms and measuring their precise length in meters. This method was applied by sampling culms in several clumps and an average height per species was calculated.
4) The wall thickness of the bamboo culms was calculated based on published information (as well as on unpublished information collected by the author over the years) regarding the ratio of wall thickness to culm diameter per species.
5) The dry weight of culms was calculated of the basis of the solid volume of the bamboo culm, using the specific gravity of bamboo to determine the mass. In calculating the volume of the culms, radial shrinkage of the culms is taken into account. Shrinkage ranges from 4-14% in the wall thickness and 3-12% in diameter. (Liese, 1985.) Culm shrinkage varies from species to species and depends very much on the moisture content of the culm at the time of harvesting. As a working assumption, the mean radial shrinkage factor of 9% in the wall thickness and 7.5% in diameter for tropical bamboos was assumed. The specific gravity of bamboo ranges from 0.5 to 0.8 (0.9) g/cm^3 (Liese, 1985). The value of 0.65 was taken as a working assumption for all species, which is the approximate value for most species of the *Bambusa* and *Dendrocalamus* genera. The mass to volume ratio of air dried bamboo with 11% moisture is about 0.7 g/m^3 and this was used as a working assumption for determining air dry weight of culms. The solid volume of bamboo is determined by multiplying the length of the culm by the solid cross section area of the culm. The solid cross section area is calculated by subtracting the culm cavity cross section area from the total cross section area. The cross section areas are calculated using the formula for the area of a circle (Area = Πr^2). Once the solid volume of the culm is estimated, the mass can be determined by means of the mass to volume ratio of bamboo. The method is purely mathematical but provides a rough estimation of culm weight. The actual average weight of the culms may vary by +/-20%. Clearly, the most accurate way of

determining culm weight is by physically weighing the dry culms, but this was not possible due to time and logistical constraints.

6) The estimated potential yield in tons (dry basis) per hectare per year was made with the assumption that, on average, 25% of the culms per clump are annually harvested. The figure of 25% or ¼ of the culms was used on the basis that only 3 year old mature culms are harvested and that new culms (year 0), as well as 1 and 2 year old culms are left to mature. There are variations in the number of new shoots that appear each year so the figure of 25% is a working assumption. There may be years when fewer culms are mature and ready for harvesting, while in other years the harvest will be much greater. Clump management and maintenance as well as climactic factors play a leading role in productivity. In this regard, bamboo is not different from most other crops.

7) Given the fact that the plantations are not well managed, it was assumed that the commercial yield would be lower than the potential yield. It was assumed that in a poorly managed plantation only 40% of the culms would be sellable.

8) To compare the performance of the species in the KEFRI trials, collected data on the average physical properties of the culms of the species in their natural range in Asia was used for benchmarking. Averages of culm height, diameter, wall thickness, and dry weight culm in the KEFRI plantations were calculated and compared to the benchmark values.

9) Analytic data per species and per location was sorted in order to rank the species in terms of three categories: (a) Estimated Potential Yield in Tons (Air Dry Basis) per ha/year; (b) Average dry weight of the culm; and (c) Height of the culm.

Analyses of the KEFRI Bamboo Trials

Abbreviations Used in the Analytic Tables:

- H = Average Height of mature culms in Meters
- D = Average Diameter of Mature Tapered Culms in Meters
- WT = Average Wall Thickness in millimeters
- DM = Estimated Average Air Dry Weight of Culm in Kilograms
- AC = Average number of culms per clump
- EY = Estimated Potential (air dried) Yield in Tons per hectare per year based on 5mX5m planting (400 plants/ha) with felling of only mature culms (25% of total culms) and extraction of dead or rotting culms.
- CY = Commercial yield refers to tons per ha per year of top quality culms. 40% of Estimated Potential Yield (EY) is assumed.
- RYS = Relative Yield Performance Ratio of a Species in Kenya. Each species with the highest Estimated Potential Yield (EY) is used as the basis for calculating the RYS ratio for the same species in different trial sites in Kenya. Thus, RYS = EY of a Species in Site X / EY of the same Species in the site where it obtains the highest EY. The RYS of the species with the highest yield in any of the various trial sites is therefore equal to 1.

Performance of Bamboo Species per Trial Site

Following the methodology outlined above, the performance of each observed species per trial site was assessed.

Table 2: Performance of *Bambusa bambos*

Species:	Bambusa bambos						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	5	7.5	3.8	25	9.4	3.8
Jilore	15	9	13.5	18.3	22	40.2	16.1
Kakamega	4	7	10	3.1	22	6.9	2.8
Muguga	4	6	9	2.4	22	5.3	2.1

Table 3: Performance of *Bambusa tulda*

Species:	Bambusa Tulda						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	No Data available						
Jilore	No Data available						
Kakamega	6	7	10	4.7	17	8.0	3.2
Muguga	6	7	10	4.7	17	8.0	3.2

Table 4: Performance of *Bambusa vulgaris* 'Vitatta'

Species:	Bambusa vulgaris 'Vitatta'						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	8	6	8	4.3	30	13.0	5.2
Jilore	No Data available						
Kakamega	8	7	9	5.7	28	16.0	6.4
Muguga	7	7	9	5.0	28	14.0	5.6

Table 5: Performance of *Cephalostachyum pergracile*

Species:	Cephalostachyum pergracile						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	Not Planted						
Jilore	No Data available						
Kakamega	Not Planted						
Muguga	10	6	5	3.5	17	5.9	2.4

Table 6: Performance of *Dendrocalamus asper*

Species:	Dendrocalamus asper						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	Not Planted						
Jilore	Not Planted						
Kakamega	Not Planted						
Muguga	No Data available / Possibly mixed with D. brandisii						

Table 7: Performance of *Dendrocalamus brandisii*

Species:	Dendrocalamus brandisii						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	15	10	18	29.7	6	17.8	7.1
Jilore	No Data available						
Kakamega	12	11	15	22.3	17	37.9	15.2
Muguga	10	10	18	19.8	17	33.7	13.5

Table 8: Performance of *Dendrocalamus membranaceus*

Species:	Dendrocalamus membranaceus						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	5	5	2.6	28	7.2	2.9
Jilore	12	7	10	9.4	39	36.8	14.7
Kakamega	7	7	8	4.5	17	7.6	3.0
Muguga	7	6	6	2.9	17	4.9	2.0

Table 9: Performance of *Dendrocalamus strictus*

Species:	Dendrocalamus strictus						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	3	11.3	3.0	25	7.5	3.0
Jilore	No Data available						
Kakamega	5	7	25	8.7	11	9.6	3.8
Muguga	5	6	23	6.7	11	7.4	3.0

Table 10: Performance of *Dendrocalamus hamiltonii*

Species:	Dendrocalus hamiltonii						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	5	7.5	3.8	30	11.3	4.5
Jilore	10	6	9	6.0	28	16.9	6.8
Kakamega	10	10	10	11.5	19	21.8	8.7
Muguga	9	10	10	10.3	28	29.0	11.6

Table 11: Performance of *Thyrsostachys siamensis*

Species:	Thyrsostachys siamensis						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	6	2.5	9.4	1.4	39	5.4	2.2
Jilore	No Data available						
Kakamega	5	2.5	9	1.1	28	3.1	1.2
Muguga	5	3	9	2.4	28	6.8	2.7

Benchmark Analysis

Table 12 to Table 15 below show the analyses of the performance of species at each KEFRI trial site. The average characteristics of species under cultivation within their natural range in Asia are used as a benchmark. The average weight and physical characteristics of the culm of the species in the trials are compared to data of the same species in Asia.

It is important to draw attentions to the limitations of this method of analysis. The benchmark analysis only provides a basis for comparing the characteristics of the culm, but it does not, by itself, allow for any conclusions regarding the suitability of a species for a particular site.

For instance, Table 12 shows that, in Gede, *D. brandisii* performed comparatively well in terms of culm diameter (D=83%) and culm weight (DM=49%). However, on the site, the clumps of *D. brandisii* were very sparsely populated with culms (AC=6). The high estimated potential yield (EY) of this species is due to the weight of the culms, but under better conditions and with good management, it can have a much better overall performance.

