VOLUME 3

Bamboo and the Environment

Table of Contents

Preface 1

A Study on the Environmental Role and Economic Potential of Arundinaria callosa, Munro 2

A Contribution to Flood Management in European Cities through Bamboo Plantations 10

Energy Crops in Western Europe: is Bamboo an Acceptable Alternative ? 22

Role of Bamboo in Conservation of Biodiversity and Promoting Ecotourism in Tripura, India 35

Chemistries of Throughfall and Stemflow in Two Bamboo Forests and a Japanese Cedar Forest in Japan 51

***Guadua angustifolia* Forestry nucleus in Colombia: Contribution to Environmental Preservation and to Local Social Development.. 60**

Oxygen Oasis 69

Bamboo as Carbon-Sink - Fact or Fiction? 71

Preface

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Because of the effects of global warming of our earth, the effect of mitigation by plants, including bamboo, is very important. Bamboo is a plant with vigorous growth ability, enabling sustainable harvesting in abundance in a short time period, and has been noticed as a useful resource plant from ancient time. This plant has been utilized not only as a timber resource, but as a useful plant for environment conservation in disaster avoidance, landscaping, and so on. This session examines traditional and new viewpoints of bamboo as a solution to environmental problems such as global warming.

In the first half of this session, we will hear presentations from the indigenous areas concerning the effect of bamboo on environment issues. The contents of this part include the regional and economical effect of bamboo, the influence of bamboo to the environment and biodiversity, and the chemical influence of bamboo forests.

The great characteristics of bamboo as a plant species is also noted in the non-indigenous areas of bamboo. Even in these areas, bamboo has been planted for many purposes to alleviate environmental problems. After the coffee break, new utilization of bamboo in such areas will be introduced. Presentations concerning bamboo plantations in Europe for flood control and the potential for bamboo as an energy resource are planned.

The final part of this session includes the presentation about alleviation of global warming with the viewpoint of the economical benefit. In the past we have not discussed bamboo from this kind of view. At the end of the Session, we will discuss about how this great plant, bamboo, can help solve environmental problems.

A Study on the Environmental Role and Economic Potential of Arundinaria callosa, Munro

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Abstract

The North Eastern Region of Indian sub-continent is well known for the rich depository of bamboo. More than 65% of total bamboo populations of the country are growing in this region. Manipur is one of the eight states of the North Eastern Region situating in the Indo-Myanmar Border. The state is a hilly state. Nearly 80% of the total geographical areas of the state are the hilly terrains. The central region comprising of four valley districts are surrounded by nine different ranges of hills. The state, therefore, has unique topographical features. Besides, the unique topography, the climatic conditions prevailed in the state are of varied nature. Such features favour the growth of different bamboo species both in the valley and hilly areas. The distinguishing characteristics of the species that grow in the hills are somewhat altitude-oriented and monopodial too. The present study has been made on one of the thorny species of bamboo, *Arundinaria callosa* Munro, regarding its growth, role in the environment and its economic potential. This species is widely growing in the hills at high altitudes and as it an edible one, helps much in the socio-economic upliftment of the hilly people of the State. This green gold can be regarded as renewable wealth of the state and hence a gift of Nature.

Introduction

Bamboos, in nature, exhibits two types of growth patterns-Monopodial and Sympodial. Monopodial bamboos are mostly small sized, branched profusely at the nodes, produced thin and broad leaves and have long creeping rhizomes, such creeping rhizomes called as leptomorph type can produce nodal outgrowths every year. As it extends long, further it produces more vegetative outgrowths and new culms are formed extensively in greater numbers. They produce fast growing culms and can cover a wide area with thick populations of new culms. Sympodial growth patterns are clump-forming and have pachymorph types of rhizomes and Caespitose in nature. The monopodial bamboos include species belonging to *Arundinaria*, *Melocanna*, *Pseudostachyum* etc. These three genera of bamboos are growing abundantly and extensively in the hills of Manipur. *Melocanna* can be listed in the first, second *Arundinaria* and *Pseudostachyum* at the third place. However, Melocanna can grow successfully in the plain areas too whereas Arundinaria and Pseudostachyum cannot grow. Mostly species under the genus Arundinaria are altitude-oriented and found to grow at high altitudes and also occupied the top of hills showing its dominant characteristics. *Arundinaria callosa* syn. *Chimonobambusa callosa* is a thorny bamboo of high altitudes. It can grow luxuriantly occupying wide spaces and with larger populations.

They love the foggy, moist, climatic conditions with acidic soil. They have thorns around the nodes, thick and dark green in colour. In rainy season of each and every year, new shoots come up from the rhizomes and undergo successful vegetative propagation in nature. The young shoots are harvested on a large scale by the inhabitants and made available in the local market for 3 to 4 months continuously. The young shoots are used in making different types of delicious curry in raw, and fermented forms. Even though, in the hardly undisturbed and disturbed forest areas, it still grows extensively shaping the landscape, preventing the soil erosion and functioning as wind breaker. It has manifold applications and utilizations. The mature culms are hard and thick and hence used in making poles of huts, in fencing and in making handles of knives and swords and in making walking sticks.

Therefore, keeping with the interesting viewpoints of observations on its growth pattern and ecofriendly nature, contribution to the socio-economy of the state and favourable climatic conditions and restricted growth, the present study has been made selectively and particularly on this bamboo.

Materials and methods

Material : A thorny bamboo, *Arundinaria callosa* Munro.

Local Name – *Laiwa*

Methods : 1) Field/Ground study on the spot in its natural habitat.

The natural habitat of this thorny bamboo is the hill tops or peaks. Ground was made visiting the spots during the months of April to July i.e. before the onset of winter season. This species was found to be extensively growing wild in the thick, undisturbed forest areas. Mostly the hill tops are covered densely by various types of vegetations and hence always remained cooled and foggy.

2) Taxonomic study based on criteria viz. Culm, Culm sheath, branching, Leaves & Phyllotaxy, Growth Patterns etc. (Photo 1)

3) Study on Plant Association – Mode & Population.

This bamboo is truely an ecofriendly plant. Mode of plant association was studied by observing the plants growing together on the spot. Observation was made regarding the ground vegetations too. The ground soil surfaces were found to be covered by different species of bryophytes, pteridophytes and small agiospermic plants etc. The population density was observed to be high. Population of culms were counted at equal distances from a fixed point.
(Quadrate methods). (Photograph 2)

4) Market Survey – Production, Price, Demand and Supply etc.

A survey was made at the main market places and local market of the state.

Young shoots of 2/3 nos. are tied into bundles and sold at the rate of Rs.5 to Rs.10. The fresh, edible shoots are preferred widely by the people of all caste and creeds. Mainly harvesting and selling works is done by the women folks. Both fresh and fermented ones are delicious curries of different taste and flavor. Price also varies from month to month

5) Role in Environment – Propagation and Conservation.

Mode of propagation and its abundance in the natural habitat was studied thoroughly. Vegetative propagation was observed to be very fast and fruitful. The new outgrowths grew extensively nearby the parent culms. Long running and creeping root system help in conservation in the particular eco system. Environmental factors like climatic condition, soil condition, rainfall etc. favours the natural growth of the plant. The plant is well adapted to the said environmental conditions.

Result and Discussion

Scientific Name	- *Arundinaria callosa*, Munro.
Local Name	- *Laiwa*
Habit	- Small sized, Erect, Thorny bamboo, Monopodial with
	1782 – 2500 msl and above.
	- Foggy & Moist climatic condition.
	- Soil Acidity 5.6 – 6.5 (P^H)
Most Associated	- *Teinostachyum* Wightii, Beddome.
Bamboo Species	And *Arundinaria rolloana*, Gamble.
Most Favourable Area	- Hill slopes away from sunlight, in Dampy areas.
Taxonomic Character	- Culm 12-20 ft; high; 05-1 inches in diameter; Nodes single-ringed, prominent; Thorns present more than 8; Internodes nearly solid at the base; Culm-sheath deciduous, longer than the internode, Hairy & grey in colour, Imperfect blade short, subulate long fringed, short auricles present; Leaf thin, Oblong-lanceolate, hairy above on the marginal veins, Pubescent beneath, Leaf-sheath striate, glabrous ciliate on the edges. (Photograph 3)
Utilization	- Young shoots & Tender stems are boiled & used in preparation of local curries.
	- Culms used in making handles of knives & spears.

	- Used in making weaving implements.
	- In making walking sticks.
	- In making fishing rod.
	- Roofing of huts, fencing the walls etc.
Growth	- Fast, highly successful in vegetative propagation on the onset of Monsoon.
Period of Propagation	- Mostly June to October each & every Year.
Harvesting	- New outgrowths i.e. shoots 2-3 ft. high are harvested every year. From rainy season till the month of October. Harvested in terms of lakhs.
Status in Market	- Plenty in the local market in the season, Highly demand, 3-4 months continuously available; Raw or Fresh are consumer's choice; Good income source, affordable price.
Resource Type	- Renewable, Regeneration fast & Forest Resources.
Role in Environment	- i) Helps in landscaping ii) Prevents soil-erosion iii) Keeps the surroundings cool and fresh iv) Helps in growth of many pteridophytes, Bryophytes, algaes etc. on the ground soil. v) Do not graze by the cattles & any other livestocks, because of the presence of thorns. vi) Sometimes acts as wind breaker. vii) Ecofriendly plant.
Conservation	- Wild in nature; well – adapted to the climatic conditions & range of altitudes; Rich diversity; Hence, Natural conservation is observed.

The above findings are made after strict and keen observations made on the spots. It is traditional of the local people too, to keep at least one culm with branches and leaves at the home. Very regularly every year in the month of March or April, people of Manipur State particularly Meiteis used to observe the New Year's Day just the next of new moon. Before this day, people used to climb the Koubru Hill and worship the deities there. At this time, this plant is collected and brings home with deep faith in mind of protecting from all the worses and evils of life.

Conclusion

From the above findings and discussions made it can be concluded that this bamboo is of utmost importance to the local people both from the angle of environmental protection and economic source. Now, the global issue of climate change is agreed to be the result of environmental deterioration. Deforestation and forest firing for cultivation and communication purposes will enhance the untimely disappearance of rich flora and fauna of a region. Climate change is also a man created and invited non-recoverable phenomena. Conservation is a continuous ongoing natural process. Man only disturbs such process by creating unlawful exploitation of forest areas. Adaptation is the best means of conservation in nature. Thorny plants are considered as morphologically and physiologically modified xerophytic plants, which can withstand the strong heats and hot winds of deserts. The desert conditions are tough and hard enough to withstand for the human beings. *Arundinaria callosa* is a thorny bamboo well adapted to the high altitudes and protects itself from freely moving speedy winds and frost. So, it is the right time to explore the natural and environmental principles and laws prevailed in the living planet to make our natural resources, a sustainable one.

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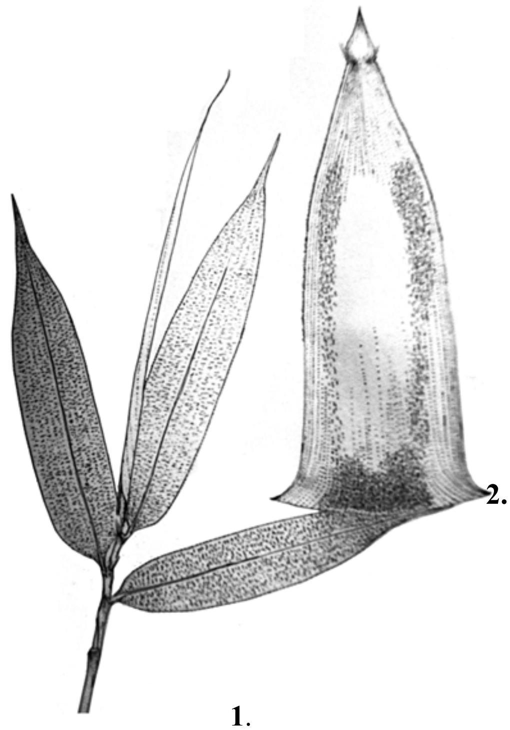

1.Leaf
2. Culm Sheath

Figure 1. Arundinaria callosa

Photograph 2 Arundinaria callosa in its natural habitat

Photograph 3 Thorny nodes of Arundinaria callosa

A Contribution to Flood Management in European Cities through Bamboo Plantations

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Abstract

In conventional wastewater management systems, the so called "end-of-the-pipe" system, Rainwater (RW) is an entire component of the collected effluent as it is mixed with urine (yellow water-YW), faeces (brown water-BW) and wastewater from sink and washing rooms (grey water-GW) before it is transported via pipes and discharged to the municipal wastewater treatment plant (WWTP). The system is well established as wastewater management system in most European cities. In the recent decades with the rise of water resources scarcity in many parts of the World and the necessity of managing flood in other parts, new approaches of RW management occurred. Among the modern techniques are recharge of groundwater through infiltration and RW harvesting. This paper is a contribution to infiltration methods. It proposes bamboo plant as filter medium to allow the runoff of RW to infiltrate and go back to the water cycle by enriching the groundwater reservoirs. It will provide the fundamental advantages of the system (RW infiltration through bamboo plantations) and will expose some limitations as well.

Keywords: Flood management – Rainwater - European cities - Bamboo Plantations – Ecological Sanitation

Introduction

Two fundamental environmental issues have caused RW to be considered differently starting from the last decades. The first one is water resources scarcity that many countries in the world as Mediterranean countries suffer. The second environmental reason relates the management of flood. The European continent falls within this latter issue. Greenpeace (2005) reported that more that 100 floods have hit Europe between 1998 and 2002, that made roughly 700 victims, rendered one half million of people homeless and caused economical loses of more than 25 billion EURO. The pick of this series of catastrophes in that period of time occurred in August 2002 (EU, 2004). Three years later (2005) stronger rainfall comes in by causing severe floods in Switzerland, Germany and Austria. As damages thousands of properties were flooded and hundreds of people forced to leave their homes. Figure 1 below is the European continent; the flooded area in the countries mentioned above is shown in red.

This alarming situation results from the combination of different factors: among them are climate change that increases the ambient air temperatures, resulting to more and more rainfall. The sealing of soils with constructions from the development of cities reduces cultivable lands and consequently increases the runoff of rainfall. The overall direct consequence is overwhelming of wastewater treatment infrastructures with huge volume of wastewater. It is not to mention the induced consequences in terms of dramatic increase of investment costs for construction and maintenance of wastewater treatment plants. It makes sense therefore to consider RW separately by not mixing it with the other effluents to reduce the volumes arriving at the WWTP and therefore reducing the risks of flood. In doing this a key point is to infiltrate the effluent near to the source. Searching for new ways in municipal water management, decentralised solutions for the rainwater runoff must also be found as a matter of course in order to refill the aquifers when using them for local water supply (Otterpohl et. al., 2002). Furthermore in nowadays researches on RW management, Matsushita et. al., (2001) reported that infiltration is seen as one of the best methods to let RW back to the natural water cycle.

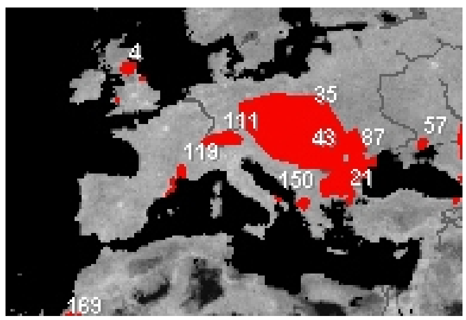
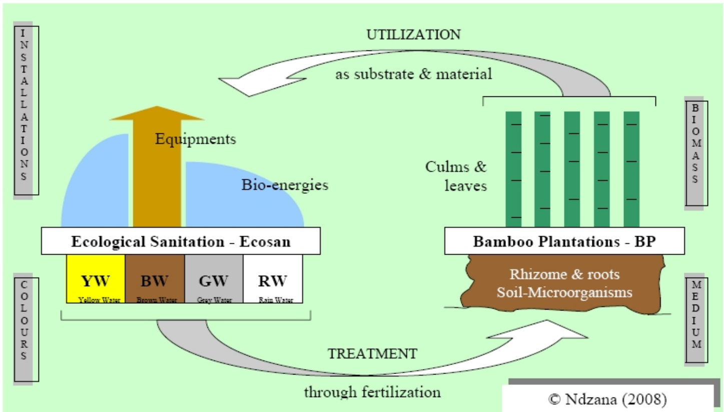


Figure 1. The most flooded area in Europe, August 2005

The most known techniques that allow the infiltration of RW include surface infiltration, hollow infiltration, infiltration in trenches, tubing infiltration or pit infiltration. Surface infiltration through a bamboo plantation (bamboo filter: the Bamboo Plantation Rain Water Management-BPRWM) is the purpose of this paper. In fact at the Institute of Wastewater Management and Water Protection of the Hamburg University of Technology-TUHH a research work on Wastewater Management with bamboo plantations is going on. Figure 2 below presents a simplified structure of the research (the ecosan-bamboo concept) where the waste streams of Ecological Sanitation-ecosan (a decentralized approach of sanitation -with source separation collection and treatment of the waste streams- that aims at nutrient recovery and water reuse for agricultural purposes) are collected and treated separately in the underground part of bamboo plantation (rhizome and roots). In fact bamboo utilizes water and nutrient content of these streams to grow. This results in the production of biomass that could serve the ecosan system again in terms of construction of ecosan superstructures or feeding bio-energy units.