Bamboos are not created equal. In the family of woody bamboos, there are small, medium, large, and giant species. Apart from good climatic conditions, sufficient sunlight and rainfall, each species needs enough space to grow in order to reach its full size. This seriously has to be considered at the time of planting. In the KEFRI trials; all bamboo species were treated equally and planted at the spacing of 5m x 5m. This spacing was excessive for a small clumping species like *T. siamensis*, but insufficient for a giant like *D. brandisii* or large species like *D. hamiltonii* and *B. bambos*. Depending on the purpose of the plantation, large tropical bamboos with pachymorph rhizomes can be planted at distances of up to 10 m by 10m (100 clumps per hectare) to allow for the establishment of huge clumps. If the plantation is intended for the production of edible shoots, spacing can be reduced significantly, because the aim is to maintain thin clumps and harvest most of the shoots.

Table 12: Benchmark analysis of species in KEFRI Bamboo Trial in Gede

KEFRI Trial Site Location: Gede								**Ave. Performance in Natural Range in Asia**				**Comparative Performance in Gede**			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	9	5	7.5	3.8	30	11.3	4.5	20	10	15	33.6	45%	50%	50%	11%
B. tulda	No Data available							18	10	17	33.9	No Data available			
D. membranaceus	9	5	5	2.6	28	7.2	2.9	18	10	10	20.7	50%	50%	50%	12%
D. asper	Not Planted							22	12	20	58.5	No Data available			
B. vulgaris	8	6	8	4.3	30	13.0	5.2	15	7	10	11.8	53%	86%	80%	37%
D. brandisii	15	10	18	29.7	6	17.8	7.1	25	12	18	60.4	60%	83%	100%	49%
D. strictus	9	3	11.3	3.0	25	7.5	3.0	10	8	30	23.6	90%	38%	38%	13%
B. bambos	9	5	7.5	3.8	25	9.4	3.8	20	12	18	48.3	45%	42%	42%	8%
T. siamensis	6	2.5	9.4	1.4	39	5.4	2.2	9	4	15	5.3	67%	63%	63%	26%
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	Not Planted							18	8	6	10.1	No Data available			

Table 13: Benchmark analysis of species in KEFRI Bamboo Trial in Jilore

KEFRI Trial Site Location: Jilore								**Ave. Performance in Natural Range in Asia**				**Comparative Performance in Jilore**			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	10	6	9	6.0	28	16.9	6.8	20	10	15	33.6	50%	60%	60%	18%
D. membranaceus	12	7	10	9.4	39	36.8	14.7	18	10	10	20.7	67%	70%	100%	46%
B. bambos	15	9	13.5	18.3	22	40.2	16.1	20	12	18	48.3	75%	75%	75%	38%
T. siamensis	No Data available							9	4	15	5.3	No Data available			
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	No Data available							18	8	6	10.1	No Data available			

Table 14: Benchmark analysis of species in KEFRI Bamboo Trial in Kakamega

KEFRI Trial Site	**Location: Kakamega**							**Ave. Performance in Natural Range in Asia**				**Comparative Performance in Kakamega**			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	10	10	10	11.5	19	21.8	8.7	20	10	15	33.6	50%	100%	67%	34%
B. tulda	6	7	10	4.7	17	8.0	3.2	18	10	17	33.9	33%	70%	59%	14%
D. membranaceus	7	7	8	4.5	17	7.6	3.0	18	10	10	20.7	39%	70%	80%	22%
D. asper	No Data available				0			22	12	20	58.5	No Data available			
B. vulgaris	8	7	9	5.7	28	16.0	6.4	15	7	10	11.8	53%	100%	90%	48%
D. brandisii	12	11	15	22.3	17	37.9	15.2	25	12	18	60.4	48%	92%	83%	37%
D. strictus	5	7	25	8.7	11	9.6	3.8	10	8	30	23.6	50%	88%	83%	37%
B. bambos	4	7	10	3.1	22	6.9	2.8	20	12	18	48.3	20%	58%	56%	7%
T. siamensis	5	2.5	9	1.1	28	3.1	1.2	9	4	15	5.3	56%	63%	60%	21%
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	No Data available							18	8	6	10.1	No Data available			

Table 15: Benchmark analysis of species in KEFRI Bamboo Trial in Muguga

KEFRI Trial Site	**Location: Muguga**							**Ave. Performance in Natural Range in Asia**				**Comparative Performance in Muguga**			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	9	10	10	10.3	28	29.0	11.6	20	10	15	33.6	45%	100%	67%	31%
B. tulda	6	7	10	4.7	17	8.0	3.2	18	10	17	33.9	33%	70%	59%	14%
D. membranaceus	7	6	6	2.9	17	4.9	2.0	18	10	10	20.7	39%	60%	60%	14%
D. asper	No Data available				0			22	12	20	58.5	No Data available			
B. vulgaris	7	7	9	5.0	28	14.0	5.6	15	7	10	11.8	47%	100%	90%	42%
D. brandisii	10	10	18	19.8	17	33.7	13.5	25	12	18	60.4	40%	83%	100%	33%
D. strictus	5	6	23	6.7	11	7.4	3.0	10	8	30	23.6	50%	75%	77%	29%
B. bambos	4	6	9	2.4	22	5.3	2.1	20	12	18	48.3	20%	50%	50%	5%
T. siamensis	5	3	9	2.4	28	6.8	2.7	9	4	15	5.3	56%	75%	60%	46%
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	10	6	5	3.5	17	5.9	2.4	18	8	6	10.1	56%	75%	83%	34%

As the preceding tables show, the average culm size and weight of most of the species planted in Kenya are far below the benchmark values. Most likely this is not only because the species are planted outside their natural range, but also because they have not been managed. Under good management, where systematic harvesting of mature culms is carried out, it is likely that better results would be obtained for most species. Furthermore, despite the fact that most species are stunted in height, good climatic conditions-especially rainfall-coupled with a good management regime usually leads to vigorous shoot development, and hence, higher biomass productivity over time per unit area.

Species to Site Matching

Table 16: General Ranking of Species based on Estimated Potential Yield

Ranking of Species in the trial sites according to Estimated Potential Yield in Tons (Dry Matter) / Ha									
Rank	Species	Trial Site	H	D	WT	DM	AC	EY	CY
1	B. bambos	Jilore	15	9	13.5	18.3	22	**40.2**	16.1
2	D. brandisii	Kakamega	12	11	15	22.3	17	**37.9**	15.2
3	D. membranaceus	Jilore	12	7	10	9.4	39	**36.8**	14.7
4	D. brandisii	Muguga	10	10	18	19.8	17	**33.7**	13.5
5	D. hamiltonii	Muguga	9	10	10	10.3	28	**29.0**	11.6
6	D. hamiltonii	Kakamega	10	10	10	11.5	19	**21.8**	8.7
7	D. brandisii	Gede	15	10	18	29.7	6	**17.8**	7.1
8	D. hamiltonii	Jilore	10	6	9	6.0	28	**16.9**	6.8
9	B. vulgaris	Kakamega	8	7	9	5.7	28	**16.0**	6.4
10	B. vulgaris	Muguga	7	7	9	5.0	28	**14.0**	5.6
11	B. vulgaris	Gede	8	6	8	4.3	30	**13.0**	5.2
12	D. hamiltonii	Gede	9	5	7.5	3.8	30	**11.3**	4.5
13	D. strictus	Kakamega	5	7	25	8.7	11	**9.6**	3.8
14	B. bambos	Gede	9	5	7.5	3.8	25	**9.4**	3.8
15	B. tulda	Kakamega	6	7	10	4.7	17	**8.0**	3.2
16	B. tulda	Muguga	6	7	10	4.7	17	**8.0**	3.2
17	D. membranaceus	Kakamega	7	7	8	4.5	17	**7.6**	3.0
18	D. strictus	Gede	9	3	11.3	3.0	25	**7.5**	3.0
19	D. strictus	Muguga	5	6	23	6.7	11	**7.4**	3.0
20	D. membranaceus	Gede	9	5	5	2.6	28	**7.2**	2.9
21	B. bambos	Kakamega	4	7	10	3.1	22	**6.9**	2.8
22	T. siamensis	Muguga	5	3	9	2.4	28	**6.8**	2.7
23	C. pergracile	Muguga	10	6	5	3.5	17	**5.9**	2.4
24	T. siamensis	Gede	6	2.5	9.4	1.4	39	**5.4**	2.2
25	B. bambos	Muguga	4	6	9	2.4	22	**5.3**	2.1
26	D. membranaceus	Muguga	7	6	6	2.9	17	**4.9**	2.0
27	T. siamensis	Kakamega	5	2.5	9	1.1	28	**3.1**	1.2