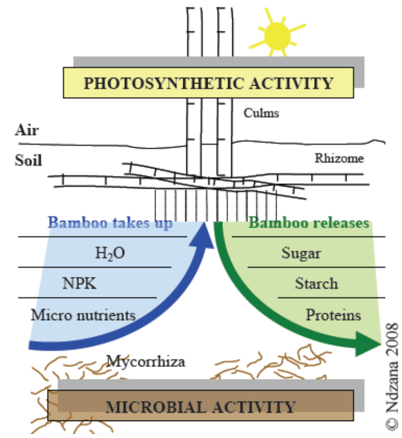


Figure 2. Figure 3

Figure 2. The Ecosan-bamboo concept (source: Ndzana, 2008)

Figure 3. Simplified bamboo nutrient uptake mechanism (source: Ndzana, 2008)

On the one hand the system developed at the mentioned Institute has potential for implementation in Europe: because the sewer system for RW exists in most European cities RW can be diverted with control. This means that in the existing RW sewer system, measures to take can be put in place so that RW is diverted with control on the catchments' area of runoff and volumes diverted. On the other hand the potentialities of bamboo allow it to act as a filter medium of wastewater. Bamboo plantations possess a very dense underground structure governed by the rhizome that grows continuously during the whole life of the plant. The rhizome system constitutes the structural foundation of the plant, in which nutrients are stored and through which they are transported (Liese, 1985). Because bamboo is the fastest growing plant on the Earth (Villegas et. al., 1990) it has potential to take-up large quantities of nutrients. A simplified mechanism of nutrient uptake is shown on figure 3 above. The combined actions of microbial activity in the soil through mycorrhiza and the photosynthetic activity through sunshine provided to bamboo plant allow it to use water and absorb macro and micronutrients. In turn the bamboo plant will basically release sugar, starch and proteins into the soil for the benefit of soil microorganisms. Moreover the plant is regenerative; once it is planted there is no need to replant it rather is there a need of harvesting the mature culms. Although bamboo is an exotic plant for Europe, it develops very good and normally there. Bamboo was reintroduced in Europe in the 20s from Central China and Japan (Eberts, 2004). The project "Bamboo for Europe" is the living fact not only for the interest of Europeans in bamboo, but also the scientific proof that bamboo can contribute efficiently to some extend and remedy or alleviate some environmental treads such as flood within the European Community.

The concept of infiltration of RW through the bamboo filter will be presented and the paper will discuss the main advantages provided and limitations for the system.

Materials and Methods

The experimental set-up

A schematic experimental set-up of one of the installation in which investigations are performed is shown on figure 4 below. Basically it is a container –called reactor in this paper- of 160 litres in which bamboo is planted. Openings were made at the bottom pat of the reactor to allow effluent collection. The reactors are in open air inside the inner yard of the Institute. The soil in the reactor is of two different layers; the first layer is the top soil in which the rhizome and the roots of bamboo plants are lain. It allows rapid percolation of influent through the reactor. The second layer is a gravel layer of 5.00 cm that enables the rapid leaking of influent arriving from the upper part. Grown bamboo plants were transplanted from a living stand of the Botanical Garden of Hamburg and put into the containers. The bamboo specie used is Phyllostachys *viridiglaucescens* (P. *viridiglaucescens*), a hardy bamboo specie that resist winter temperatures up to -22°C.

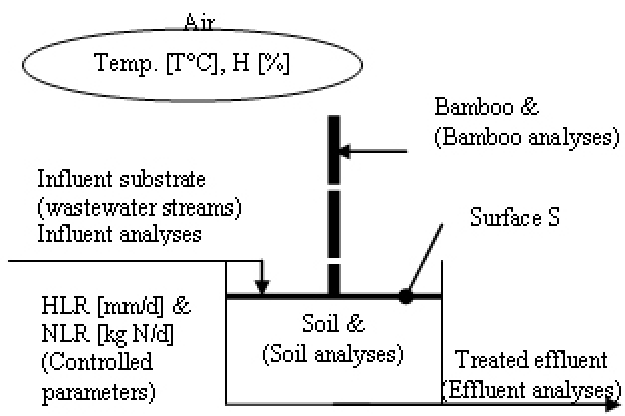


Figure 4. Schematic experimental set-up

Soil characteristics

The soil in the reactor is a mixture of compost, sand and crushed bark. It will be called soil in this paper. The proportion of each component is shown in table 1 below. The nutrient content of soil was analysed for the macronutrients Nitrogen (N), Phosphorus (P), Potassium (K) and Magnesium (Mg) according to LUFA (Landwirtschaftliche Untersuchungs-und Forschungsanstalt) method of measurement "Gehaltklasse von LUFA" as presented in table 1 below. The composition of soil achieves permeability between 10^{-6} and 10^{-3} m/s. According to LUFA method a normal soil contains from 8 – 12 mg/100 g Mg. Because the Magnesium content of soil was very low (see table), 10 g Mg in form of $MgSO_4$-$7H_2O$ was added in each reactor in a soluble form by mixing with tap water. In fact Mg plays a very important role in the photosynthesis of plants for nutrient absorption. The pH and conductivity of the soil were measured by using the German standards methods for soil and analysis.

Table 1. Soil characteristics and pH and conductivity

Soil								
Composition			Nutrient content (mg/100 g)				pH and conductivity	
Compost	Sand	Crushed bark	N (kg/ha)	P	K	Mg	pH-$CaCl_2$	LF
85%	10%	5%	< 40 little	16–30 normal	> 50 over fertilized	1-4 poor	6,17	-0,31

The issue of acid rain occurs only in highly polluted urban areas. It sometimes causes RW to be regarded as a problematic source of water. But RW is basically a very good source of water as it contains a very limited amount of pollutants. In fact the nutrient content and organic matter of RW is insignificant compared to those of urine or grey water, making RW to be an important component of water resources. Due to its low nutrient content the matter of RW management by the bamboo filter relies not in the nutrient uptake aspect rather on the evacuation of RW through percolation in the bamboo filter, thus on the capacity of the bamboo bed to act as a filter for RW. Therefore RW is not percolated through the reactor rather a mixture of urine and tap water (which contains much more nutrient than RW) to investigate the long term effect about bamboo filter clogging in case some nutrient remains in it that may disturb the basic role of the bamboo filter bed: filtration. The substrate is a mixture of urine and tap water (U+TapW). High rates nutrient content of substrate based on urine nitrogen were defined: 400, 800, 1200 and 1400 kg N/ha/a. The substrate was feed into the 9 reactors (3 for 400 kg N/ha/a, 2 for 800 kg N/ha/a, 2 for 1200 kg N/ha/a and 2 for 1400 kg N/ha/a) so that less losses of nutrient from the effluent occur as the clogging effect due to nutrients is researched.

Concept of diversion of RW

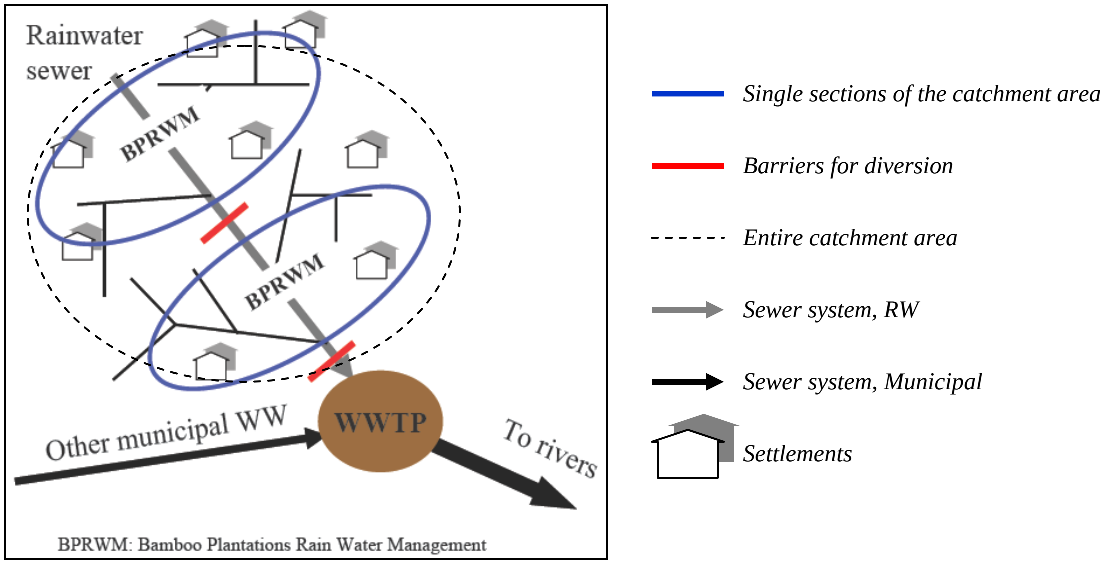


Figure 5. RW diversion concept

Figure 5 above is the concept of diversion of RW in a given area where a sewer system of RW exist and conveys RW into the sewer system of wastewater prior to treatment at the WWTP. The aim of it is to divert RW from its conventional flow line and rather infiltrate that influent into the aquifer with the use of the bamboo filter: the BPRWM. The entire catchment area (interrupted circle on figure 5) corresponding to a collection line of RW is broken down into single sections (oval blue line on figure 5) by introducing nodes in the main RW sewer (see on figure 5 the red divisions). These are sort of barriers (seen in red on figure 5) that prevent the flow of RW in the main collection line continuously rather favour the gathering of RW in the corresponding single section. Fundamentally the RW sewer system is not destroyed rather participates in the collection of RW on a given single section of the catchment area. Technically this is feasible as the collection of RW to the main drain that leads directly to the WWTP is done by gravity and RW converges therefore towards the same point. Where necessary depending on the slope of ground in place the gathering of RW may need a pumping system. Bamboo filters are installed within each single section of the entire catchment area. The topography of the entire catchment area is an important factor in the breaking down of it into single sections. Thus single sections of the entire catchment area will be of different sizes.

Results and Discussion

Clogging effect due to nutrient content of substrate

Figures 6 and 7 below are respectively results about the Total Organic Carbon removal from the substrate (TOC) and the uptake of phosphorus by the system soil-bamboo as function of nutrient content of the substrate. For figure 6 the TOC removal efficiency varied from 74.6, 87.1, 90.8 to 91.1 respectively for 400, 800, 1200 and 1400 kg N/ha/a. Independently of the nutrient content of the substrate nearly 250 mg/l organic carbon was found in the effluent. For figure 7 the uptake of phosphorus by the system soil-bamboo was nearly 100%: 97.9% as average for all reactors. In order to separate the activity of soil from the one from bamboo the conductivity the conductivity in the top soil was measured. Initial soil conductivity at the beginning of the experiment was 201 µS/cm. In the course of the study it decreased (detail results are not shown) in all 9 reactors. An average decrease was 37%, meaning that the salts content of the soil decreased as conductivity correlates with salts content. This result was not expectable as usually addition of urine to the soil for certain crops such as vegetables results in the increase of conductivity (Pearson et. al., 2007). In the case of bamboo the decrease of salts concentration in the top layer of soil can be explained by the statement of Kleinhenz and Midmore (2001) that the top soil of bamboo stands is typically aerated and natural mineralization of nutrients is usually quicker there than in the deeper layers. The effectiveness of absorption of plant-available ions by the dense root system of bamboo is in this horizon. This explains the other well-known statement that bamboo plants sequester nutrients in its top layers. Further investigations are carried out on the nutrient content in bamboo culms and soil to confirm and comfort this thesis.

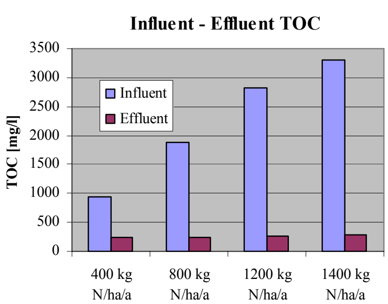


Figure 6. Influent and effluent TOC

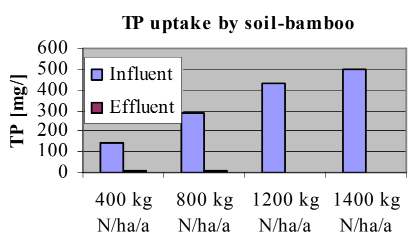


Figure 7. Total Phosphosrus (TP) uptake by soil-bamboo

The bamboo filter design in a single section of the catchment area

The design of the bamboo filter (BPRWM) is presented with its efficiency in terms of rough calculations and the advantages and its limitations mentioned and discussed. The calculations are made for a city like Hamburg, with relatively high rainfall in Europe (800 mm/a). The demonstration case is considered to show how the diversion is done and the bamboo filter is installed within the settlements for the infiltration of RW into the aquifer. Figure

8 below is a plan view of a single section of the entire catchment area within which the bamboo filter is installed. The settlement concerned in this single section is composed of 6 buildings for which the bamboo filter is dimensioned. The RW flow in the main sewer (see in grey colour in figure 8) is interrupted by

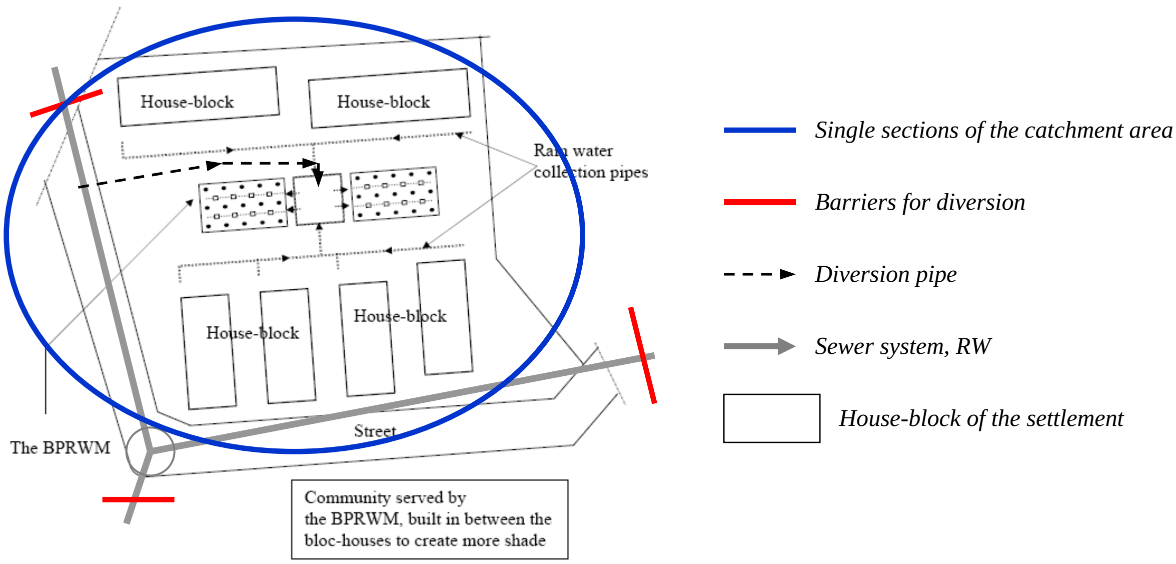


Figure 8. Plan view of single section of catchment area including the bamboo filter

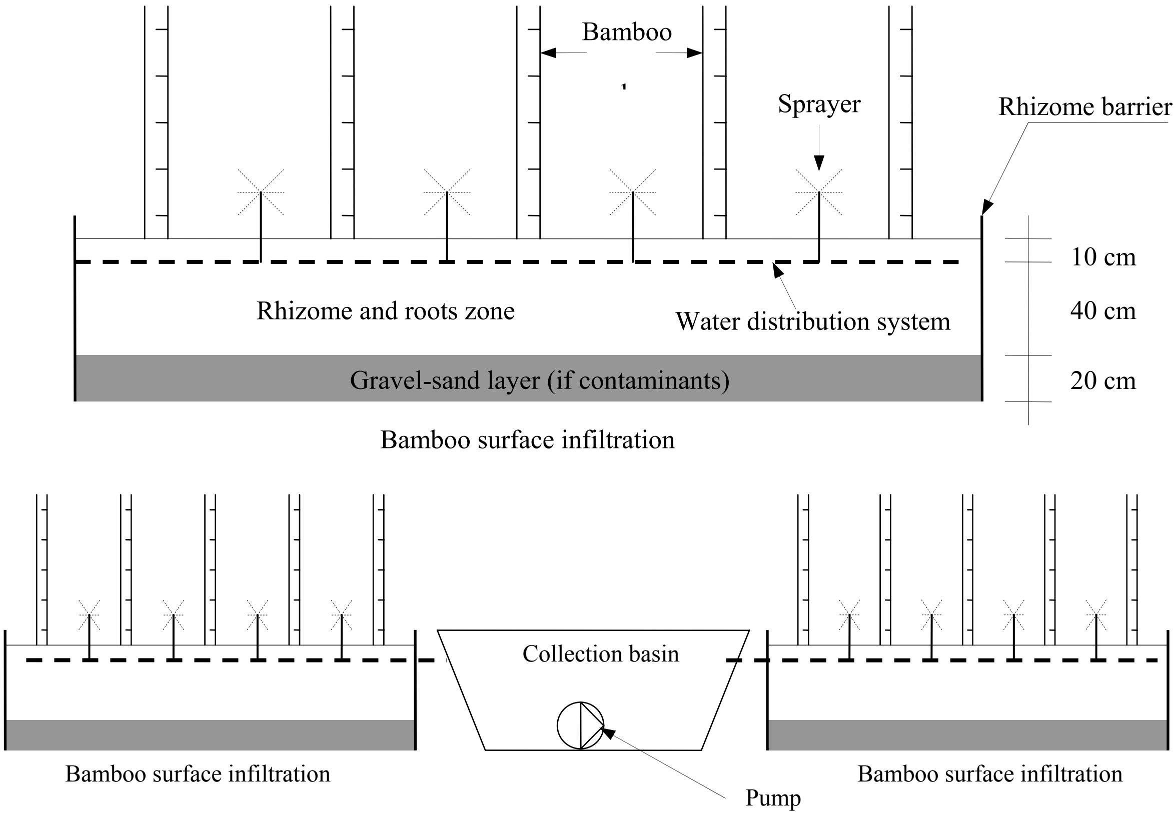


Figure 9. Cross section of the bamboo filter; the collection basin and the bamboo surface infiltration

barriers (see in red on figure 8) that provoke diversion to the bamboo filter via pipe; the diversion pipe (see black interrupted arrow on figure 8). Depending on the case according to the slope of the ground a pump may be needed at the junction of the main RW sewer and the diversion pipe.

The design of the bamboo filter shows a collection basin (in the middle) and two bamboo surface infiltration beds placed each by side of the collection basin. (see figure 8). While being an infiltration area, the role of the collection basin is to gather the RW diverted from the main sewer and to evacuate RW on the bamboo surface infiltration beds in an intermittent fashion at regulated velocity via a piping system (see water distribution system on figure 9). It must allow a retention time of 3 days rainfall on the surface considered. The pump in the collection basin pumps the gathered RW to the bamboo surface infiltration beds through the piping system that could be installed above ground or a few centimetres in the top soil of the bamboo filter. The water is spread on the bamboo infiltration bed through sprayers as shown on figure 9 above.

Calculations for design

The stormwater source control design guidelines (2005) stipulate that the amount of space required for stormwater source controls is a direct function of: the volume and intensity of rainfall hitting the site, and the associated rainfall capture target, the amount of impervious area on the site, the area of infiltration surface on the site, the rate of infiltration into the infiltration surface, the amount of rainfall storage that can be provided to temporarily hold water until it can infiltrate into the ground.

Assuming a single section area of 10.000 m², a rainfall capture target of 50 mm, 15% of impervious area on the single section with consideration of an average infiltration rate of 10^{-5} m/s and 10% infiltration from the collection basin per day, the total area needed for infiltration (bamboo surface infiltration) and the volume of the collection basin can be determined:

Volume of the collection basin $[V_c]$:

$10.000\ m^2 * 15\% * 50 * 10^{-3}\ m * 3\ days = 225\ m^3$

With consideration of 10% daily infiltration from the collection basin,

$[V_c] = 225\ m^3 - (10\% * 225 * 3\ days) = 160\ m^3$

If $[V_c]$ is to evacuate in a max. time of 3 days, the total bamboo surface infiltration bed $[S_b]$ is:

$[S_b] = 160\ m^3 / (10^{-5} m/s * 24 * 60 * 60s) * 3\ days = 560\ m^2$

Because there are 2 bamboo infiltration beds, each bed will be an equivalent of:

560 m² / 2 = 280 m² (chosen dimensions: 10.00m width and 28.00m length)

The spacing of bamboo in the infiltration bed is chosen 1.00m * 1.50m that is also the spacing suggested by Gielis (2000) during the trials in the framework of the project "Bamboo for Europe". With this spacing Gielis (2000) got good growth response of some bamboo species. The higher spacing density for Europe is comprehensible when consideration is made on the fact that bamboo is an exotic plant for Europe and therefore will grow relatively slowly compared to origin land where the spacing density is lower. Bamboo species to use for the infiltration bed will include Phyllostachys (P) species such as P. *aurea*, P. *nuda*, P. *aureosulcata 'spectabilis'* which showed good performance in growth in the trials of Gielis (2000). Other could be P. *viridiglaucescens* (the one used in this study) and P. *vivax* which produce bigger culms compared to the other species, although the last one in the study of Gielis did not perform as well as the others. All of them are running type of bamboos that possess a spreading growth pattern through the rhizome; they will be preferably used.

Advantages of the bamboo filter concept

The implementation of the bamboo filter concept in European settlements will provide many advantages. First of all the bamboo filter concept embedded on the diversion of stormwater for the purpose of safe infiltration of collected water into the groundwater is a contribution to water resources management. This basic role will involved obviously the reduction of volume of water that flows to the WWTP and thus reducing and even avoiding flood risks if more and more units are implemented in a given entire catchment area. This will impact on the investment costs for WWTP that will drop down considerably. Additionally putting in place the bamboo filter concept will allow soil stabilization and therefore preserve fertile soil because the system favours infiltration as near as possible to the source, at the single section of the catchment area considered. Moreover running bamboos tend to spread laterally in the 50 cm of top soil rather than growing in depth. Environmentally speaking and when the bamboo filter is established (after 6 to 7 years) it will provide shadow and could be used as recreational area. After that period of time, it is expected to harvest first culms from the bamboo filter beds; these could be reused for several purposes.

Limitations of the bamboo filter concept

The bamboo filter intends not to be a solution for every single case rather a contribution wherever possible. The bamboo filter must be seen as an alternative among the possible solutions to remediate the question of flood risks in Europe. First of all the concept will require the provision of enough space. In the example above, approximately 600 m² are needed for the 6 house-block erected on roughly 1.00 ha. This might represent in some cases enormous piece of land, especially in the inner parts of cities where most land have been sealed with constructions and buildings. Provided that the space is not a limiting factor, there is the need of careful analyses of preparation steps prior to implementation. These relate: the provision of bamboo plants and related costs, the entire catchment area and its associated sewer system of RW in order to understand how it will be broken down into single sections, soil analyses where the bamboo filter concept will be erected. The bamboo filter concept must be planned for an entire region (corresponding to a given catchment area) in order to impact significantly on the risk of flood. Therefore as several units need to be installed the associated investment analyses must be run. Harvesting grown bamboo culms might be a problem in some cases where the use of it is irrelevant. Bamboo leaves must be removed periodically, especially in summer time. But this is also the case with other trees planted within the settlements near roads or on recreational areas.

Conclusion

Flood is more and more hitting many parts of the World and Europe is not at rest about it. This paper is a rapid investigation on the possible contribution of bamboo in terms of the bamboo filter concept (BPRWM) to reduce the risk of flood in European cities. The existing RW sewer system in most European cities is a good and precious starting point for diversion of RW as the BPRWM sectioned the main sewer into single sections to infiltrate the water as soon as it rains by reducing therefore the runoff. Provided that there is sufficient space and good analyses prior to the implementation is performed, the BPRWM can efficiently participate to flood risk avoidance. The efficiency of the BPRWM concept is at sight if planned for an entire catchment area of RW. A single unit will not impact on flood risk unless the system corresponds to the given catchment area. The BPRWM concept is also suitable in planned residential area; in this case diversion is directly done from each single catchment as no sewer system for RW is necessary to construct. The implementation of the BPRWM concept will automatically induce some further benefits for the sake of the environment including water resources management, soil stabilization. Furthermore recreational areas will be created within the settlements.

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Energy Crops in Western Europe: is Bamboo an Acceptable Alternative ?

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Abstract

Most attention in Western Europe goes to the classical bionergy crops poplar, willow and *Miscanthus*. However, several other plants are useful candidates to provide biomass for the production of electricity. Bamboo is among them. Pilot tests of bamboo growth in Ireland show that bamboo produces enough biomass, even under a rather adverse climate, to make the plant economically an equal investment as the classic crops. Moreover, bamboo tends to have a higher capacity for uptake of heavy metals than poplar and willow, offering possibilities for an efficient combination of biomass production and heavy metal phytoremediation.

Introduction

Given the ambition of the European Union to enhance the production and consumption of renewable energy types over the next decade (Commission of the European Communities 2006, 2008; Martinez de Alegria Mancisidor et al. 2009), as well as the current state in nearly every one of the Member States, a large effort will be needed to provide the means to make these plans come true. Second generation biomass products are currently most welcome as alternatives, albeit to be used in the future in combination with third generation fuels (transgenic carbon dioxide neutral crops) and fourth generation (transgenic carbon dioxide negative) fuels (Gressel 2008).

Currently, *Miscanthus*, *Salix* and *Populus* are best established as second generation biocrops for cultivation in Europe (Commission of the European Communities 2006, http://www.eubia.org/192.0.html and http://www.eubia.org/193.0.html). However, several other species might contribute to the production of biomass for fuel production. There is an emerging interest into oil from *Jatropha* (Achten et al. 2008) for the deciduous legume tree *Pongamia pinnata* (Mukta et al. 2009; Murugesan et al. 2009), or in the usage of waste material (Felizardo et al. 2006).

A source of biomass that should not be forgotten is bamboo (Scurlock et al. 2000; Atkinson 2009). Bamboo is one of the fastest growing sources of biomass on earth with an unsurpassed regeneration potential. In this paper, we first analyse whether it is opportune to use bamboo as an energy crop in Europe, outside its native region. We will then compare bamboo with the three energy species that are best characterised (*Miscanthus*, willow and poplar) in terms of biomass production, energy production and phytoremediation potential.

Bamboo As An Energy Crop

Woody bamboos have usually been considered (Ohrnberger 1999) to belong to the tribe *Bambuseae* Kunth ex Nees within the *Bambusoideae,* a subfamily within the grass family *Poaceae*. This tribe contains 1200-1300 different species, divided over 130 genera of woody bamboos and 25 genera of herblike plants that function for the most part as undergrowth in forests. Bamboos are endemic to all continents, except for Europe. In Europe bamboo fossils dating back to the last Ice Age have been found and bamboos have been cultivated intensively for the last 150 years. The plants grow via a rhizome system from which hollow culms originate. Depending on the species, these culms can attain a diameter of up to 20 cm and a height of 10-30 m (El Bassam 1998; Scurlock et al. 2000).

Bamboo has several characteristics that might be useful for future energy plantations (Scurlock et al., 2000):

- As mentioned above, there is the high growth rate (Shanmughavel and Francis 2001; Scurlock et al. 2000 and references cited therein).
- Once properly set up, a bamboo plantation needs little care. Bamboo grows due to an extensive underground system of roots and rhizomes; this system not only procures a regular regeneration of the harvested parts above ground, but also protects scarcely vegetated soils from wind or water erosion (El Bassam et al. 2002; Scurlock et al. 2000).
- Bamboo can be used as a bio-fuel, short-circuiting the current CO_2 cycle, which draws on fossil fuels. This will offer an advantage in terms of greenhouse gas production.
- Bamboo does not need to grow on optimal agricultural land (which remains available for food crops), but can withstand a certain level of pollutants. It remains to be seen, however, to what extent.
- A bamboo plantation requires 5-7 years to achieve full maturity. Even during that time, though, management is quite inexpensive in terms of effort and costs. During the first two years, maintenance consists mainly of weed control, and possibly adding organic fertilisers. Once the plantation reaches maturity (after 5 years), it will maintain itself.
- Harvested bundles of bamboo can be kept for at least 3 months (Gielis 2000; Temmerman et al. 2005). Combined with an optimal harvesting season of 6 months (from October to March), this means that bamboo can be supplied as raw material to the industry for about 8-9 months per year, offering the possibility for a nearly year-round, rather steady supply of biomass for energy production.
- The preferred method of harvesting the bamboo plants depends on the intended use for the plants and on the available options for storage of the harvested biomaterial. Harvesting for future combustion occurs mechanically by use of a light-weight short rotation forestry harvester, which harvests the culms completely and chips them, if desired. This bamboo biomass can also be transformed into bricks or pellets, or be gazified.

These advantages notwithstanding, concerns have been raised that bamboo species are an exotic species in (Western) Europe. Failure to contain bamboo plants to the plantation areas (due to its spreading rhizomes) might therefore impact the development of nearby (natural) ecosystems, and past experiences with other exotic, potentially invasive species, has provided plenty of reasons for a genuine concern. In the case of bamboo, however, spreading is easy to contain if taken into account from the start. With a few very simple solutions (such as the use of commercially available polyethylene sheets, to be put in the soil around the plantation at a depth of 50-70 cm), the rhizome outgrowth can be effectively blocked. Moreover, given the propensity of a bamboo stand to set flowers simultaneously throughout the entire stand (Janzen 1976), the formation of (limited) seed formation and dispersal can be avoided by harvesting the stand upon the onset of flowering.

Bamboo Yield In Europe

Bamboo growth has been studied with great care in India and the Eastern Asia. El Bassam (1998) mentions bamboo yields between 1.5 t ha^{-1} (for *Thyrostachys siamensis*, grown in Thailand) and 14 t ha^{-1} (for *Phyllostachys bambusoides* grown in Japan). The highest yield has been attained in a field test in India, focusing on *Dendrocalamus strictus*, leading to a production of 27 t ha^{-1} after 18 months at a density of 10000 plants per hectare. This test also demonstrated that bamboo produces most biomass when growing at a high density (albeit with smaller plants), whereas lower densities produced sturdier culms, but lower biomass yields. Lastly, in a study in India, optimal fertilization was determined to be 100 kg N, 50 kg K_2O and 50 kg P_2O_5 per hectare, resulting in a threefold yield (El Bassam 1998).

Little is known about the growth of bamboo in Western Europe. In 1990 the Federal Agricultural Research Center in Braunschweig, Germany, investigated the biomass production of 17 different bamboo genotypes. On the average, these plants produced 7 t dry matter (DM) ha^{-1} y^{-1}, attaining a shoot height of 3 m and around 200 shoots per clump. A plantation established in 1996 in Belgium of *Phyllostachys vivax, Phyllostachys aureosulcata* and *Phyllostachys praecox* was assessed to produce 10-13 DM ha^{-1} y^{-1} for *Phyllostachys vivax* and 4-5.5 ton DM ha^{-1} y^{-1} for the other two species (Temmerman et al. 2005).