Table 17: Ranking of Species Per Site based on Estimated Potential Yield

Ranking of Species per Trial Site according to Estimated Potential Yield in Tons (Dry Matter) / Ha									
Rank	Species	Trial Site	H	D	WT	DM	AC	**EY**	CY
1	D. brandisii	Gede	15	10	18	29.7	6	**17.8**	7.1
2	B. vulgaris	Gede	8	6	8	4.3	30	**13.0**	5.2
3	D. hamiltonii	Gede	9	5	7.5	3.8	30	**11.3**	4.5
4	B. bambos	Gede	9	5	7.5	3.8	25	**9.4**	3.8
5	D. strictus	Gede	9	3	11.3	3.0	25	**7.5**	3.0
6	D. membranaceus	Gede	9	5	5	2.6	28	**7.2**	2.9
7	T. siamensis	Gede	6	2.5	9.4	1.4	39	**5.4**	2.2
1	B. bambos	Jilore	15	9	13.5	18.3	22	**40.2**	16.1
2	D. membranaceus	Jilore	12	7	10	9.4	39	**36.8**	14.7
3	D. hamiltonii	Jilore	10	6	9	6.0	28	**16.9**	6.8
1	D. brandisii	Kakamega	12	11	15	22.3	17	**37.9**	15.2
2	D. hamiltonii	Kakamega	10	10	10	11.5	19	**21.8**	8.7
3	B. vulgaris	Kakamega	8	7	9	5.7	28	**16.0**	6.4
4	D. strictus	Kakamega	5	7	25	8.7	11	**9.6**	3.8
5	B. tulda	Kakamega	6	7	10	4.7	17	**8.0**	3.2
6	D. membranaceus	Kakamega	7	7	8	4.5	17	**7.6**	3.0
7	B. bambos	Kakamega	4	7	10	3.1	22	**6.9**	2.8
8	T. siamensis	Kakamega	5	2.5	9	1.1	28	**3.1**	1.2
1	D. brandisii	Muguga	10	10	18	19.8	17	**33.7**	13.5
2	D. hamiltonii	Muguga	9	10	10	10.3	28	**29.0**	11.6
3	B. vulgaris	Muguga	7	7	9	5.0	28	**14.0**	5.6
4	B. tulda	Muguga	6	7	10	4.7	17	**8.0**	3.2
5	D. strictus	Muguga	5	6	23	6.7	11	**7.4**	3.0
6	T. siamensis	Muguga	5	3	9	2.4	28	**6.8**	2.7
7	C. pergracile	Muguga	10	6	5	3.5	17	**5.9**	2.4
8	B. bambos	Muguga	4	6	9	2.4	22	**5.3**	2.1
9	D. membranaceus	Muguga	7	6	6	2.9	17	**4.9**	2.0

Table 18: General Ranking of Species based on Culm Weight

Ranking of Species in the various trial sites according to Weight (Kg) DM of Culms									
Rank	Species	Trial Site	H	D	WT	**DM**	AC	**EY**	CY
1	D. brandisii	Gede	15	10	18	**29.7**	6	**17.8**	7.1
2	D. brandisii	Kakamega	12	11	15	**22.3**	17	**37.9**	15.2
3	D. brandisii	Muguga	10	10	18	**19.8**	17	**33.7**	13.5
4	B. bambos	Jilore	15	9	13.5	**18.3**	22	**40.2**	16.1
5	D. hamiltonii	Kakamega	10	10	10	**11.5**	19	**21.8**	8.7
6	D. hamiltonii	Muguga	9	10	10	**10.3**	28	**29.0**	11.6
7	D. membranaceus	Jilore	12	7	10	**9.4**	39	**36.8**	14.7
8	D. strictus	Kakamega	5	7	25	**8.7**	11	**9.6**	3.8
9	D. strictus	Muguga	5	6	23	**6.7**	11	**7.4**	3.0
10	D. hamiltonii	Jilore	10	6	9	**6.0**	28	**16.9**	6.8
11	B. vulgaris	Kakamega	8	7	9	**5.7**	28	**16.0**	6.4
12	B. vulgaris	Muguga	7	7	9	**5.0**	28	**14.0**	5.6
13	B. tulda	Kakamega	6	7	10	**4.7**	17	**8.0**	3.2
14	B. tulda	Muguga	6	7	10	**4.7**	17	**8.0**	3.2
15	D. membranaceus	Kakamega	7	7	8	**4.5**	17	**7.6**	3.0
16	B. vulgaris	Gede	8	6	8	**4.3**	30	**13.0**	5.2
17	D. hamiltonii	Gede	9	5	7.5	**3.8**	30	**11.3**	4.5
18	B. bambos	Gede	9	5	7.5	**3.8**	25	**9.4**	3.8
19	C. pergracile	Muguga	10	6	5	**3.5**	17	**5.9**	2.4
20	B. bambos	Kakamega	4	7	10	**3.1**	22	**6.9**	2.8
21	D. strictus	Gede	9	3	11.3	**3.0**	25	**7.5**	3.0
22	D. membranaceus	Muguga	7	6	6	**2.9**	17	**4.9**	2.0
23	D. membranaceus	Gede	9	5	5	**2.6**	28	**7.2**	2.9
24	T. siamensis	Muguga	5	3	9	**2.4**	28	**6.8**	2.7
25	B. bambos	Muguga	4	6	9	**2.4**	22	**5.3**	2.1
26	T. siamensis	Gede	6	2.5	9.4	**1.4**	39	**5.4**	2.2
27	T. siamensis	Kakamega	5	2.5	9	**1.1**	28	**3.1**	1.2

Table 19: Ranking of Species Per Site based on average culm weight

Ranking of Species per Trial Site according to Weight (Kg) DM of Culms									
Rank	Species	Trial Site	H	D	WT	**DM**	AC	EY	CY
1	D. brandisii	Gede	15	10	18	**29.7**	6	17.8	7.1
2	B. vulgaris	Gede	8	6	8	**4.3**	30	13.0	5.2
3	B. bambos	Gede	9	5	7.5	**3.8**	25	9.4	3.8
4	D. hamiltonii	Gede	9	5	7.5	**3.8**	30	11.3	4.5
5	D. strictus	Gede	9	3	11.3	**3.0**	25	7.5	3.0
6	D. membranaceus	Gede	9	5	5	**2.6**	28	7.2	2.9
7	T. siamensis	Gede	6	2.5	9.4	**1.4**	39	5.4	2.2
1	B. bambos	Jilore	15	9	13.5	**18.3**	22	40.2	16.1
2	D. membranaceus	Jilore	12	7	10	**9.4**	39	36.8	14.7
3	D. hamiltonii	Jilore	10	6	9	**6.0**	28	16.9	6.8
1	D. brandisii	Kakamega	12	11	15	**22.3**	17	37.9	15.2
2	D. hamiltonii	Kakamega	10	10	10	**11.5**	19	21.8	8.7
3	D. strictus	Kakamega	5	7	25	**8.7**	11	9.6	3.8
4	B. vulgaris	Kakamega	8	7	9	**5.7**	28	16.0	6.4
5	B. tulda	Kakamega	6	7	10	**4.7**	17	8.0	3.2
6	D. membranaceus	Kakamega	7	7	8	**4.5**	17	7.6	3.0
7	B. bambos	Kakamega	4	7	10	**3.1**	22	6.9	2.8
8	T. siamensis	Kakamega	5	2.5	9	**1.1**	28	3.1	1.2
1	D. brandisii	Muguga	10	10	18	**19.8**	17	33.7	13.5
2	D. hamiltonii	Muguga	9	10	10	**10.3**	28	29.0	11.6
3	D. strictus	Muguga	5	6	23	**6.7**	11	7.4	3.0
4	B. vulgaris	Muguga	7	7	9	**5.0**	28	14.0	5.6
5	B. tulda	Muguga	6	7	10	**4.7**	17	8.0	3.2
6	C. pergracile	Muguga	10	6	5	**3.5**	17	5.9	2.4
7	D. membranaceus	Muguga	7	6	6	**2.9**	17	4.9	2.0
8	B. bambos	Muguga	4	6	9	**2.4**	22	5.3	2.1
9	T. siamensis	Muguga	5	3	9	**2.4**	28	6.8	2.7