While few, these studies indicate that bamboo offers some possibilities in terms of biomass production, even in Europe, a region without any endemic species. This has prompted more recent research into the possibility of growing bamboo in Western Europe. In May 2005, a 0.4 ha bamboo plantation (for research use) was set up in the Irish village of Ballyboughal (Co. Dublin, Ireland) on a field that had been used previously for vegetable growing. Four species were planted: *Phyllostachys humilis, Phyllostachys decora, Phyllostachys bissetii* and *Phyllostachys aurea*. The plants were planted at a density of 2500 plants per hectare. Before planting, the field was sprayed with glyphosate, and plowed both in February and April. No fertilizer was added given the high quality of the loam clay soil. A second herbicide treatment (Simazine) was performed right after planting ; three more treatments were exacted during the year 2006. Irrigation has been performed in the dry summer of 2005, but not in 2006. From 2007 onwards, no further actions were undertaken. As an aside, it should be noted that, although *Phyllostachys* sp. are known for their aggressive rhizome outgrowth, and although no rhizome fencing had been installed at the time of planting, no escaping bamboo plants have been noticed.

A manual harvest of a strip of 5 m wide, performed in April 2008, resulted in the yields given in table I. The plants were tied together before harvesting, cut at 10 cm above the soil and left in a nearby shed to dry for three months. For all species involved, this led to relative water contents between 20% and 27%. Extrapolated yields ranged from 7.7 t DW ha^{-1} (for *P. bissetii*) to 17.65 t DW ha^{-1} (for *P. humilis*).

Table I. Bamboo yield in a pilot plot in Ballyboughal, Co. Dublin, Ireland

	P. humilis	*P. decora*	*P. bissetii*	*P. aurea*
Area (m x m)	5 x 3	5 x 3	5 x 3	5 x 11
No. of plants	9	9	8	32
Fresh weight (kg)	34.56	21.53	9.86	61.1
Dry weight (kg)	26.47	17.22	7.7	44.57
Relative water content	23%	20%	22%	27%
Extrapolated yield (t DW ha^{-1})	17.65	11.48	5.13	8.10

For future economic implementation, bamboo should be harvested between growth seasons (October to March). During these months, other mechanical harvesters (corn harvesters, sugar cane harvesters, …) are usually not used for other crops. This offers the possibility of economizing the use of this expensive equipment – in autumn, corn can be harvested, while bamboo can be harvested during the winter. Moreover, the rhizome system can support the (considerable) loads of these harvesting machines. A tractor for chipping equipped with rubber tires exerts a load of 0.5 kg/cm^2. On the other hand, when one is reduced to use forestry harvesting machines, weighing up to 14 tonnes and exerting 1 kg/cm^2, this may lead to serious compaction and damage to the winter wet soils and the rhizome system, as shown in the EU-FAIR project "Bamboo for Europe" (Gielis 2000).

Bamboo Biomass Represents Energy Potential

The next question in this study focuses on the use of the produced bamboo biomass. It is evident that any new energy crop should guarantee a high level of energy production, whether it is a woody plant to be used for electricity generation, or for the distillation of bioethanol or biodiesel.

The physico-chemical characteristics of bamboo make it a good biomass fuel for classic combustion. It is composed of easily harvested woody tissues, containing cellulose, hemicelluloses and lignin, with an average calorific value of 18.3 MJ/kg, which falls within the range of wood species of 18.2 to 18.7 MJ/kg (Scurlock et al. 2000; El Bassam 1998). Bamboo is therefore a biofuel source similar to other woody fuels, with the exception of the mineral content, which is higher (2.5 % dry basis) for bamboo than for wood (1 % dry basis), although this was not confirmed in the Bamboo for Europe project. Bamboo wood thus is comparable to other woody plant material. On the other hand, Bamboos have a nitrogen and sulphur content that is lower than that of other potential bioenergy, leading to a smaller exhaust of the pollutants nitric oxide and sulphur dioxide (Scurlock et al. 2000).

El Bassam et al. (2002) reports the pyrolysis of bamboo biomass (90% stem and 10% leaves) at 487°C. Approximately 70% of the fed material was converted into pyrolysis oil (bio-oil) which can be used as a fuel. Bamboo is also an interesting material for producing charcoal. The calorific value of bamboo charcoal (31.66 MJ/kg) is equivalent to the calorific value of beech and poplar charcoals. The mass yield is higher (33 % on initial anhydrous mass) than for wood (29 % on initial anhydrous mass) carbonised in the same conditions of temperature, residence time and heating rate. The production of non-condensable gases is also higher (26.5 % vs. 18-20 %), while the tar production is lower (42 % vs. 50 %). Differences in volatile matter yield and composition are also noticed. These differences observed in bamboo carbonization result from the cutinized inner and outer layers of bamboo culms. This particular structure limits the gases outflows from the solid to the surrounding environment. This is favourable for the secondary pyrolysis reactions: cracking of heavy tars, recombination of volatile carbon with the fixed carbon structure.

As a final remark - the annular structure of bamboo culms makes it a very aerated and bulky fuel if used in rings or sticks. This means that bamboo would burn very quickly and would request bigger combustion or gasification chambers to obtain the same heating rate. However, if bamboo culms are chipped, these drawbacks are avoided. Bamboo chips are a suitable fuel for fluidized bed combustors and spreader stoker boilers. Bamboo can be adapted to briquette production and gasification using the same procedures as for as other species such as pine tree or eucalypts.

Economic comparison between willow, poplar, *Miscanthus* and bamboo

Based upon the energy content and the culture method for bamboo described in the previous paragraphs, as well as the culture methods described by El Bassam (1998) for *Miscanthus*, willow and poplar, we can now evaluate the different energy crops in terms of rentability. To this end, we will compare the classic biofuel crops for Western Europe with *Phyllostachys* sp., using the yield data from the preliminary trial in Ballyboughal (Table I), and using a cost structure which would be typical for our own region, Flanders (the northern part of Belgium). Given the fact that Flanders has a climate that is equal to or even milder than the climate in Eastern Ireland, bamboo yields can be expected to be equal as well.

The costs for initiating and maintaining an energy plantation are represented in table II.

Table II: Cost in €/ha of Agricultural activities for set-up and maintenance of bio-energy plantations in Flanders (Belgium).

Activity	cost (€/ha)	Reference
field preparation (plowing-harrowing)	225	[b]
mechanical weed removal	50	[b]
herbicides	50	[a]
fertiliser	50	[a]
planting willow	450	[a]
planting poplar	450	[a]
planting *Miscanthus*	450	[c]
planting bamboo	450	[c]
lease agricultural land	216	[b]
harvesting willow	850	[a]
harvesting poplar	850	[a]
harvesting *Miscanthus*	237	Styles et al. 2007
harvesting bamboo	250	[c]
storage and drying wood chips	110	Styles et al. 2007
removal willows	1850	[a]
removal poplar	1850	[a]
removal *Miscanthus*	207	Styles et al. 2007

Estimates are based upon data from [a] the Research Institute for Nature and Forest (INBO, Flanders, Belgium) (given in Meiresonne 2006), and from [b] the Department Agriculture and Fisheries of the Flemish regional government; through personal communications of [c] Dr Victor Brias of Oprins Plant NV, and the last author.

Willow and poplar cuttings were estimated to €0.08 apiece (Meiresonne, 2006). The cost for *Miscanthus* plants was derived from Styles et al. (2007) and set at €0.13 for a plant. Young bamboo plants (taken as rhizome cuttings) were estimated at €0.5 for a plant. The cost of leasing an area of agricultural land in Flanders was set at €216 (Department Agriculture and Fisheries of the Flemish regional government, 2008). It should be remarked, that this price may be lower if the plantation is set on marginal land. Chipping was estimated to cost €10/tonne DM ; the resulting chips were sold at an average price of €130 per tonne DM. Willow and poplar plantations can be harvested every three years. Miscanthus and bamboo can be harvested yearly. Finally, the Flemish government offers in addition a subsidy of €552 per ha for the production of biomass on agricultural soil (Department Agriculture and Fisheries of the Flemish regional government, 2008).

Estimates for the yield of a plantation were 6 t ha^{-1} y^{-1} for willow (averaged from Scholz and Ellerbrock 2002), 6.5 t ha^{-1} y^{-1} for poplar (averaged from Laureysens et al. 2004), 10 t ha^{-1} y^{-1} for *Miscanthus* (averaged from El Bassam (1998) and Boehmel et al. (2007), and corrected for the survival rate of less than 50%, as reported by Eppel-Hotz et al. (1998)). The yield of bamboo has been taken from table I (for *Phyllostachys humilis*) and corrected cautiously for what could be produced in one year. Willow and poplar were simulated for resp. 21 and 26 years, *Miscanthus* for 15 years (according to El Bassam 1998). Bamboo is not restricted by this life span, but the analysis was performed for 30 years.

All these data and considerations have lead to a general economic comparison between these different crops, as presented in Table III. Figure 1 gives the course of the net present value over the years. This is the value of the plantation and its products, corrected for the interests to be gained in a high risk investment such as an energy crop plantation. Based upon the fact that a bamboo plantation has the highest return on investment and the highest net present value after 30 years, bamboo can be considered at least equally useful as (and potentially more interesting than) the other three bio-energy species.

Table III. Economic comparison between willow, poplar, Miscanthus and bamboo upon production in Europe

	Willow	*Poplar*	Miscanthus	*Bamboo*
Survival	*97.6%*	*86.3%*	*49.7%*	*90%*
Yield (t ha^{-1} y^{-1})	*6*	*6.5*	*10*	*10*
1 ton pellets : cost (EUR)	*177*	*169*	*200*	*172*
Net present value (EUR)	*4083*	*5318*	*2886*	*7910*
Internal rate of return	*26%*	*30%*	*22%*	*29%*
Payback period (years)	*4.5*	*4.08*	*4.75*	*5.25*
Return on investment	*675%*	*965%*	*408%*	*1574%*

Bamboo Is Able To Decontaminate Polluted Land

A last topic to be discussed in this paper concerns the use of marginal soils for the production of biofuels. There are plenty of contaminated, previously industrial areas in Europe that are unfit for agriculture, because of the high levels of contamination in the soil. In spite of this pollution, however, these areas offer an enormous potential in terms of the growth of biofuels, linked to a simultaneous cleanup of the soil. To decontaminate large areas of land, several methods are available. Most of these methods are fast, but use a high level of technology and are very to extremely expensive. An alternative method, namely phytoremediation, is less expensive, but has as main disadvantage that it takes a long time before all contamination has been cleared. It should be noted, however, that with the correct choice of plants, the terrain could obtain an additional economic value. For example, when one wants to set up a large-scale phytoremediative effort, one could consider crop species as bioaccumulators of heavy metals; in fact, some of them can accumulate heavy metals while producing high biomass in response to established agricultural management (Ebbs and Kochian 1997).

This approach has been followed previously by different research teams. Huang et al. (1997) and Burke et al. (2000) worked on maize*;* Shahandeh and Hossner (2000) on sunflower, and Linger et al. (2002) on hemp. Other teams focused on fast growing trees such as *Salix* spp. (Punshon and Dickinson 1999; Mottier et al. 2000; Klang-Westin and Perttu 2002, Vandecasteele et al. 2005, Meers et al. 2007) and *Populus* spp. (Shannon et al. 1999, Banuelos et al. 1999, Vose et al. 2000, Laureysens et al. 2005). Marchiol et al. (2004) investigated the use of *Brassica napus* and *Raphanus sativus*. It remains to be seen if such an effort is possible based upon the use of bamboo as well.

To assess this possibility, our group has performed a preliminary test on the capacity of bamboo to retain heavy metals from the soil (data presented in Table IV). Bamboos were cultivated in pots in the local greenhouse and subjected to heavy metal concentrations of 0-8 mg kg^{-1} Cd, 0-1000 mg kg^{-1} Zn and 0-400 mg kg^{-1} Pb. Heavy metal contents were measured by atomic absorption spectroscopy (according to the methods of Blust et al. 1998). Table IV gives the ranges of uptake capacity in different species (*P. humilis, P. atrovaginata, P. bissettii, P. decora and P. aurea*) and after exposure to the abovementioned range of concentrations. Field data for willow and poplar (exposed in the same range, cfr. Vervaeke et al. (2003) and Laureysens et al. (2005)) were used as a comparison.

Table IV – Preliminary comparison of heavy metal uptake by different bio-energy crops

BAMBOO	*leaves*	*culms*	*rhizomes*
Zn (µg/g)	87-450	141-795	72-1900
Cd (µg/g)	8-27	7-27	5-50
Pb (µg/g)	33-60	33-61	32-260
WILLOW	*leaves*	*stem*	*roots*
Zn (µg/g)	411-695	24-40	ND
Cd (µg/g)	3.07-8.26	0.80-3.29	ND
POPLAR	*leaves*	*stem*	*roots*
Zn (µg/g)	362.5	146.1	243
Cd (µg/g)	4.3	3.6	3.2
Pb (µg/g)	2.9	12.7	17.7

The given range of values for bamboo was obtained in a pot/greenhouse experiment where 5 different *Phyllostachys* species were exposed to different concentrations of Pb, Cd and Zn, comparable to the concentrations of the field experiments with willow (Vervaeke et al. 2003) and poplar (Laureysens et al. 2005). ND : not determined

These data indicate that bamboo has an at least equal ability to take up heavy metals from contaminated soil. Moreover, given the fact that upon harvesting and drying, more than 90% of the leaf biomass stays attached to the culms, whereas the leaves of poplar and willow will generally fall off before the harvest starts, thereby either releasing the metal content of the leaves back into the soil, or requiring an extra effort to collect the fallen leaves. Bamboo will therefore be able to clean up a given soil faster than the other crops. On the other hand, an advantage of poplar and willow is, that the plants are able to take up metals from much deeper in the soil, whereas the bamboo roots and rhizomes are confined to the upper 50-70 cm.

As an aside – the major technological problem in a system that combines biomass production and heavy metal cleanup is that any metal exhaust should be avoided during combustion. Also, in general, electricity producers are not quite keen on having to invest too much in modifications of their installation. It is therefore clear that this problem needs a proper sustainable solution, before this strategy can be put into practice.

Conclusion

The data presented here, preliminary as they sometimes are, indicate that bamboo is a useful species for eco-engineering applications in Western Europe that combine bio-energy production and heavy metal phytoremediation, equally valid to plant species that have been studied already in more detail. Moreover, knowledge about the behavior of bamboo (albeit under European climate conditions) offers possibilities about the application of bamboo in its native regions. What is needed, in order to make these eco-engineering methods more efficient, is a better knowledge of bamboo ecophysiology on marginal lands in order to be able to predict future yields and, evidently, future income. Also, there is a clear need for further technological advancement and management of the waste material after combustion. Given the fulfillment of these conditions, however, bamboos are sure to be of great service in energy production and pollution management, both in Europe, and in the rest of the world.

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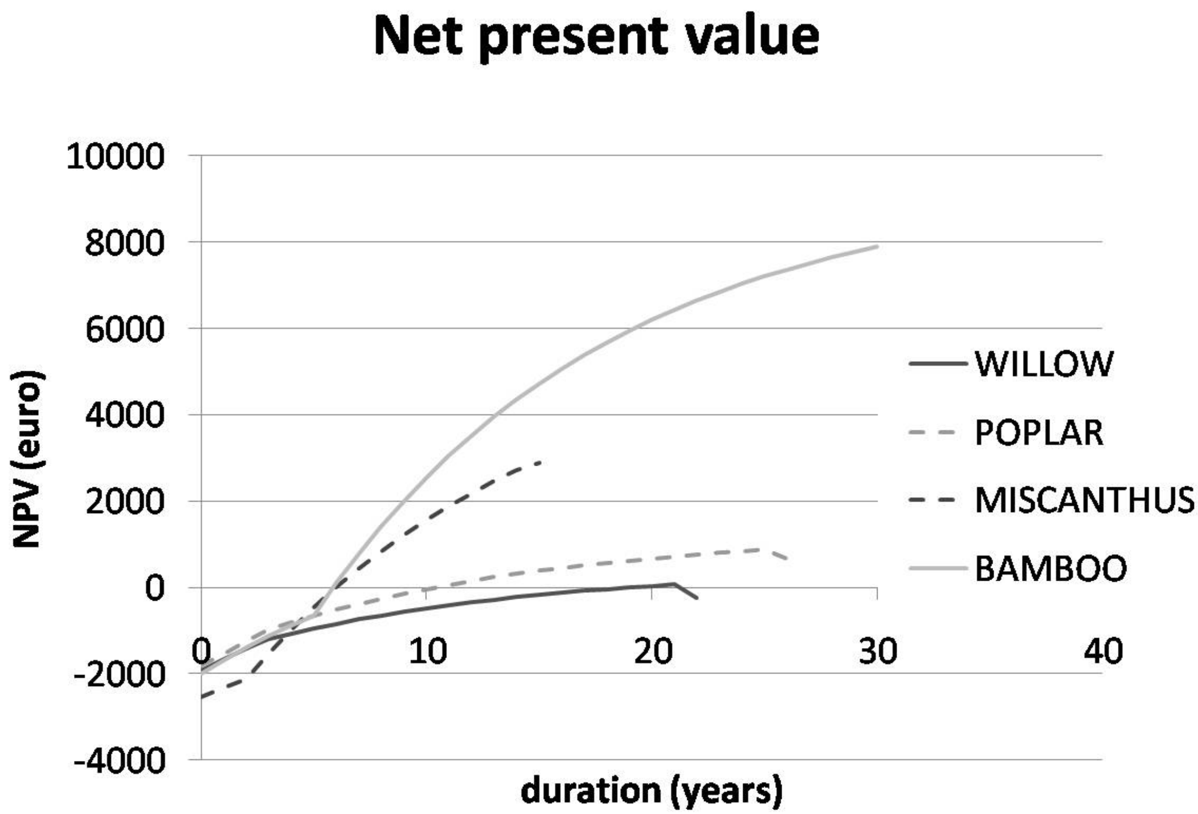

Figure 1. Net present value, calculated at an inflation level of 8% (to allow for comparison with a typical high risk investment) over the years for plantations of the different energy crop species.

Role of Bamboo in Conservation of Biodiversity and Promoting Ecotourism in Tripura, India

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Abstract

Almost 33% of the total geographical area and about 55% of the total forest area in Tripura is covered with 19 different species of bamboo. This proverbial 'poor man's timber' is used extensively by almost cent percent people in the state for various purposes. Presence of 19 different tribal communities mandates use of bamboo practically for everything they do in their day to day life. Moreover, practice of shifting cultivation (jhooming) by these tribal communities across the State has led to more and more use of bamboo rich areas for ease in working and yielding more output per unit as compared to output from jhooming over dense forest areas. Of late, industrial and commercial values of this grass species has been appreciated as a substitute to the wood based products leading to enhanced use of bamboo at all fronts. Tripura is an integral part of one of the two hot spots in the country. The state located at 9B NE Hills Oriental Zoogeographical region is very rich in her floral and faunal diversity and exhibits close affinity with flora & fauna of Indo-Malayan and Indo-Chinese sub-regions. The linkage between bamboo and biodiversity both of which are in abundance and complements and supplements each other is yet to be objectively appreciated. An attempt has been made through this paper to study this relationship and explore ways and means to make it an integral part of existing policies and schemes on biodiversity conservation, with special reference to the participatory approach. The paper also highlights at the possible conflicts in interests while putting to use this unassuming grass species for socio-economic development of the people (yielding tangible, commercial and industrial benefits) vis-à-vis its use for biodiversity conservation (yielding intangible and ecosystem benefits).

Introduction

The bamboo is a large woody grass belonging to the sub-family Bambusoideae and its ca 1250 species from 75 genera are distributed mostly in tropics besides occurring naturally in subtropical and temperate zones of all continents except Europe. Bamboo is an important resource in the Indian socio-economic-cultural-ecological-climatic-functional context with about 1500 recorded uses. India having ca 9 million hectare area under bamboo growth supporting ca 130 million tons of resources with annual harvest of 12.5 MT places, is second only to

China in bamboo resources. Bangladesh, Indonesia and Thailand are other nations with substantially high bamboo resources. However, this grass species has yet to come out of its current status as 'poor man's timber', by which it is known for many centuries in the past.

In India, a total of 140 wild and cultivated species of bamboo from 19 genera are spread over about 96,000 sq km of the total geographical area except in Kashmir valley. Compared to China with only about 3% of the total forest area under bamboo growth, India has ca 13% of the total forest area covered with bamboo. All the seven northeastern states together contributing ca 66% bamboo resource in quantity and 28% in terms of area coverage under bamboo growth make up for largest bamboo resources in India. Region wise distribution of bamboo resources in India suggests maximum number of species/genera is recorded in Eastern India (63/16), followed by Peninsular India (24/8), Western Himalayas (14/5), Indo-Gangetic Plains (8/4) and Andaman & Nicobar Islands (7/6).

Although, there are multifarious commercial and domestic uses of bamboo varying from its use as constructional material, handicrafts, agriculture, paper and pulp, textiles, wood substitute and meeting subsistence economy of poor people, yet, its importance and role for conservation of biodiversity, howsoever inconspicuous it may appear in comparison to the tangible commercial uses, are too vital to be ignored. The intangible benefits contribute directly to the survival of the human kind through biodiversity conservation and thus raise the status of bamboo as a very important commodity in this field. Unfortunately, in spite of this direct relationship between bamboo and human survival through multifarious uses from 'cradle to coffin', its status has not gone up from what it is known for ages as a 'poor man's timber'. The tangible uses of bamboo, though, have attracted attention of commercial entrepreneurs, yet, the role of bamboo in meeting objectives of biodiversity conservation through its ecological-economical-social-cultural mix is yet to be properly discerned and understood. This paper addresses the importance of bamboo for conservation of biodiversity and ecotourism in Tripura and attempts at setting up linkages between these two concepts.

Bamboo and Biodiversity Conservation

Conservation refers mainly to the protection of natural resources and their sustainable use for the benefit of dependent (directly and/or indirectly) stakeholders. Protection (of wildlife species and other resources on which those species depend) and participation (of local human communities in conservation processes in lieu of usufruct sharing for their socio-economic-cultural well being) have been identified as two main approaches towards biodiversity conservation. Protection leads to viable population growth and survival of all wild flora and fauna, while participation allows survival of dependent human populations through sustainable utilization of natural resources (resulting from protection approach). In Tripura, bamboo plays a very crucial role in implementation of both above approaches.

Protection approach

In the past extraction of natural resources was within the sustainable limits (within the carrying capacity of the given resource base) as there were fewer dependent people compared with the available natural resource, and hard-core protection to the habitat and all its varied elements worked as the only means of conservation strategy of the forest department. This protection measure was also in total agreement with the biological and ecological needs of different dependent wildlife species. A *habitat* is a place where given species gets required mix of food, cover, water and other resources to fulfill its biological needs. The stability, increase or decline of wildlife species and their populations depend directly on the extent of available habitat. Such habitats also play a vital role in meeting the subsistence needs of dependent human populations inhabiting biodiversity-rich areas.

Bamboo, covering almost 13% of the total forest area of the country, as a rich habitat provides a direct link with biodiversity conservation. In more than 88% of the total protected areas in the country different bamboo species act as rich habitats for innumerable number of wildlife species from avifauna to large mammalian species. Due to high adaptability, versatility and ability to improve soil conditions facilitating fast and diverse growth of bamboo even on degraded areas, make it a preferred species for restoration of degraded wildlife habitats across the length and breadth of the country. This characteristic of bamboo is of utmost importance in the north-eastern state, including Tripura, where wildlife habitats are degraded following *jhooming.* On an average Ca 50000 to 60000 hectare of rich forested area gets affected due to *jhooming* every year resulting into large-scale soil-erosion and landslides. Besides, repeated *jhooming* over a given piece of land for consecutive 2-3 years renders the soil impoverished in its nutrient contents unable to support the luxuriant growth of high forest species. Under such conditions, the fast-growing bamboo species provides much needed green cover to the naked soil within shortest possible time period thus protecting it from the vagaries of intensive rainfall in the entire region. The treatment of fallow land (deserted jhoom plots) is very crucial from biodiversity conservation view point and here too fast and luxuriant growth of bamboo facilitates faster uptake and storage of essential nutrients and quicker turnover to supplement soil flux and provides stability to the fallow land. The fast growth of bamboo groves across every possible soil-types (organically poor to mineral rich soil) and moisture regimes (rich leaf-litter of bamboo increases soil porosity thus raising the soil moisture retention capacity) act as one of the most important habitat components providing refuge to varied faunal and floral species. Extensive root system and vast underground rhizome network almost covering ca 100 m^2 area around bamboo clumps strongly hold and bind the soil and make the bamboo growth capable of tolerating the onslaughts of landslides, floods, hurricanes and quacks (Varshney, 2004).

In both the biodiversity hot-spots in India, namely, the Western Ghats and Eastern Himalayas (including all the seven northeastern states) the bamboo is present in its densest and most diverse forms and support some of the highly endangered and endemic faunal species. The bamboo shoots and other parts of culms provide a rich, nutritious and unlimited source of food to many animal species. Similarly, dense growth of bamboo culms and their canopy contiguity in association with high forests impart protection, breeding cover and connectivity for uninterrupted ranging to the animals. Bamboo growth on degraded lands provides a very crucial habitat element to wildlife who is able to tolerate some degree of habitat disturbances. This is more evident in jhoom fallows where bamboo covers as early and the only secondary growth act as a life-supporting micro-habitat for the conservation of many species ranging from insects to even some of the largest mammalian species (elephant, primates, gaur, etc.). Therefore, management of bamboo growth may also be equated by and large with the management of biodiversity rich areas in India leading to biodiversity conservation, which in final analysis leads to poverty alleviation, especially of those living below poverty line (BPL). The above account substantiates existence of an intimate and very important direct link between bamboo management and biodiversity conservation through protection measures.

Participatory approach

Over the last few decades, unsustainable utilization of natural resources by ever increasing population of stakeholders has led to the decimation of the habitat at a much faster rate than expected and within the limits of restoration. The 'Protection' strategy, in absence of sufficient man-power to impart protection to each and every important habitat and species, also fell far short in curbing this onslaught. This scenario forced policy makers to introduce new policy initiatives at the National level for management of forests and wildlife (Anonymous, 1998) and thin turn underlined a necessity for a 'participatory' approach for management of natural resources. In 1991, the Ministry of Environment & Forests brought about a Resolution on Joint Forest Management (JFM) in the territorial forest areas and within a span of 2 to 3 years practically all the states adopted this approach. In protected areas, this participatory approach was known as Eco-development. This approach entails people's involvement in the decision-making and execution of various conservation related measures and in lieu of participation the local communities get the usufruct benefits from the harvested natural forestry resources and/or alternative means of earning their livelihood mostly based on non-forestry resources with the sole aim of reducing the dependency of local people over natural resources. This ultimately aims at restoring and maintaining the balance between the availability, extraction, and exploitation of the natural resources within the sustainable limits.

The role of bamboo and its products is again very important and crucial in meeting the subsistence needs of most of the dependent local human populations. This intimate relationship is much more evident in northeastern states having ca 66% and 28% of the total bamboo resources in India in terms of production and cover and finds its utility in socio-economic-cultural domain of various communities practically for all their needs. The bamboo and its products are very intimately linked with successful implementation of the participatory approach for biodiversity conservation.

Development of Bamboo Resources and Wildlife Conservation Strategies in Tripura

Tripura is a small, land–locked hilly state situated in the north–eastern part of India. The state has a total geographical area of 10,492 sq. km. accounting for barely 0.342 per cent of the total area of the country. In terms of area, it is the third smallest state in the country, after Goa and Sikkim. The state lies between latitudes $22^0$56' N and $24^0$32' N are longitudes $91^0$09' E and $92^0$20' E. The total length of its international borders is 1018 km but it is bound by Bangladesh on three sides covering 856 km. of its total border. It is connected with the remaining part of India through Assam, via a small strip of border of 53 km – the Siliguri neck. The state is predominantly hilly and is dissected by six low ranges of hills running north–west to south–east. The state is located in bio-geographic zone of 9B- North-East hills with a rich diversity of resources. There are six important rivers but none is perennial. According to provisional estimates of 2001 census, the state's population stood at 31.91 lakh, with a population density of 304 persons per sq. km. The birth rate in the state is 16.5 per thousand which is lowest in north–east region much lower than the national average of 25.8. Again its death rate is 5.4 per thousand which is much below than the all India level of 8.5. Of the states in the North East, Tripura is the second most populated state after Assam, though in terms of area it is also the second smallest state. There are 19 sub–tribes among the scheduled tribes in the state with their own cultural diversity. Magority of the population depend on agriculture and allied activities. The productivity of main agricultural crops and plantation crops like rubber has been found higher than the national average. The state is predominantly rural, accounting for 82.91 per cent of population in rural areas. About 58 per cent of the area of the state is under different categories of forests, and land suitable to normal agricultural operation is relatively scarce. In fact, the net sown area is only 26.5 per cent of Tripura's land mass and average size of operational holdings is 0.97 hectare, which is below the national average. Only about 20 per cent of gross cropped area is irrigated and agriculture is mainly rain–fed. The crop intensity is 176 per cent, which is higher in the land situated in the valley. The major part of the land of the state is dry, consisting of laterite soils suitable for some selected crops only. Important crops in the state are rice, wheat, potato, pulses and vegetables. Cash crops like jute, mista, cotton, tea, rubber and plantation crops are also produced in the state. Tripura, with about 6500 hectares of tea plantation, 28000 hectares of rubber plantation (assessed potential for rubber plantation of 1,00,000 hectares), is rich in plantation crops like rubber, tea, pineapple, orange, litchi, banana and lemon. Nearly 67 percent populations are below the poverty level.

Tripura is called the 'home' of bamboo. The wonder plant is intimately interwoven in the socio-cultural fabric of the State. Bamboo based economic activities are an intrinsic part of life; the importance of the resource in the State's predominantly agrarian economy is well recognised. Bamboo finds many uses, and is a major source of income and employment as well. It is estimated that 2.46 lakh families in the State are engaged in bamboo related vocations. The average productivity of the resource for forests and farm areas is estimated to be 0.73 MT/ha/annum, which is higher than all India average of 0.51 MT/ha/annum but compares very poorly with productivity level of 3.79 MT/ha/annum in China. There are 19 species of bamboo found in Tripura. Out of the 19 species of bamboo muli bamboo is found extensively all over the State and is the most important species from ecological and economical view point.

Protection Strategy : Current status of bamboo as Habitat

In Tripura, the area under bamboo cover in the protected areas is generally managed as a routine alongside other habitats, of which, bamboo habitat may form just a small part. In none of the four protected areas in the state, the areas under bamboo are treated as specific wildlife habitat. Very rarely, do we come across any case related to a protected area where the bamboo as a habitat has been given a very specific and special attention. The only few instances are probably found in those protected areas where the gregarious flowering of bamboo has either taken place or is in the offing in the near future. In fact, in most cases the wildlife management strategies that are adopted and practiced are solely dependent more on the kind of major/important/flagship wildlife species inhabiting a given protected area. and, any kind of apparent management of bamboo areas found in and around any given protected area happens to be just incidental. In no way the management of bamboo habitats in the protected areas wherever found is in commensurate with the vast potential that the bamboo as a habitat possess and that can be harnessed for the protection and conservation of many a key endangered and endemic species of flora and fauna.