Table 20: General Ranking of Species based on Average Culm Height

Ranking of Species in the various trial sites according to Height (m) of Culms									
Rank	Species	Trial Site	**H**	D	WT	DM	AC	**EY**	CY
1	B. bambos	Jilore	**15**	9	13.5	18.3	22	**40.2**	16.1
2	D. brandisii	Gede	**15**	10	18	29.7	6	**17.8**	7.1
3	D. brandisii	Kakamega	**12**	11	15	22.3	17	**37.9**	15.2
4	D. membranaceus	Jilore	**12**	7	10	9.4	39	**36.8**	14.7
5	D. brandisii	Muguga	**10**	10	18	19.8	17	**33.7**	13.5
6	D. hamiltonii	Kakamega	**10**	10	10	11.5	19	**21.8**	8.7
7	D. hamiltonii	Jilore	**10**	6	9	6.0	28	**16.9**	6.8
8	C. pergracile	Muguga	**10**	6	5	3.5	17	**5.9**	2.4
9	D. hamiltonii	Muguga	**9**	10	10	10.3	28	**29.0**	11.6
10	D. hamiltonii	Gede	**9**	5	7.5	3.8	30	**11.3**	4.5
11	B. bambos	Gede	**9**	5	7.5	3.8	25	**9.4**	3.8
12	D. strictus	Gede	**9**	3	11.3	3.0	25	**7.5**	3.0
13	D. membranaceus	Gede	**9**	5	5	2.6	28	**7.2**	2.9
14	B. vulgaris	Kakamega	**8**	7	9	5.7	28	**16.0**	6.4
15	B. vulgaris	Gede	**8**	6	8	4.3	30	**13.0**	5.2
16	B. vulgaris	Muguga	**7**	7	9	5.0	28	**14.0**	5.6
17	D. membranaceus	Kakamega	**7**	7	8	4.5	17	**7.6**	3.0
18	D. membranaceus	Muguga	**7**	6	6	2.9	17	**4.9**	2.0
19	B. tulda	Kakamega	**6**	7	10	4.7	17	**8.0**	3.2
20	B. tulda	Muguga	**6**	7	10	4.7	17	**8.0**	3.2
21	T. siamensis	Gede	**6**	2.5	9.4	1.4	39	**5.4**	2.2
22	D. strictus	Kakamega	**5**	7	25	8.7	11	**9.6**	3.8
23	D. strictus	Muguga	**5**	6	23	6.7	11	**7.4**	3.0
24	T. siamensis	Muguga	**5**	3	9	2.4	28	**6.8**	2.7
25	T. siamensis	Kakamega	**5**	2.5	9	1.1	28	**3.1**	1.2
26	B. bambos	Kakamega	**4**	7	10	3.1	22	**6.9**	2.8
27	B. bambos	Muguga	**4**	6	9	2.4	22	**5.3**	2.1

Table 21: Ranking of Species per Site based on Average Culm Height

Ranking of Species per trial site according to Height (m) of Culms									
Rank	Species	Trial Site	**H**	D	WT	DM	AC	EY	CY
1	D. brandisii	Gede	**15**	10	18	29.7	6	**17.8**	7.1
2	D. hamiltonii	Gede	**9**	5	7.5	3.8	30	**11.3**	4.5
3	B. bambos	Gede	**9**	5	7.5	3.8	25	**9.4**	3.8
4	D. strictus	Gede	**9**	3	11.3	3.0	25	**7.5**	3.0
5	D. membranaceus	Gede	**9**	5	5	2.6	28	**7.2**	2.9
6	B. vulgaris	Gede	**8**	6	8	4.3	30	**13.0**	5.2
7	T. siamensis	Gede	**6**	2.5	9.4	1.4	39	**5.4**	2.2
1	B. bambos	Jilore	**15**	9	13.5	18.3	22	**40.2**	16.1
2	D. membranaceus	Jilore	**12**	7	10	9.4	39	**36.8**	14.7
3	D. hamiltonii	Jilore	**10**	6	9	6.0	28	**16.9**	6.8
1	D. brandisii	Kakamega	**12**	11	15	22.3	17	**37.9**	15.2
2	D. hamiltonii	Kakamega	**10**	10	10	11.5	19	**21.8**	8.7
3	B. vulgaris	Kakamega	**8**	7	9	5.7	28	**16.0**	6.4
4	D. membranaceus	Kakamega	**7**	7	8	4.5	17	**7.6**	3.0
5	B. tulda	Kakamega	**6**	7	10	4.7	17	**8.0**	3.2
6	D. strictus	Kakamega	**5**	7	25	8.7	11	**9.6**	3.8
7	T. siamensis	Kakamega	**5**	2.5	9	1.1	28	**3.1**	1.2
8	B. bambos	Kakamega	**4**	7	10	3.1	22	**6.9**	2.8
1	D. brandisii	Muguga	**10**	10	18	19.8	17	**33.7**	13.5
2	C. pergracile	Muguga	**10**	6	5	3.5	17	**5.9**	2.4
3	D. hamiltonii	Muguga	**9**	10	10	10.3	28	**29.0**	11.6
4	B. vulgaris	Muguga	**7**	7	9	5.0	28	**14.0**	5.6
5	D. membranaceus	Muguga	**7**	6	6	2.9	17	**4.9**	2.0
6	B. tulda	Muguga	**6**	7	10	4.7	17	**8.0**	3.2
7	D. strictus	Muguga	**5**	6	23	6.7	11	**7.4**	3.0
8	T. siamensis	Muguga	**5**	3	9	2.4	28	**6.8**	2.7
9	B. bambos	Muguga	**4**	6	9	2.4	22	**5.3**	2.1

Table 22: Relative Yield Performance of Species per Site

Relative Performance and Ranking of Species in Each Site based on EY of Species with Highest Yield (EY)								
Species	Trial Site	H	D	WT	DM	AC	EY	RYS
B. bambos	Jilore	15	9	13.5	18.3	22	**40.2**	100%
B. bambos	Gede	9	5	7.5	3.8	25	**9.4**	23%
B. bambos	Kakamega	4	7	10	3.1	22	**6.9**	17%
B. bambos	Muguga	4	6	9	2.4	22	**5.3**	13%
B. tulda	Kakamega	6	7	10	4.7	17	**8.0**	100%
B. tulda	Muguga	6	7	10	4.7	17	**8.0**	100%
B. vulgaris	Kakamega	8	7	9	5.7	28	**16.0**	100%
B. vulgaris	Muguga	7	7	9	5.0	28	**14.0**	88%
B. vulgaris	Gede	8	6	8	4.3	30	**13.0**	81%
C. pergracile	Muguga	10	6	5	3.5	17	**5.9**	100%
D. brandisii	Kakamega	12	11	15	22.3	17	**37.9**	100%
D. brandisii	Muguga	10	10	18	19.8	17	**33.7**	89%
D. brandisii	Gede	15	10	18	29.7	6	**17.8**	47%
D. hamiltonii	Muguga	9	10	10	10.3	28	**29.0**	100%
D. hamiltonii	Kakamega	10	10	10	11.5	19	**21.8**	75%
D. hamiltonii	Jilore	10	6	9	6.0	28	**16.9**	58%
D. hamiltonii	Gede	9	5	7.5	3.8	30	**11.3**	39%
D. membranaceus	Jilore	12	7	10	9.4	39	**36.8**	100%
D. membranaceus	Kakamega	7	7	8	4.5	17	**7.6**	21%
D. membranaceus	Gede	9	5	5	2.6	28	**7.2**	20%
D. membranaceus	Muguga	7	6	6	2.9	17	**4.9**	13%
D. strictus	Kakamega	5	7	25	8.7	11	**9.6**	100%
D. strictus	Gede	9	3	11.3	3.0	25	**7.5**	78%
D. strictus	Muguga	5	6	23	6.7	11	**7.4**	78%
T. siamensis	Muguga	5	3	9	2.4	28	**6.8**	100%
T. siamensis	Gede	6	2.5	9.4	1.4	39	**5.4**	80%
T. siamensis	Kakamega	5	2.5	9	1.1	28	**3.1**	11%