Protection of Bamboo as Habitat: Future suggestive measures

Considering the importance of bamboo as a habitat for many wildlife species, more proactive measures are needed to make bamboo habitat contributing much more effectively in addressing the direct protection approach towards wildlife conservation. Some of the suggestive measures that can be adopted in this regard could be the following:

1. The wildlife habitat can be enriched both in quality and quantity by proper selection and scientific propagation and establishment of suitable bamboo species. The suitability of a given groups of bamboo species can be determined based on the ecological and biological needs of key and flagship wildlife species. This tool can also be very effectively used to address man-animal conflict problems in many a cases depending upon the need of the wildlife species by making food and cover available to the animal species in conflict with humans in required quantities and quality (e.g., suitable bamboo species could be very important in competing with the more palatable and nutritious domestic grass species (maize etc.) that are more preferred by elephants leading to man-wildlife conflict situation).
2. It may be difficult to increase the net area under bamboo cultivation in a given protected area due to other priorities and needs of different user groups. But, the productivity and value of the existing growing stock of bamboo within the given area can be enhanced in much higher proportions by using genetically improved planting stocks. New technologies using tissue culture are now available to improve the genetic viability of the bamboo stock this adding to its existing productivity and value in a given unit area of consideration.
3. Making use of the property of most of the bamboo species to very quickly allow soil-binding facilitating soil conservation process, the degraded and soil erosion prone areas can be immediately planted with bamboo, even though it could be a stop-gap arrangement before the same degraded land is reclaimed raising other plant species.
4. As mentioned earlier, the northeastern states are facing one major habitat destruction problem through the practice of non-traditional shifting cultivation. Thousands of hectares of areas in all the seven northeastern states are laying fallow and unproductive following *jhooming*. In such cases too, the raising of bamboo plantations using commercially important species could lead to meeting two fold benefits: one, restoring and reclaiming the degraded fallow land, and two, increasing the economy of the local people by planting commercially important bamboo species in some cases and also by raising cash crop plantations of rubber, tea, orange, etc. on the restored and reclaimed jhum fallow areas of the yesteryears.
5. Most of the bamboo species can come up in combination with many other tree species of definite importance to many wildlife species. This unique property of bamboo species may further allow the managers to grow bamboo groves with suitable tree species mixtures. This will support more diversity of wildlife species and may also add to the ecotourism as well.
6. Few bamboo species act as a major source of food and cover for some of the highly endangered and endemic primate species (Hoolock gibbon, slender and slow loris, lion-tailed macaque, Nilgiri langur, Golden langur, Phayre's langur, and capped langur) in the northeastern states and the Western Ghats, especially during the pinch period when the food productivity of other plant species

is either very low or altogether nil. In all such areas, special emphasis on the species-specific plantations and management of bamboo growths will help in the long term protection and conservation of all those primate species.

Participatory Strategy : Current status of use of Bamboo in Participatory strategy

The participatory approach to forestry and wildlife conservation is mainly addressed through three distinct processes, namely, the Joint Forestry Management (JFM), the Eco-development (ED) and the Joint Protected Area Management (JPAM). The JFM was started in the country following the new National Forest Policy of 1988, which recognized the symbiotic relationship between the (tribal) people and forests and stated that a primary task of all agencies responsible for forest management including the forest development corporations should be to associate the (tribal) people closely in the protection, regeneration and development of forests as well as to provide gainful employment to people living in and around the forests. The policy further observes that the "Forests should not be looked upon as a source of revenue, but as a National asset to be protected and enhanced for the well being of the people and the nation" and the current approach of 'Protect from the people' should be changed to 'Protect through the people'. This policy decision led to the issuance of Joint Forest Management Guidelines by the Ministry of Environment and Forests in the year 1991 to all the State Forest Departments. Over the years, these guidelines have been modified to accommodate the changes in the external environment, the latest being the Guidelines of 2000 and the latest decision to constitute Forest Development Agencies where all the forestry related works have to have the participatory component as a must. Similarly, in the field of wildlife management too, the Ministry of Environment & Forests had come up with a special Central Sponsored Scheme (Eco-development around National Parks and Wildlife Sanctuaries) in 1991 in which the funds were placed with the States/UTs for undertaking participatory approach towards wildlife management for the following main activities:

- Biomass regeneration
- Soil and Water Conservation
- Use of alternative sources of energy to replace non-renewable natural forestry and wildlife resources
- To undertake necessary health measures both for Humans and their livestock
- To initiate and establish welfare measures for the people at the cottage (small) industry level.
- Research and monitoring to gauge the progress of this process to fine tune it according to the site and issue specificity.

Over the years, the eco-development has been made a mandatory instrument of wildlife management, it is the Wildlife Conservation Strategy of GOI, National Wildlife Action Plan (2002-15), or the schemes under the auspices of Directorate of Project Tiger, Directorate of Project Elephant, other Centrally Sponsored Schemes, and Schemes of States/Us forest department.

The eco-development aims to conserve biodiversity by addressing both the impact of local people on the protected areas and the impact of the protected areas on local people. The eco-development is defined as a site specific package of measures, developed through people's participation, with the objective of promoting sustainable use of land and other resources, as well as on-farm and off-farm income-generating activities which are not deleterious to PA values. The eco-development is also referred to as a limited rural development designed with the participation of local people, for the purpose of reconciling genuine human needs with specific aims of Protected Area management.

The two main elements of eco-development approach are (1) Habitat Improvement and Management addressing directly at the level of the Biodiversity Conservation, and (2) the Village eco-development looking at the Resource Sustainability aspect to ensure that equitable resource allocation is done for viable survival and growth of each of the stakeholders of biodiversity conservation. Based on these two basic premises, the major specific activities being undertaken for eco-development could be as follows (this list is not exhaustive as at many places new innovations are made in the process and techniques to best suite the given site):

1. Improved collection and use of non-wood products.
2. Improved dry farming techniques
3. Efficacious water harvesting
4. Soil conservation measures
5. Preferences to cash crops (pulses, oil seeds, spices, cotton, medicinal plants, commercial bamboo plantations)
6. Agro-forestry
7. Sericulture, horticulture and Apiculture.
8. Development of Minor Irrigation measures
9. Animal husbandry, dairying and wool crafts
10. Fisheries
11. Ecotourism
12. Development of Infrastructure
13. Cottage industry and Handicrafts

Among the various potential activities listed as above for undertaking participatory eco-development approach, the use of bamboo can be very conveniently and justifiably defined in most of these listed activities. The bamboo and its products, both in its raw and in value added form, can contribute substantially in meeting the targets of various participatory activities for providing alternate use of livelihood options as listed above at the serial numbers 1, 2, 3, 4, 5, 6, 7, 11, 12 and 13.

Both eco-development and the Joint Forest Management for biodiversity conservation are performed through the specifically constituted Committees for this purpose, called eco-development Committees (EDCs) and Village Forest Committees or JFM Committees (JFMCs)

Therefore, as described in the preceding paragraphs, the bamboo along with its varied and diverse products has strong (direct and indirect) linkages with the conservation of biodiversity in general and wildlife in particular.

Use of Bamboo in Participatory Approach: Future Suggestive Measures

However, in spite of the fact that the bamboo and its products can contribute substantially in achieving the targets of participatory wildlife conservation, not much systematic attempts have been taken to make use of highly valuable properties of bamboo and its products at the advanced technical and scientific levels. The main reason for this neglect has been more due to ignorance about the multitude properties of bamboo and its products and their importance for multi-facet integrated development through its use as:

- As a bio-energy crop
- As food crop
- For environmental amelioration
- As a substitute of wood
- As a material for infrastructural development
- As environment friendly housing and building material
- As a renewable energy and fuel source
- As herbal medicinal plant
- As a controller of ecosystem damages and
- For overall integrated development (Rao *et. al*. 2004 and Varshney 2004)

Therefore, ample scope still exists to fully exploit the untapped potential of the vast bamboo resources across its range in the country (with bamboo plantations over about 8.96 mha roughly equivalent to 130MT in quantity yielding an annual harvest of roughly 14.5MT).

Bamboo as an Alternative Resource for the Participatory Approach to Biodiversity Conservation: A Suggestive Model

In order to fully utilize the strong direct and indirect linkages of bamboo as a habitat and its importance as a potential resource for undertaking measures for providing alternate means of livelihood options within the ambit of eco-development planning, I propose a Model. This Model looks at the utility of bamboo and its products at two very distinct levels:

(1) at the level of domestic usages, and

(2) at the level of commercial and industrial usages.

At the level of domestic usage

Given the distribution range of bamboo coinciding mainly with areas of high population density of tribal and aboriginal communities mostly in and around the protected areas, the bamboo is used by those communities in practically every activity performed as daily chores. The domestic uses of bamboo and its products relate mostly to as construction material, as utensils, as decorative items, as food (shoots), as raw material for various cottage and handicraft items, as an important species in various social-religious functions, etc. The nick name of bamboo as a 'poor man's timber' denotes its utility for those communities from 'cradle to coffin'. But, unfortunately, the traditional methods of propagation, exploitation and usage of bamboo as adopted by these communities over the past many years are still in use. Those traditional methods might have been in conformity at the level of sustainable management of bamboo resources at that time, but due to drastic changes in the demographic patterns and other external environment as a result of changes in the development paradigm, those methods now do not yield desired benefits anymore. Moreover, it is now understood that most of the traditional methods do not help in upgrading the bamboo to its fullest potential to what it is worth of, thus leading to much more per capita consumption for the similar amount of benefits/yields that can be achieved from much less per capita consumption using advanced scientific and technical know how. Therefore, it is very important to reassess the feasibility and applicability of many traditional methods and to upgrade those, if need be, by integrating those methods with the advanced technical and scientific methods. Presently, in absence of any improvements in the shelf life and strength of bamboo, its per capita consumption as food and for other purposes is very high. With the use of advanced scientific methods, the shelf life and strength of bamboo and its products can be increased to reduce the quantity required for per capita consumption. This savings in the bamboo resources without compromising in its usage patterns shall add to its conservation value for wildlife and this saved bamboo resource can also be made available for its increased alternative usages.

The EDCs and JFMCs have to come up with definite plans to ensure that in all those areas where the bamboo and its products contribute substantially in meeting the sustenance needs of the local communities, the traditional methods are integrated with advanced methods so that per capita income from bamboo and its products could be increased in leaps and bounds, as ample scope do exist for this change over. If this approach is institutionalized and practiced as an accepted norms and policy, has the potential of fulfilling the objectives of participatory approach without much bothering for bringing in the alien methods and resources as substitutes to the other forestry and wildlife resources being used currently. One biggest advantage of bamboo-based eco-development measures would be the recognition of bamboo and its products by the targeted communities and their preliminary knowledge on the cultivation, exploitation and utilization of bamboo and its products.

The EDCs and JFMCs can also take up the programmes for imparting proper training to the users both at the individual and group levels to build up on their existing capacity enabling them to use bamboo and its products in much more scientifically and technically advanced form. The National Mission on Bamboo Application and many other similar institutions can be roped in for this purpose of integrating the local traditional knowledge of user groups with the advanced scientific and technical aspects of this species.

At the level of Commercial/Industrial usages

The use of bamboo at the commercial and industrial level is practically limited right now only to the extent that local people harvest bamboos and sell it in raw or semi-processed form in the local markets or to some select co-operatives. The income from this transaction is just not sufficient to meet their subsistence economy. Moreover, the major benefit of their labour and time spent in these activities goes to the middle men, who by taking advantage of poor transportation, processing and marketing facilities at the disposal of the local people, exploit this situation at the detriment of the local beneficiaries.

However, vast potential does exist in this field for local people to raise their economy by utilizing the bamboo and its products for many different types of commercial and industrial activities. In this aspect too, the role of EDCs and JFMCs is very important and crucial in that these bodies can associate themselves with different industries and institutions involved in the technically and scientifically advanced commercial and industrial usage of bamboo and its products.

The Model that I propose is based on the cottage industry concept of the past where the individual families are provided scope to set up their kind of small scale industry for bringing out marketable products both in raw and value added processed form for domestic and commercial/industrial uses. The end products of such cottage industry will constitute the raw material for larger commercial and industrial units located elsewhere. The transportation and marketing of raw material to the big and commercial industrial units will form an integral part of this Model. The following steps may be taken to make this Model run successfully:

1. Bamboo based small scale cottage industries can be set up at individual beneficiary and/or at the level of entire Eco-development and Joint Forest Management Committees.
2. These cottage industries should act as feeder channel for providing the raw and semi-processed and value added raw material for bigger bamboo based industries for various products (paper and pulp; construction materials; food processing; handicrafts; bamboo furniture; bamboo plywood; bamboo flooring; bamboo grids; bamboo as wood substitutes; and for variety of miscellaneous industries for agarbatti sticks, ice-cream sticks, fire cracker, lathis, ladders, etc.). This direct linkage between the beneficiary-run cottage industry and large scale commercial industries shall ensure that the total sale of processed raw material fetches the appropriate market price without the involvement of middle men who do not allow the real benefit flow to the actual beneficiaries. This institutionalized arrangement shall help raise the economy of the local people based on the same resources that they are familiar with and recognise it in their day to day activities. This linkage between the cottage industry (bamboo based) and the bigger industries shall also help sustain the concerned EDCs and JFMCs financially in the long run. Currently, most of the Committees survive only till the external funding is able to support their existence. The much desired transport and marketing facilities for the individual local level beneficiaries will also be developed through this means, which would also help in the marketing of other non-bamboo based products of those Committees to further boost the economy of the Committee members.

3. The required value addition to bamboo and its products at both the domestic and commercial scale can be done through capacity building of local artisans and local people; with the use of advanced scientific technologies and as highlighted time and again in the preceding paragraphs, the integration of advanced technical and scientific know-how with the traditional knowledge of different user groups.
4. This bamboo-based Model is best suited to achieve the desired objectives of biodiversity conservation through participatory approach under the auspices of EDCs and JFMCs because of the following properties of bamboo:
   a. Its immediate acceptability among the beneficiaries both economically and culturally.
   b. As stated earlier, the cultures and traditions of many communities inhabiting areas of bamboo abundance are closely interwoven and integrated with bamboo and its varied usages for meeting many a daily needs. Therefore, alternative programmes based on bamboo shall be immediately acceptable to them (in fact in many cases various alternatives suggested for economic upliftment of local communities have failed as those alternatives were not in consonance with the local traditions and culture and the communities found it difficult to identify themselves with those alternative measures).
   c. Another positive aspect associated with the use of bamboo is its bio-degradable nature. Although, the bamboo and its products find their use in many activities that the people perform during the day, yet, there is no danger of ecological hazard, which is associated with the use of plastics. This eco-friendly nature of bamboo makes it one of the most favorite as an alternative for other natural resources.
   d. The bamboo and its products can be used for various commercial and industrial products that would prove ideal for raising the economy of the local people without making any compromise to their other social-cultural-traditional needs and aspiration. Some of the important industrial usage of bamboo could be the following:
      i. Industry: Wood substitute (laminates, flooring, panels, particle boards, roofing, false ceiling, insulation material, chipboard, wafer board, bamboo ply, veneer); Building, Construction and Structural Application Industrial Products (shelter, community building, earthquake resistant construction, scaffolding and ladders, road enforcement grids, embankment and slope protection, check dams and bridges, truck bodies, activated carbon); Specialized Bamboo Processing Machinery and Process Technology (dyes and modules, development of special purpose resin, etc.).
      ii. Food and Agro-Processing: Bamboo shoots, props for horticulture crops, sericulture, drip irrigation, cultivation and propagation.
      iii. Product Application – small scale Enterprise: Bamboo furniture, kiosks, woven bamboo application, stick making, pencil, safety matches and other consumer applications.
   e. Increased use of bamboo and its products for meeting various needs will also help in protection of the habitat from wanton destruction through felling of hardwood trees. Protection of habitat will directly contribute to the conservation of biodiversity.

Bamboo and Ecotourism: The Link

Ecotourism is an amalgamation of three basic ethos, namely, the conservation ethos ensuring conservation of resources on which the ecotourism is based; meaningful community participation ethos ensuring that the benefits of ecotourism does flow to the local communities residing in and around the areas of ecotourism sites; and economic consideration ethos ensuring that the ecotourism venture is profitable and self-sustaining. The ecotourism is considered another form of participatory approach towards biodiversity conservation as a strategy linking conservation with development in ecologically rich areas. In this terminology, the word 'eco' means ecological benefits to the ecosystems and economic benefits to the local communities. The National Policy on Ecotourism (Anonymous, 1998) mandates that the ecotourism should be made a grassroots, community based movement through awareness, education and training of local communities as guides and interpreters. It further calls for involvement of local communities for overall economic development of the area and further stipulates that the ecotourism development type and scale should be compatible with the environment and socio-cultural characteristics of the local communities. The Wildlife Conservation Strategy, 2002 prescribes that the revenue earned from increased tourism should be used entirely to augment available resources for conservation. World over, the ecotourism has also been defined as an environmentally friendly travel to relatively undisturbed natural areas in order to appreciate nature that promote conservation and provides for beneficially active socio-economic involvement of local human populations.