Table 23: Species to Site - Benchmark Analysis and Relative Yield Performance

Species to Site Analysis Based on Combined Benchmark Comparison and Site Performance Data									
Rank	**Species**	**Site**	**Benchmark Comparison Data**				**Site Performance Data**		
			H	**D**	**WT**	**DM**	**AC**	**EY**	**RYS**
1	B. bambos	Jilore	75%	75%	75%	37.9%	22	40.2	100%
2	" "	Gede	45%	42%	42%	7.8%	25	9.4	23%
3	" "	Kakamega	20%	58%	56%	6.5%	22	6.9	17%
4	" "	Muguga	20%	50%	50%	5.0%	22	5.3	13%
1	B. tulda	Kakamega	33%	70%	59%	13.9%	17	8.0	100%
2	" "	Muguga	33%	70%	59%	13.9%	17	8.0	100%
1	B. vulgaris	Kakamega	53%	100%	90%	48.3%	28	16.0	100%
2	" "	Muguga	47%	100%	90%	42.3%	28	14.0	88%
3	" "	Gede	53%	86%	80%	36.7%	30	13.0	81%
1	C. pergracile	Muguga	56%	75%	83%	34.4%	17	5.9	100%
1	D. brandisii	Kakamega	48%	92%	83%	36.9%	17	37.9	100%
2	" "	Muguga	40%	83%	100%	32.8%	17	33.7	89%
3	" "	Gede	60%	83%	100%	49.2%	6	17.8	47%
1	D. hamiltonii	Muguga	45%	100%	67%	30.8%	28	29.0	100%
2	" "	Kakamega	50%	100%	67%	34.2%	19	21.8	75%
3	" "	Jilore	50%	60%	60%	18.0%	28	16.9	58%
4	" "	Gede	45%	50%	50%	11.2%	30	11.3	39%
1	D. membranaceus	Jilore	67%	70%	100%	45.6%	39	36.8	100%
2	" "	Kakamega	39%	70%	80%	21.6%	17	7.6	21%
3	" "	Gede	50%	50%	50%	12.5%	28	7.2	20%
4	" "	Muguga	39%	60%	60%	14.0%	17	4.9	13%
1	D. strictus	Kakamega	**50%**	88%	83%	**36.8%**	11	9.6	**100%**
2	" "	Muguga	**50%**	75%	77%	**28.6%**	11	7.4	**78%**
3	" "	Gede	**90%**	38%	38%	**12.7%**	25	7.5	**78%**
1	T. siamensis	Muguga	**56%**	75%	60%	**45.6%**	28	6.8	**100%**
2	" "	Gede	**67%**	63%	63%	**26.1%**	39	5.4	**80%**
3	" "	Kakamega	**56%**	63%	60%	**21.1%**	28	3.1	**11%**

Table 24: Species per Site - Benchmark Analysis and Relative Yield Performance

Ranking of Species per Site Based on Combined Benchmark Comparison and Site Performance Data									
Rank	Site	Species	Benchmark Comparison Data				Site Performance Data		
			H	D	WT	DM	AC	EY	RYS
1	Gede	B. vulgaris	53%	86%	80%	37%	30	13.0	81%
2	" "	T. siamensis	67%	63%	63%	26%	39	5.4	80%
3	" "	D. brandisii	60%	83%	100%	49%	6	17.8	47%
4	" "	D. strictus	90%	38%	38%	13%	25	7.5	78%
5	" "	D. hamiltonii	45%	50%	50%	11%	30	11.3	39%
6	" "	D. membranaceus	50%	50%	50%	12%	28	7.2	20%
7	" "	B. bambos	45%	42%	42%	8%	25	9.4	23%
1	Jilore	D. membranaceus	67%	70%	100%	46%	39	36.8	100%
2	" "	B. bambos	75%	75%	75%	38%	22	40.2	100%
3	" "	D. hamiltonii	50%	60%	60%	18%	28	16.9	58%
1	Kakamega	B. vulgaris	53%	100%	90%	48%	28	16.0	100%
2	" "	D. brandisii	48%	92%	83%	37%	17	37.9	100%
3	" "	D. strictus	50%	88%	83%	37%	11	9.6	100%
4	" "	B. tulda	33%	70%	59%	14%	17	8.0	100%
5	" "	D. hamiltonii	50%	100%	67%	34%	19	21.8	75%
6	" "	D. membranaceus	39%	70%	80%	22%	17	7.6	21%
7	" "	T. siamensis	56%	63%	60%	21%	28	3.1	11%
8	" "	B. bambos	20%	58%	56%	7%	22	6.9	17%
1	Muguga	T. siamensis	56%	75%	60%	46%	28	6.8	100%
2	" "	C. pergracile	56%	75%	83%	34%	17	5.9	100%
3	" "	D. hamiltonii	45%	100%	67%	31%	28	29.0	100%
4	" "	B. vulgaris	47%	100%	90%	42%	28	14.0	88%
5	" "	D. brandisii	40%	83%	100%	33%	17	33.7	89%
6	" "	B. tulda	33%	70%	59%	14%	17	8.0	100%
7	" "	D. strictus	50%	75%	77%	29%	11	7.4	78%
8	" "	D. membranaceus	39%	60%	60%	14%	17	4.9	13%
9	" "	B. bambos	20%	50%	50%	5%	22	5.3	13%

Conclusion

The comparative analysis of each species per site benchmarked to the performance of the species in their natural range is one criterion for species to site matching. In addition it is useful to compare the relative performance of species in the various trials by considering the number of culms per clump and estimated potential yield of the species per hectare.

Table 31 shows the species to site matching for Kakamega. The overall performance ranking is based on an analysis of the various criteria of each species as shown in Table 18 to Table 30. Table 31 shows for instance, that although *D. brandisii* has a higher potential yield (see Table 23), the relative performance of *B. vulgaris* in terms of culm weight is better (see Table 30). It was observed that the culm production of *B. vulgaris* was the most vigorous in terms of culms per clump.

D. Brandisii, followed by *D. hamiltonii* and *D. strictus*, show better overall performance than the other species in Kakamega. *B. tulda* ranks fifth; despite its relatively low culm weight and height, the species shows a high potential yield due to the number of culms per clump.

T. siamensis is a small species but it showed very good relative performance in terms of culm height and number of culms per clump. However, the culms of this species are naturally small, and hence it ranked poorly in terms of potential yield. *T. siamensis* was planted using a spacing of 5m x 5m in the trials. However since it is small bamboo it may be planted at more proximate distances in order to maximize the biomass yield per hectare. The optimal plant spacing for *T. siamensis* is 4m x 4m (Dransfield & Widjaja, 1995). Had there been management and harvesting on the site, this species might have performed much better.