Bamboo and its products with eco-friendly nature and vast potential to increase community based income generation programmes, can also contribute substantially in undertaking and promoting ecotourism in areas clothed with bamboo growth. The following features of bamboo may help develop a link between bamboo and ecotourism:

1. The ecotourism based on visits to natural wilderness areas can be promoted in areas with dense bamboo covers, which, as one key habitat element, support diverse flora and fauna.
2. The facilities for tourists inside the tourism zones can be made eco-friendly with the use of bamboo and its products. The current concrete structures as tourist lodges, visitation centers, cafeterias, hotels/motels, interpretation centers, etc. can be very conveniently replaced with bamboo based structures using value added features of bamboo and its products. Use of bamboo in these cases will protect the nature and add to the natural beauty of the given areas.
3. The above mentioned tourist facilities can be created through the EDCs to provide the alternative means of livelihood to the local people that too based on resources that can be handled by them more conveniently and dexterously.
4. Bamboo made souvenir and handicraft items through the involvement of local people from different JFMCs and EDCs will also help them earn their sustenance livelihood. The concerned Committee officials have to facilitate the transportation and marketing of those products so that appropriate pricing is received by the people through the sale of such items.
5. At many nature based tourist sites, the water rafting and house-boats constitute an integral part of tourist facilities. Here too, use of bamboo and its products can be ensured through the Committees, which will earn the local people their livelihood.

6. The ecotourism, as one of the participatory approach towards biodiversity conservation, is very closely linked with eco-development and joint forest management. Therefore, usefulness of bamboo and its products towards eco-development and joint forest management also contribute in the field of ecotourism.

Implementation of the Model

As described in few preceding paragraphs, various Policies and Schemes of Government of India and States/UTs make it mandatory to have participatory approach towards biodiversity conservation. To enable it to happen, necessary changes in the National Forest Policy and National Wildlife Action Plan have already been incorporated. Recent amendments (in the year 2002 and 2003) in the Wildlife (Protection) Act, 1972 mandates to have two more categories of protected areas, namely the Conservation Reserves and Community Reserves. In both these categories strong emphasis will be to accommodate the sustenance needs of the local communities based on traditional resource through value addition and their capacity building of the local people alongside the conservation of wildlife and their habitat. All these changes in the policy and the legislation fit well in the scheme of Model proposed above.

However, at the implementation level, there are many steps that are yet to be integrated with the current working schemes. Currently, the working of the territorial forests and the protected areas is governed by the Working Plan prepared for each forest division and Management Plan for a given protected areas. Both these documents are revised every ten years to incorporate new changes for better management of forests and wildlife under the changed conditions, if any. With the practice of participatory approach to biodiversity conservation, now the scope exists to prepare Annual Micro-plans for each forest division and given protected area to incorporate all those measures associated with the effective implementation of various programmes and schemes of participatory approach. It would be of utmost importance to bring in enabling changes in the Annual Micro-Plans to include the requirement of the above described Model so that the policies are translated into action in the field to yield desired outputs.

This Model, as proposed above may appear utopian in this era of globalization where more and more emphasis is being paid to boost the economy by opening the seams that have been hitherto binding the trade and commerce within the confines of a country or at the most a region. However, this approach alone could facilitate and ensure integration of commercial interests (based on bamboo) with the sustenance-level-livelihood earning interests of scores of those people for whom an only industrial usage of bamboo and its products may not bring in desired level of economy for them to survive. The technical, industrial and commercial usages of bamboo and its products, will definitely boost the economy in leaps and bounds for various industrial and commercial units based on this species. What, of course, is required to be understood very clearly is that the bamboo as a species is very intimately associated with various ecosystems that help preserve and conserve biodiversity across the globe, and especially in areas which are referred to as ‘hot spots’. The complete and total commercialization and industrialization of this species at the cost of not allowing it to meet the demands for biodiversity conservation through intangible benefits (that can not be weighed in terms of hard cash), would definitely be suicidal. After all, not very long ago, even the high forests were sacrificed (and this trend still continues albeit at a much faster pace) to meet the industrial and commercial needs of only few elite section of the society. And we all are now paying a very heavy price of this short sightedness, with global warming challenging the very survival of human kind. Therefore, in this perspective, the small cottage-industry-level Model may prove quite appropriate that will not only ensure that the local people who are now partnered for biodiversity conservation continue to draw the benefits at the sustenance level, but also become an active partner in becoming the supplier of raw materials for industrial and commercial units. Once it is ensured, the bamboo and its products will truly justifying their very intimate association with the poverty alleviation in general and the biodiversity conservation in particular.

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Chemistries of Throughfall and Stemflow in Two Bamboo Forests and a Japanese Cedar Forest in Japan

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Abstract

Comparative studies on the chemistries of throughfall and stemflow in three forests were conducted in the southern region of Japan. Precipitation, throughfall, and stemflow were collected from the middle of June 2006 to the end of September 2006 in three adjacent forests: madake bamboo (*Phyllostachys bambusoides Sieb*), moso bamboo (*Phyllostachys pubescens Mazel*), and Japanese cedar (*Cryptomeria japonica*). The volume-weighted mean pH of precipitation was 4.7 with a range of 4.2 to 4.9 and acid rain fell over the forest. Throughfall pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.3, 5.2, and 5.3, respectively. Throughfall pH values for the three forests were higher than precipitation pH. This suggests that pH buffering mechanisms occur in the forest canopy, probably due to neutralization of cations derived from dry basic deposits and basic leachates derived from plant materials. In the bamboo forests, the relative contribution of K^+ cations to the total cations in throughfall was high—29% in madake bamboo and 42% in moso bamboo. Further, these relative contributions showed seasonal trends with a high value during the first half of the observation period, when bamboo undergoes growth and other changes. K^+ is a major contributor to the basicity of throughfall and may be strongly associated with the neutralization of acid rain. Ca^{2+}derived from leaves and NH_4^+ derived from air were major contributors to the basicity of the Japanese cedar. They may be strongly associated with the neutralization of acid rain. Stemflow pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.0, 4.9, and 4.1, respectively; that is, the stemflow pH values for the bamboo forests were higher than that for the Japanese cedar. In the Japanese cedar, excess SO_4^{2-} derived from air may mainly cause soil acidification. Soil under bamboo faces a small risk of soil acidification.

Introduction

Over the last 20 years, numerous studies on acid rain have been conducted worldwide. The relationships between acid rain and forest damage have been studied in Japan. Only a few studies have discussed chemistries of throughfall and stemflow in bamboo forests. Furthermore, in recent years, the encroachment of bamboo on forest areas has become a serious problem in Japan, and there is great concern for environmentally negative effects of bamboo encroachment. Previous report have shown that in the encroached area of bamboo on the Japanese cypress(Chamaecyparis obtuse□, 90% of trees were dead , and soil moisture contents of surface soil were lower than that of the pure Japanese cypress stand (Yokoo et al.2005). Furthermore we suggested that the bamboo could neutralize the pH of surface soil as result of the higher soil pH in bamboo forest than that of Japanese cypress forest.

For these reasons, in this study, we investigated the chemistries of throughfall and stemflow in a bamboo forest. In this paper, we discuss the chemistries of throughfall and stemflow in a bamboo forest in comparison with those in a Japanese cedar, which is a typical tree species used for afforestation in Japan.

Material and Methods

Study site

The experimental site (33°02′ N, 130°36′ E), which is located in a private forest at Nagomi Town in Kumamoto Prefecture in southern Japan, as shown in Figure 1, was used for monitoring purposes. This site is situated in a rural area. The annual mean of air temperature at this site is 17.0°C. In 2006, the annual precipitation amount at the Kahoku aerial observing station (33°07′ N, 130°42′ E), nearest to this site, was 2663 mm.

Three adjacent forest stands were selected: madake bamboo (*Phyllostachys bambusoides Sieb*), moso bamboo (*P. pubescens Mazel*), and Japanese cedar (*Cryptomeria japonica*). Experimental plots for obtaining tree census in the two bamboo forests were set in areas of 5 m × 5 m each, and that in the Japanese cedar stand was set in an area of 10 m × 10 m. In each bamboo forest, 9 sample trees of different sizes were cut down, and the culm height and the diameter at breast height (DBH) of sample trees were measured in June 2007. There was a good relationship between the culm height and DBH each bamboo forest, which described as follows:

In madake bamboo forest, $H = 1.44 \times DBH + 4.27$ $R2=0.969$

In Moso bamboo forest, $H = 0.60 \times DBH + 7.93$ $R2=0.925$

Where H and DBH are the culm height and the diameter at breast height.

The overall height of culms were calculated by DBH using the equation mentioned above. In Japanese cedar, the height of all trees were measured by using the ultrasonic hypsometer(Vertex).

Further details on each stand are provided in Table 1.

Sample Collection and Period

Bulk precipitation (hereafter referred to as precipitation) was collected in open areas adjacent to the forests, using one polyethylene funnel collector (diameter: 300 mm). Throughfall was collected by placing one polyethylene funnel collector (diameter: 300 mm) beneath the forest canopy at a height of approximately 1.5 m above the ground of each plot, as shown in Photo 1. Stemflow was collected from one tree with uretan collars placing around a trunk of tree and led into each polyethylene bottle as shown in Photo 1. The number of sampling events was 10 for a period of 3.5 months from June 16, 2006 to September 25, 2006.

Chemical Analysis

Rainwater samples were brought to the laboratory on the day of collection itself, and their pH values and electrical conductivity (EC) were immediately measured using a pH meter (Horiba, F-22) and a EC meter (Toa, CM-40S), respectively. The samples were then filtered using a cellulose acetate filter and stored at 2°C. The cations Ca^{2+} and Mg^{2+} in the filtered samples were analyzed using an atomic absorption spectrophotometer (Hitachi, Z-6100). The other cations Na^{+}, K^{+}, and NH_4^{+} and the anions Cl^{-}, NO_2^{-}, PO_3^{3-}, NO_3^{-}, and SO_4^{2-} were analyzed using an ion chromatograph (Dionex, DX-500).

Results and Discussion

The volume-weighted mean pH of precipitation was 4.7 with a range of 4.2 to 4.9 and acid rain fell over the forest (Table 2). This value of precipitation pH is the same as the annual mean volume-weighted pH of precipitation in Japan (Tamaki et al. 1991). Table 3 shows the ionic concentration (in μequiv./L) of cations and anions and ionic balance in precipitation. In order to verify the quality of data obtained by chemical analyses, quality control was carried out by achieving ion balance and by drawing a comparison between measured and calculated conductances. The charges of cations and anions in precipitation were almost in balance.

At sampling event no. 10, highest concentrations of Na^{+} and Cl^{-} were observed—251 μequiv./L, 214 μequiv/L, respectively (Table 3). The collected precipitation was significantly affected by sea salt derived from seawater attributed to Typhoon no. 13 that attacked this area on September 17, 2006. In this study, an analysis of all data except for data in the special case of sampling event no. 10 was carried out for discussion purposes.

As shown in Table 2, the throughfall pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.3, 5.2, and 5.3, respectively. Throughfall pH values for the three forests were significantly higher than the precipitation pH ($p < 0.05$), probably due to the neutralization of cations by dry deposits and basic leachates from leaves, branches, and barks. When precipitation falls through forests in the form of throughfall and stemflow, its quality changes, and usually, many kinds of soluble elements are added to the precipitation.

According to Terashima et al. (2004), elements Si, K, Ca, and Mg are predominant in the culm of bamboo, and Ca is a dominant element in the leaves and bark of the Japanese cedar. Furthermore, in a bamboo forest, leaching of K^{+} and Cl^{-} from leaves and culm has been suspected to occur, on the basis of results of comparisons among the chemistries of precipitation, throughfall, and stemflow (Sakai et al.1996; Takenaka et al.1995 & 1996; Tazaki et al.2004).

Table 4 shows the relative contributions of anions or cations to the sum of ions. K^{+} cations in the precipitation, throughfall in madake bamboo, throughfall in moso bamboo, and throughfall in the Japanese cedar accounted for 1%, 29%, 42%, and 10%, respectively, of the total cations. In bamboo forests, K^{+} is a major contributor to the basicity of the throughfall. As is the case with throughfall, the relative contribution of K^{+} in the stemflow in madake bamboo and moso bamboo to the total cations was high—21% and 27%, respectively. Similar patterns of higher relative contribution of K^{+} to the total cations in the first half of the observation period, i.e., from mid-June to mid-August, were clearly observed in the case of K^{+} in the throughfall and stemflow of bamboo forests

(Figure 2). During this period of the year, bamboo undergoes growth and other changes. For example, this period witnesses the sprouting of bamboo shoots and shedding of bamboo leaves. In our study, these phenomena were expected to affect the enhancement of K^+ in the throughfall and stemflow of bamboo.

On the other hand, in the Japanese cedar, NH_4^+ and Ca^{2+} are major contributors to the basicity of throughfall, and together, they accounted for 62% of the total cations. These results coincide with those of studies cited above (Sakai 1997; Sakai et al.1996; Takenaka et al.1995 & 1996; Tazaki et al.2004).

Cl^- anions in the precipitation, throughfall in madake bamboo, throughfall in moso bamboo, and throughfall in the Japanese cedar accounted for 13%, 49%, 58%, and 18%, respectively, of the total anions (Table 4). In bamboo forests, Cl^- is a major contributor to the acidity of both the stemflow and throughfall. Further, Cl^- in the stemflow in madake bamboo and moso bamboo accounted for 46% and 56%, respectively, of the total anions. Thus, high values of both Cl^- and K^+ in the throughfall and stemflow in bamboo suggest that the leaching as the composition of KCl occurred.

As shown in Table 2, differences were observed between the stemflow pH values for bamboo forests and Japanese cedar. Stemflow pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.0, 4.9, and 4.1, respectively. That is, the stemflow pH value for the Japanese cedar was lower than those for the bamboo forests. Furthermore, the stemflow pH value for the Japanese cedar was lower than the precipitation pH value. Because SO_4^{2-} is a major contributor to the acidity of stemflow (Table 4), this lower stemflow pH is assumed to cause soil acidification due to excess SO_4^{2-} derived from air. Several previous studies have reported the acidification of soil near the trunk of the Japanese cedar (Matsuura 1992; Sakai 1997). On the other hand, soil under bamboo faces a smaller risk of soil acidification, because the pH values of throughfall and stemflow in bamboo forests are higher than the precipitation pH value.