Table 25: Species to Site Matching for Kakamega (Lake Region)

		Ranking Criteria: Exotic Bamboos in Kakamega (Lake Region of Kenya)			
		Site Observation Analysis		Benchmark Comparative Analysis	
Species Rank	Overall Performance	Potential Yield (EY)	Culms per Clump (AC)	Culm Weight (DM %)	Culm Height (H %)
1	B. vulgaris	D. brandisii	B. vulgaris	B. vulgaris	T. siamensis
2	D. brandisii	D. hamiltonii	T. siamensis	D. brandisii	B. vulgaris
3	D. hamiltonii	B. vulgaris	D. hamiltonii	D. strictus	D. hamiltonii
4	D. strictus	D. strictus	B. bambos	D. hamiltonii	D. strictus
5	B. tulda	B. tulda	D. membranaceus	D. membranaceus	D. brandisii
6	T. siamensis	D. membranaceus	B. tulda	T. siamensis	D. membranaceus
7	D. membranaceus	B. bambos	D. brandisii	B. tulda	B. tulda
8	B. bambos	T. siamensis	D. strictus	B. bambos	B. bambos

If the purpose of the plantation is to obtain the highest culm yield in terms of tons per ha, then the selection of species to be recommended are *D. brandisii* followed by *D. hamiltonii*. However, these are merely provisionally recommended species. Culm yield, weight, and height are not the only criteria for selecting species for a bamboo plantation. It is essential to have a market and product or intended use for the bamboo. If the intended use is bioenergy, then planting species with the highest annual yield per hectare is recommended. However, species with a lower yield per hectare may be more suitable for splitting, weaving and basketry, which may have a ready market.

Muguga's altitude and climatic conditions are comparable to those of Lari. Species performance in Muguga can therefore be used as a basis for selection of species for the project sites in Lari. Olenguruone lies at a higher altitude but has excellent growing conditions and high rainfall. *Y. alpina* was not analyzed in this study, but it is should be planted in Olenguruone and at high altitude areas where it can thrive.

The overall performance ranking is based on an analysis of the various criteria of each species shown in Table 18 to Table 30. The analysis of the Muguga trial site shows the following results.

Table 26: Species to Site Matching for Muguga

		Ranking Criteria			
		Site Observation Analysis		Benchmark Comparative Analysis	
Species Rank	Overall Performance	Potential Yield (EY)	Culms per Clump (AC)	Culm Weight (DM %)	Culm Height (H %)
1	T. siamensis	D. brandisii	D. hamiltonii	T. siamensis	T. siamensis
2	D. hamiltonii	D. hamiltonii	B. vulgaris	B. vulgaris	C. pergracile
3	B. vulgaris	B. vulgaris	T. siamensis	D. brandisii	D. strictus
4	D. brandisii	D. strictus	D. brandisii	D. hamiltonii	B. vulgaris
5	D. strictus	B. tulda	D. strictus	D. strictus	D. hamiltonii
6	B. tulda	C. pergracile	B. tulda	C. pergracile	D. brandisii
7	D. membranaceus	T. siamensis	D. membranaceus	B. tulda	B. tulda
8	C. pergracile	D. membranaceus	C. pergracile	D. membranaceus	D. membranaceus

In terms of its benchmark performance, *T. siamensis* is one of the species that did well in Muguga. In the trials it was planted in intervals of 5m x 5m but, as mentioned earlier, more proximate planting distances can be used to maximize its yield per hectare.

D. hamiltonii showed good performance in terms of the number of culms per clump as well as in potential yield. Vigorous shoot growth was observed in the trial in Muguga. Although it ranks second to *T. siamensis*, it should be regarded as a priority species for the production of large culms.

B. vulgaris produces a high number of culms per clump. It showed a very good relative performance in terms of average culm weight and a high estimated potential yield per hectare.

The potential yield of *D. brandisii* was the highest of the species planted in Muguga, but its relative performance in terms of height was low. As mentioned earlier in this report, there was some confusion in the Muguga site regarding species identification. *D. asper* does not appear in the above table but it was possibly mixed up with *D. brandisii*. The reasonably good performance of *D. asper* in Gigiri, Nairobi makes it a species to be considered in areas with similar conditions.

It was observed that *B. vulgaris* grows well in Olenguruone and therefore this species should be one of the main species in plantations in that area. Other tropical species may not grow as well due to the cool climate, but they should nevertheless be tested. The species that perform poorly in the highlands are *B. bambos*, followed by *D. strictus* and *B. tulda*. These species grow more favorably in warmer conditions.

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Succession of Bamboo (*Phyllostachys bambusoides* Sieb. et Zuc.) Riparian Forest Vegetation after Gregarious Flowering

Shibata, Shozo
Field Science Education and Research Center, Kyoto University, Japan

Abstract

Ecological research of *Phyllostachys bambusoides* riparian forest was practiced for 16 years from about 20 years after gregarious flowering. As a result it was indicated that the recovering vigorousness of *P. bambusoides* after flowering was continued at least for 25 years. Tree species were suppressed by bamboo again during the research. The bamboo forest vegetation is considered to need more than 25 years after bamboo flowering to stable the vegetation condition. Moreover, at the stable and unmanaged *P. bambusoides* forests, it is shown that a large amount of new culms is produced on every two or three years, and the culms of the following year are comparatively small and die young.

Introduction

In Japan, most of *Phyllostachys bambusoides* Siebold et Zuccarini flowered gregariously and died from the end of 1960's to the beginning of 1970's (Kasahara 1971). In this gregarious flowering, it was recorded that little seeds were produced and almost all the *P. bambusoides* populations regenerated by unique behavior. Although this report is not aimed to notice this regeneration system, this was asexual reproduction by the sprouting of next generation bamboo shoots from new rhizomes.

This flowering gave severe damages to the bamboo industries in Japan. After that, most of the bamboo industries abandoned to get bamboo timbers from their local areas. Notwithstanding most *P. bambusoides* forests recovered in a following decade, the new system to get bamboo timbers was not restored to its former state. At the same time, just after the flowering, many bamboo forests were converted to the other land uses. To obtain the materials for bamboo industries, much of them were not harvested in local areas and are purchased not only from other domestic areas but also from foreign countries. At present time, many recovering *P. bambusoides* forests in Japan are under unmanaged condition and scarce of constant management. As a result, in many bamboo forests the density control is not practiced, therefore, the quality of the produced bamboo timber from such kind of bamboo forests is very low.

Here, it is reported the results of the ecological research for 16 years at the unmanaged *P. bambusoides* riparian forest, which is very common condition in Japan now, and of the analyses of the vegetation succession in mixed bamboo forest with broad-leaved trees following to the recovery of bamboo after flowering.

Research Site and Method

Research is continuing at the riparian bamboo forest along Echi River, which is one of the main rivers in the east-coast plain of Lake Biwa, Shiga Prefecture, Japan. In 1990, the physiognomy survey between the middle part and lower part of river was carried out as the first step, and the change of land use and vegetation for about 100 years was traced using the topographical maps and aerial photographs (Yoshida et. al 1991). According to the results of this survey, four research sites were set. Vegetation research was started in 1992. Here, mainly, the results of one research site, which is located in the *P. bambusoides* forests sparsely mixed with broad-leaved trees, was analyzed.

Research site locates on the right bank of Echi River, 8 km upstream from the mouth. One quadrat of 40m*40m was set up. On this site, whole area was used for the research of tree species and a half of the area (20m*40m) was used for *P. bambusoides*. The research was executed in the fall of 1992 and 1994, and in the spring of 1997, 1999, 2001, 2003, 2005 and 2007. Species name, location, and diameter at breast height (d.b.h.) were surveyed for tree species, and location and d.b.h. for *P. bambusoides*.

Results

Physiognomy Survey of Vegetation along Echi River

The occurrence of *P. bambusoides* along Echi River was frequent as a whole, and the rate of occurrence in 1990 was 70% (Table 1). A lot of deciduous tree species belonging to Ulmaceae and Fagaceae, which are very popular as the component of riparian forest vegetation, appeared. As a common forest physiognomy, *P. bambusoides* with *Celtis sinensis*, *Aphananthe aspera* and *Zelkova serrata* occupy the canopy layer, and evergreen broad-leaved tree species, like *Quercus glauca*, appear as a component of the middle and shrub layer. Nevertheless *Pinus densiflora* is presumed to have occupied large area, it is decreasing their population because of pine wilt disease. This presumption was supported by the appearance of many dead pine trees. *Cryptomeria japonica* also appeared comparatively in high frequency as plantation. All the individuals of this species are inferred to be planted just after the flowering of *P. bambusoides* aiming the change of land use.

Vegetation Transition before and after the Flowering of P. bambusoides

Using two aerial photographs, taken before and after the bamboo flowering (1961 and 1982), the comparison of vegetation was carried out. The year of 1961 and 1982 are about ten years before and after bamboo flowering, respectively. The decrease of *P. bambusoides* crown caused by the flowering obviously promoted the expansion of the crowns of tree species. *P. bambusoides* forests took at least ten years to recover enough crowns after flowering. It means that, during the recovery process of bamboo forest, the seedlings and saplings of tree species on the forest floor get a chance to grow up without any suppression of bamboo.

The rate of expansion of tree species was compared using the change of crown density and occupied area of tree crown (Table 2). The result shows that they increased 450% and 400% in maximum, respectively.

Dynamics of P. bambuoides Forest during the Recent 16 years

Trees

Table 3 shows the change of main tree species number during recent 16 years in the research site. In 1992, 262 trees of 21 species (deciduous: 13, evergreen: 8) existed in 40m*40m quadrate, and 25 trees (9.5%) formed forest canopy with bamboo. Main tree species forming forest canopy was *Aphananthe aspera*, *Celtis sinensis* and *Zelkova serrata* etc.. The rest 237 trees, mainly evergreen broad-leaved species, were not the component of forest canopy, and existed as the component of forest floor vegetation.

In 1999, tree species number decreased to 177 of 12 species (deciduous: 6, evergreen: 6). However, the number of trees forming forest canopy was invariable (25 individuals) and the rate of them increased to 14%. The individuals of *Aphananthe aspera*, *Zelkova serrata* and *Ligustrum japonicum* did not decrease. The former two species are forming forest canopy, and the latter is the component of shrub layer. *Quercus glauca* showed comparatively dynamic change. In many cases, although its trunks which were alive in 1992 died during the following years, it produced coppice shoots again. This kind of ability to produce new shoots is superior on this species. But other species poor in this ability tend to decrease their individuals. All *Cryptomeria japonica*, planted species, died out during the research. The seedlings and saplings of tree species composing the forest canopy were seldom shown in the forest floor layer except a little amount of *Zelkova serrata* saplings.

In 2003, although the number of trees decreased a little to 165, tree species components and forest canopy forming trees did not change. Decrease of the number caused by the slow-down of decrease of *Camellia japonica*, *Neolitsea sericea* and *Cinnamomum sieboldii* after 1999. On the other hand, the decrease of *Celtis sinensis* was continuing. It is considered that the change of tree species tends to become stable.

Phyllostachys bambusoides

The density of new culms of *P. bambusoides* changes every year. In the research site, the number per hectare was 738, 788, 550 and 538 in 1995, 1998, 2000 and 2006 respectively, and in the other years it was from 200 to 390. This gives us a presumption that every two or three years this site produces a large number of new culms except the case of 2003 (Table 4). The distribution of new culms diameter (Figure 1) shows a lot of thin culms probably because of unmanaged condition. All of these culms are short and impossible to form forest canopy. The average of diameters was smaller on every following year of the year when bamboo forest produced large number of new culms.

The age structures of every diameter of surviving culms in the spring of 2003 and 2007 are shown on Figure 2 and Figure 3, respectively. The average diameters of all culms in each year were 6.39 cm and 6.34 cm respectively. The diameter of a large quantity of culms is from 6 to 8 cm, and there are a lot of culms more than 11 years old. The diameter of main culms forming the forest canopy was more than 6 cm. On the other hand, thinner the culm was, shorter its longevity was. The culms with comparatively long longevity were more than 3 cm culms in diameter, and the culms of diameter less than 2 cm had extremely short longevity. This is also understood by the smaller average diameter of new culms on every year than those of surviving culms in 2003 and 2007.

Discussion

As of the research in 1990, it was concluded that *P. bambusoides* forest did not finish the recovering process from flowering completely and that tree species tended to extend their territories (Yoshida et. al 1991). Nevertheless, the results of the following vegetation research in the mixed bamboo forest indicate that, in some cases, *P. bambusoides* does not continue to decline its territory and begins to defeat tree species again. This is clear from the decrease of the number of individuals and number of tree species during 16 years. Especially, the decline of planted trees, *Cryptomeria japonica* in this research site, caused by suppression of bamboo is conspicuous. Furthermore, even the evergreen broad-leaved shrub species tend to decline when they do not have enough capacity to make coppice shoots. Also the tall Ulmaceae species, which are forming forest canopy with bamboo, are presumed to decline because of the lack of succeeding seedlings and saplings, except in case with large disturbance.

P. bambusoides is thought that its activity was still increasing in comparison with the condition of 1990, and that the process of recovery from flowering had been continued for 25 years after flowering. However, it is estimated that the tendency of increase of its activity is slowing down after 1995. This presumption is followed by the increase of the percentage of small new culms and by the decrease of the number of large culms. Nevertheless, it is difficult to identify the cause whether to the end of process of recovery from flowering or to the careless management condition.

In this research it was indicated that the vigorousness of *P. bambusoides* after flowering was continued at least for 25 years. Tree species, which enlarged the territories during the recovery of bamboo, were suppressed by bamboo again. The bamboo forest vegetation is considered to need more than 25 years after bamboo flowering to stable the vegetation condition which means the coexistence of bamboo and trees. Moreover, at the stable *P. bambusoides* forest, it is shown that a large amount of new culms is recognized on every two or three years, and on each following year new culms are comparatively small and died young.

Now, in Japan, the resumption of management, like density control of bamboo culms, fertilizing and so on, is expected to set the domestic supply of materials for bamboo industry on the suitable way and to restore it in the stable condition before the flowering of *P. bambusoides*.

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Table 1. Tree species and their percentages occurred by physiognomy survey at riparian forests along Echi River, Shiga prefecture, Japan (from Yoshida *et al.* 1991)

Phyllostachys bambusoides	70	*Cornus controversa*	20
Quercus glauca	60	*Camellia japonica*	20
Celtis sinensis	40	*Castanea crenata*	10
Aphananthe aspera	30	*Quercus serrata*	10
Quercus aliena	30	*Quercus variabilis*	10
Quercus acutissima	30	*Pterocarya rhoifolia*	10
Pinus densiflora	30	*Kalopanax pictus*	10
Cryptomeria japonica	30	*Ulmus parvifolia*	10
Zelkova serrata	20	*Robinia pseudo-acacia*	10
Neolitsea sericea	20	*Persea thunbergii*	10
Meliosma myriantha	20	*Fraxinus sieboldiana* f. *serrata*	10
Prunus grayana	20		

Table 2. Change of density and occupied area (%) of tree crown in *P. bambusoides* riparian forests along Echi River, Shiga prefecture, Japan. (comparison of 10 plots between 1961 and 1982 through aerial photograph) (from Yoshida *et al.* 1991)

Plot (size)	Distance from mouth of river (km)	Crown density (no./ha) 1961 to 1982	Occupied area of Tree crown (%) 1961 to 1982
A1(200m×200m)	2.1	0.50 to 2.25	3.51 to 12.06
A2(200m×200m)	2.4	1.00 to 2.00	6.78 to 8.78
A3(100m×400m)	2.9	4.00 to 8.50	16.47 to 34.60
A4(100m×400m)	3.3	3.50 to 6.25	14.34 to 17.45
A5(100m×400m)	4.0	1.50 to 2.50	4.64 to 8.00
A6(100m×400m)	4.8	3.00 to 4.50	8.19 to 15.45
A7(100m×400m)	5.7	2.00 to 4.25	2.82 to 11.45
A8(100m×400m)	7.5	2.00 to 5.50	3.55 to 7.39
A9(100m×400m)	8.1	4.75 to 17.75	10.10 to 40.48
A10(100m×200m)	8.4	3.50 to 10.50	6.44 to 19.56
Average		2.53 to 6.18	7.75 to 17.53

Table 3. Change of main tree species number from 1992 to 2003 per hectare of *P. bambusoides* riparian forests along Echi River, Shiga prefecture, Japan (>=3cm)

	1992	1994	1997	1999	2001	2003	Layer
Quercus glauca	52	49	42	47	46	40	shrub
Camellia japonica	51	54	41	37	37	35	shrub
Neolitsea sericea	31	28	15	13	13	12	shrub, middle
Aphananthe aspera	30	30	29	29	28	28	top
Cinnamomum sieboldii	20	18	9	9	9	10	shrub, middle
Zelkova serrata	17	21	18	15	14	13	all
Ligustrum japonicum	13	14	13	14	14	13	shrub
Celtis sinensis	11	10	8	7	6	4	all
Cryptomeria japonica	9	6	-	-	-	-	(planted)

Table 4. Average diameter at breast height (cm) and total number of new culms in each year (/ha) of *P. bambusoides* riparian forest along Echi River, Shiga prefecture, Japan

	Before 1993	1993	1994	1995	1996	1997	1998	1999
d.b.h. of new culms	6.99	5.70	7.27	6.66	5.18	7.00	6.06	4.65
no. of new culms	---	275	350	738	250	363	788	350

	2000	2001	2002	2003	2004	2005	2006
d.b.h. of new culms	6.79	5.44	6.07	3.37	5.33	5.09	5.99
no. of new culms	550	350	200	225	388	263	538

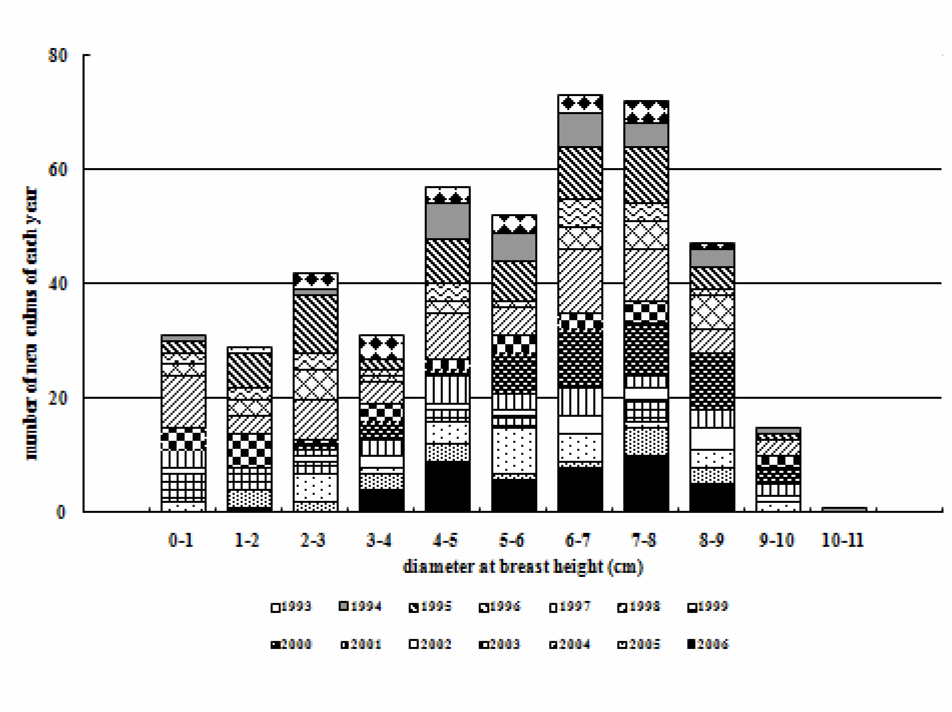

Figure 1. Distribution of diameter at breast height of new culms of each year in 800 m^2 of *P. bambusoides* riparian forests for ten years along Echi River, Shiga prefecture, Japan

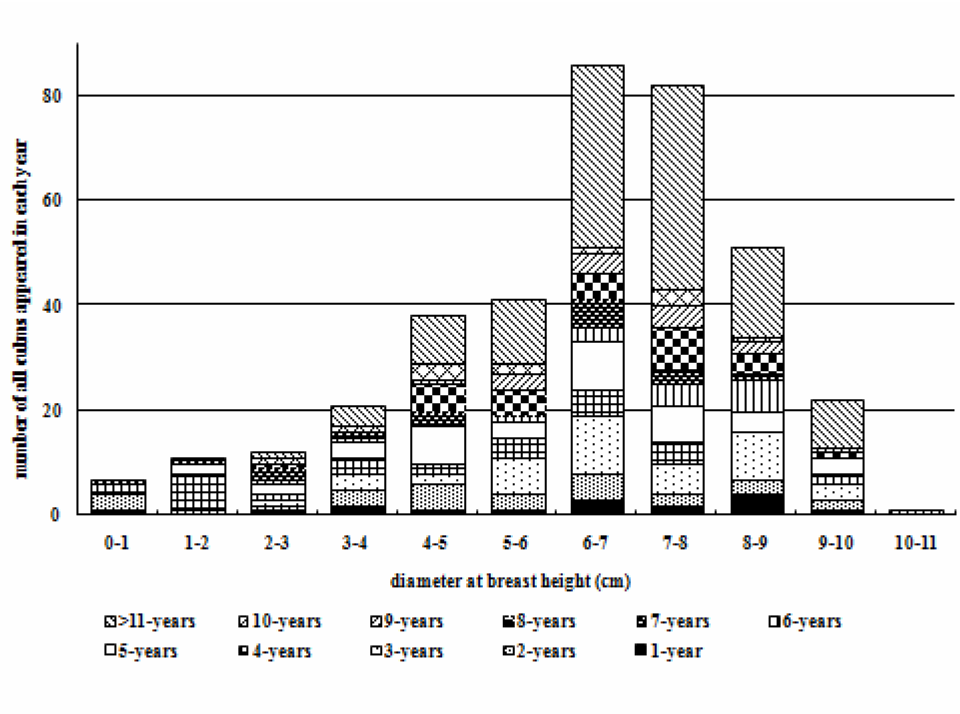

Figure 2. Distribution of diameter at breast height of all culms in 800 m^2 research site in spring, 2003

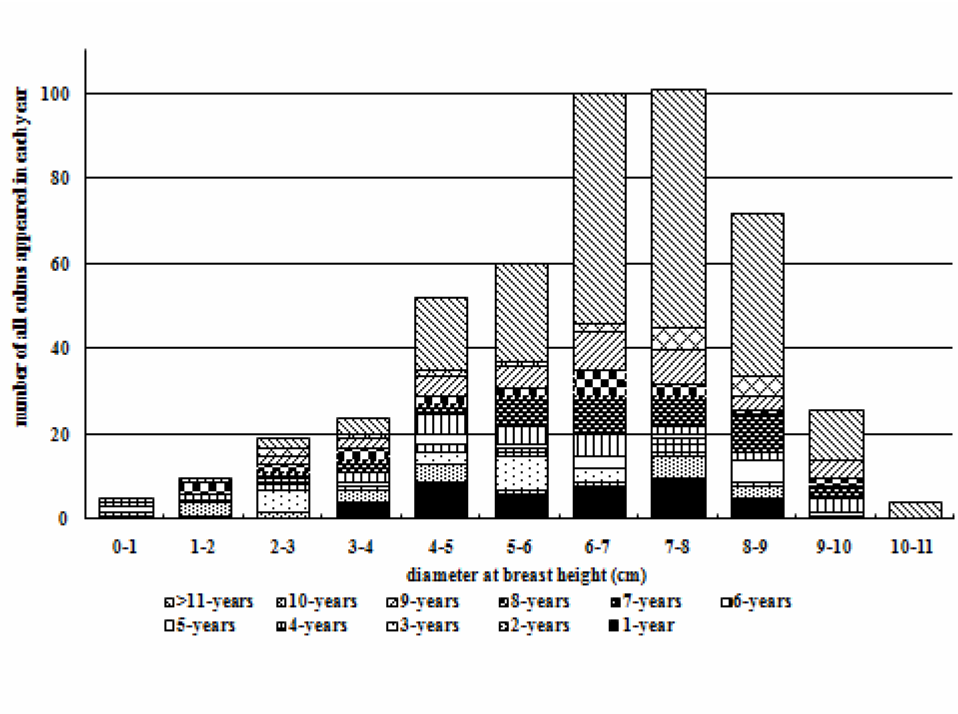

Figure 3. Distribution of diameter at breast height of all culms in 800 m^2 research site in spring, 2007