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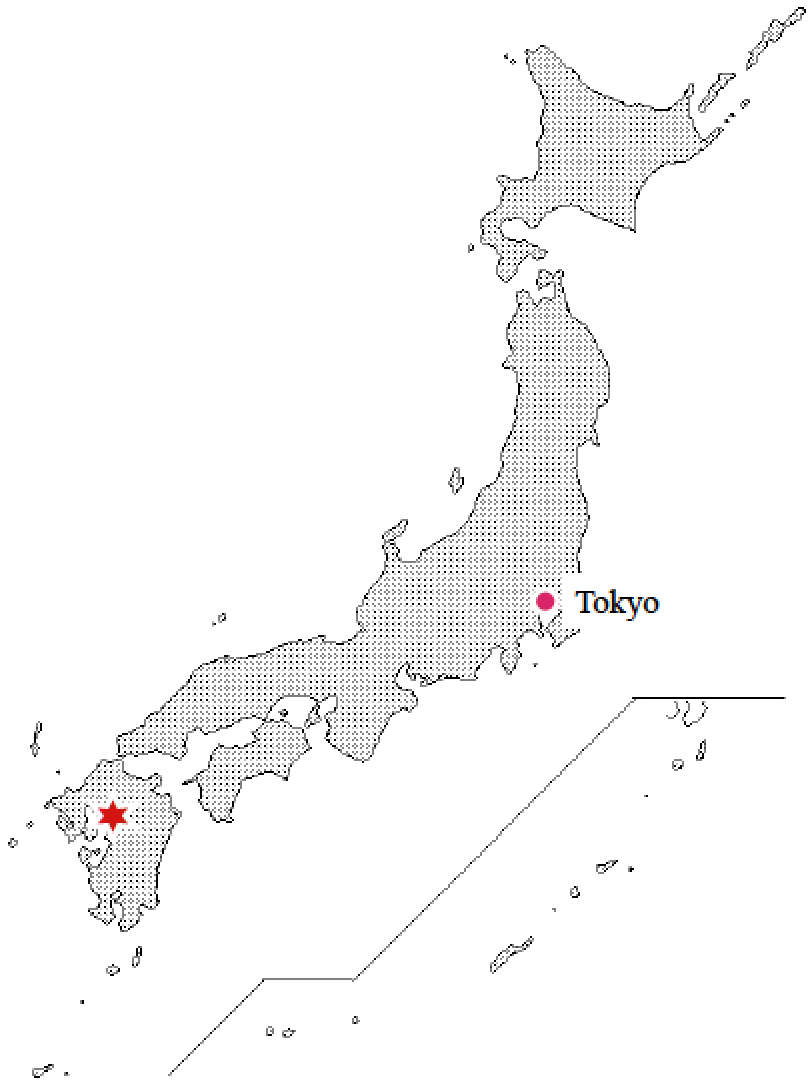

Figure 1 A location of Nagomi experimental site in Japan (★)

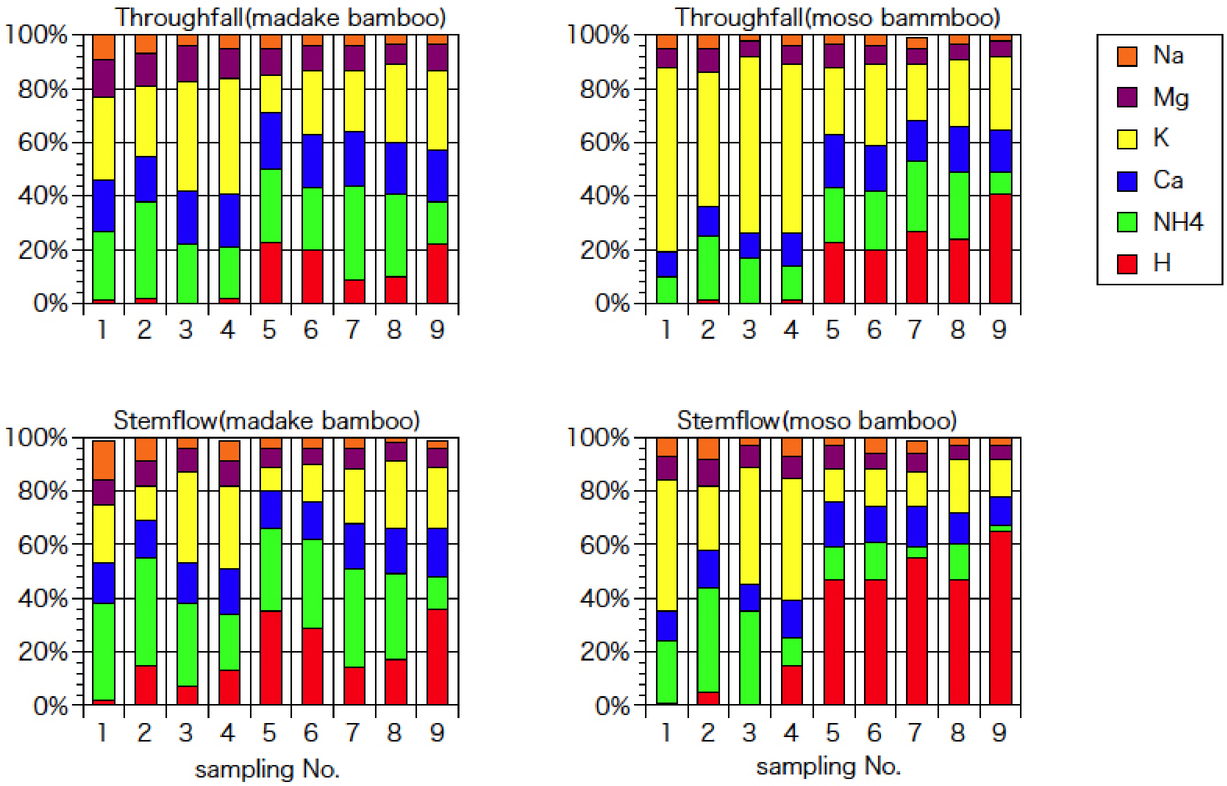

Figure 2 Relative contributions of cation to the sum of catios each sampling event

Photo 1 Collectors for throughfall and stemflow

Table 1 Site description of three forest stands

Stand name	Forest type	Age (years)	Mean DBH (cm)	Mean Tree Height (m)	stand density (No.of Stem/ha)	Direction	Inclination	Altitude (m)	Species
Madake	Bamboo	-	7.3	14.8	24800	SW	5	105	*Phyllostachys bambusoides Sieb*
Moso	Bamboo	-	9.3	13.5	12800	SW	16	100	*P.pubescens Mazel*
Japanese cedar	conifer	30	21.8	21.2	1900	SW	18	100	*Cryptomeria japonica*

A measurement date : November 2006

DBH: a diameter of tree at breast height.

Table 2 The volume-weighted mean pH and electric conductivity(EC)

		pH	EC (μS/cm)
	Precipitation	4.7	13.8
Madake bamboo	Throughfall	5.3	21.3
	Stemflow	5.0	19.8
Moso bamboo	Throughfall	5.2	30.3
	Stemflow	4.9	22.9
Japanese cedar	Throughfall	5.3	13.4
	Stemflow	4.1	42.2

Table 3 The values of pH,electric conductivity(μS/cm), and ionic concentration(μequiv./L) of precipitation

sampling No.	sampling date	days	an amount of precipitation (mm)	pH	EC	Cl^-	NO_3^-	SO_4^{2-}	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	Σcations	Σanions	ionic balance
1	12/Jul/06	26	738	4.7	15.4	13.8	13.1	32.7	13.0	20.0	0.8	3.3	4.0	62.759	59.573	1.05
2	31/Jul/06	19	568	4.8	9.2	5.1	8.1	22.3	5.2	10.5	0.8	2.5	3.5	37.154	35.419	1.05
3	04/Aug/06	4	31	4.7	25.5	11.6	39.0	78.7	9.1	68.7	4.6	12.3	25.9	140.557	129.292	1.09
4	21/Aug/06	17	229	4.9	8.9	6.2	9.4	18.7	5.2	8.9	1.0	2.5	7.5	38.448	34.298	1.12
5	25/Aug/06	4	67	4.4	22.8	4.5	28.4	43.5	3.9	25.5	0.8	2.5	5.0	77.134	76.410	1.01
6	29/Aug/06	4	64	4.6	15.0	5.6	17.3	26.4	4.3	17.2	0.5	1.6	3.0	54.008	49.339	1.09
7	04/Sep/06	6	37	4.4	20.6	8.5	22.3	45.6	6.1	28.8	0.5	2.5	4.0	78.745	76.314	1.03
8	11/Sep/06	7	39	4.2	32.0	10.2	21.3	68.9	4.3	22.7	1.0	2.5	5.0	104.192	100.357	1.04
9	15/Sep/06	4	32	4.2	30.0	8.2	13.4	62.5	3.0	8.3	0.5	2.5	3.5	88.065	84.026	1.05
10	25/Sep/06	10	35	4.8	43.2	251.3	7.9	48.5	214.0	0.0	9.7	46.1	25.0	310.470	307.753	1.01

ionic balance:Σcations/Σanions

Table 4 Relative contributions of cations or anions to the sum of ions (%)

			madake bamboo		moso bamboo		Japanese cedar	
		precipitation	throughfall	stemflow	throughfall	stemflow	throughfall	stemflow
Cations	H^+	46	10	19	15	31	10	58
	Na^+	9	5	6	4	5	10	10
	NH_4^+	29	26	30	18	17	37	8
	K^+	1	29	21	42	27	10	4
	Mg^{2+}	5	11	8	7	7	8	5
	Ca^{2+}	10	19	16	14	13	25	15
	total	100	100	100	100	100	100	100
Anions	Cl^-	13	49	46	58	56	18	25
	NO_3^-	27	16	19	12	13	29	22
	SO_4^{2-}	60	35	35	30	31	53	54
	total	100	100	100	100	100	100	101

Guadua angustifolia Forestry nucleus in Colombia: Contribution to Environmental Preservation and to Local Social Development

Ximena Londoño
Colombian Bamboo Society

Abstract

The Nucleo Forestal de Guadua La Esmeralda – NFGLE (La Esmeralda Guadua Forestry Nucleus) was established in 2007 in the coffee growing region of Colombia. It is operated by the Colombian Bamboo Society and has the following objectives: a) to integrate the area planted in guadua that had different owners under one same figure; b) order and improve the forestry quality of the plantations; c) ensure a better quality and better price for the raw material; d) guarantee protection of the water resources and biodiversity; e) generate employment; f) provide support and incentives for the research processes; and g) strengthen the social and entrepreneurial organizations existing in the region. NFGLE is formed by 11 farms, having a total area of 315,7 hectares, out of which 27,74 ha (8,8 %) are planted in *Guadua angustifolia* Kunth. With this organizational scheme we expect to guarantee the sustainability of the resource, do a friendly management of the environment, and achieve greater profitability for the owners.

Resumen

En la región cafetera de Colombia se conformó en el año 2007 el Núcleo Forestal de Guadua La Esmeralda, operado por la Sociedad Colombiana del Bambú, cuyos objetivos son: a) integrar área de *guaduales* de diferentes propietarios bajo una misma figura; b) ordenar y mejorar la calidad forestal de estos rodales; c) asegurar un mejor precio y calidad de la materia prima; d) garantizar la protección del recurso hídrico y de la biodiversidad; e) generar empleo; f) apoyar e incentivar los procesos de investigación; y g) fortalecer los procesos de organización social y empresarial que existan en la región. El NFGLE está conformado por 11 predios que cuentan con un área total de 315,7 ha de las cuales 27,74 ha (8,8%) están cubiertas por *Guadua angustifolia* Kunth. Con este esquema organizacional se espera garantizar la sostenibilidad del recurso, realizar un manejo amigable con el medioambiente y lograr una mayor rentabilidad para el propietario.

Introduction

La Esmeralda Guadua Forestry Nucleus - NGFLE was established in March 2007 having as its main objective: a) to integrate the area planted in guadua having different owners under one same figure; b) order and improve the forestry quality of the plantations; c) ensure a better quality and better price for the raw material; d) guarantee protection of the water resources and biodiversity; e) generate employment; f) provide support and incentives for the research processes; and g) strengthen the social and entrepreneurial organizations existing in the region.

NFGLE is located in the Province of Quindío, Colombia, in the Municipalities of Montenegro and Armenia, on the western side of the Cordillera Central (Central Mountain range), at an elevation of 1200 to 1250 meters above sea level, and with a rainfall regime of approximately 1800-2500 millimeters per year. In the location of the Nucleus there is guadua of good quality and a very good size and an adequate infrastructure of roads, electrical networks, and rural aqueduct which are basic conditions to exploit and commercialize guadua culms, and to establish a primary transformation center in the future.

NFGLE is made up by 11 farms having a small to medium size, with a total area of 315, 7 hectares, of which 27, 74 ha (8.8 %) are covered by the American native bamboo *Guadua angustifolia Kunth* (see Table 1). The area in *guaduales* represents very low economic profits for the farms, while the plantain, coffee, banana, tropical flowers, cassava and grass crops generate the greatest income.

Three main aspects have contributed towards the reduction of the agricultural vocation of guadua in this zone, and to the reduction of the area planted in guadua: 1) The large and medium sized properties have been divided due to inheritance processes and have become smaller farms with areas between 1 and 9 hectares; 2) the change of land ownership, whereby the new owners have a different culture, eradicating traditional crops, and planting grass and other foreign products requiring less labor, contributing significantly to damage the soil and its agricultural potential; 3) The increase of atypical climatic phenomena, represented by wind storms with wind speeds over 150 km/h that seriously affect the crops and the watersheds of rivers and creeks.

Given this situation, CBS has promoted the integration of medium and small sized farmers in forestry management activities related to improve the environmental, social and economic quality of the community.

Guadua represents a low income in the total economics of the farm owner, who has not yet identified the great business opportunities that exist in relation to guadua, thus the farmers don’t have great interest in this crop and devote most of their efforts to crops that are 30% more profitable, such as plantain and coffee.

According to Botero et al. (2006) “10% of the total cost of guadua in a lumber yard corresponds to the value of the standing raw material, that is, what the farm owner receives; 43% of the total cost corresponds to labor intensive tasks that take place in the stand and inside farm (eliminating weeds, harvesting and transportation by technical assistants and forestry operators); 38% corresponds to land transportation, where there is only one actor; and 9% corresponds to commercialization”.

Creating and operating NFGLE successfully has required quite a bit of organizational work with the farm owners, the local environmental authorities, the forestry operators, transporters, and dealers, the companies interested in this raw material, and the academia, with the objective of integrating the different actors of the Guadua chain.

Table 1. Area of the farms, area in guadua and percentage of the *guaduales* in NFGLE.

Property (Farm)	Farm Area (ha)	Area (ha) of the Guadua Plantation		Percentage of the area in *Guaduales* (%)
		Natural	Cultivated	
Guadualito	37,15	2,0	0	5
La Esmeralda	3,75	0,5	0	13
La Manuela	31,61	0,5	0	2
El Guatín	16,78	2,2	0	13
El Bambusal	16,78	0,6	0,8	4
La Negrita	4,48	0,01	0	0,2
La Elena	23,56	4,09	0	17
La Manila	28,65	2,15	0	8
El Volga	41,8	1,45	0	4
La Balsora	108,9	12,8	0	12
El Jardín	2,24	0,64	0	29
TOTAL	315,7	26,94	0,8	8,8

What is a Guadua Forestry Nucleus?

A Guadua Forestry Nucleus is the forestry organization of the guadua plantations into an area united by homogeneous characteristics or by geographical factors (watersheds, micro watersheds, mountain systems, valleys, etc), where the silvicultural activities concentrate using a criteria of sustainable practices that aim to improve supply and generate social and economic benefits (Botero et al. 2006; Castaño & Moreno 2004; Moreno 2007).

Organizational Structure of NFGLE

The land owners who form part of the NFGLE assign their right to exploit their guadua plantations to the Colombian Bamboo Society - CBS, which in turn, commits to manage the guadua resource with a dual purpose: guaranteeing an environmentally friendly management and achieving greater profits for the owner (Diagram 1).

To operate the NFGLE, the Colombian Bamboo Society has a group of 5 workers: 1 forestry operator, 2 harvesters, and 2 guadua loaders who extract and transport the raw materials from the stand to a storage area. This personnel is properly trained and must wear personal protection elements (helmet, leg protection, goggles, thick books – with a leather sole and steel structure to prevent perforations), ear plugs (only for work done with a chain saw), and a raincoat. To commercialize the products of the NFGLE, commercial agreements have been entered into with local and national dealers and members of the CBS in order to supply them with high quality guadua and to guarantee the custody chain in the certification processes.

To participate in the legalization projects of the forestry sector, NFGLE forms part of the Forestry project FLEGT- Colombia (2007-2010) sponsored by the European Community, which promotes the improvement of forestry legalization and governance, and the increase of legal production and commercialization of forestry resources in Colombia. In 2005, illegal operations in the forestry sector of Colombia were estimated to be 35%. This represents illegal transportation and transformation of over 1,5 millions of cubic meters of timber (Ecoforest 2009). Through this project, NFGLE has received equipment donations that make the forestry operation more efficient (brush cutters, chain saws) as well as training and assistance on the concept of voluntary forestry certification and legal timber.

With the local environmental authority a cooperation agreement was drawn with the objective of joining efforts and resources that lead to inter-institutional support in the areas of research, promotion, cultivation, forestry management, and sustainable exploitation of native bamboos and of bamboos introduced into the zone of their jurisdiction.

Since 2003, NFGLE has worked together with the Instituto Colombiano de Normas Técnicas - ICONTEC (Colombian Standards Authority) and with the Technical Committee 178 Bamboo-Guadua on the drafting of the guadua standards to establish basic quality, security, health and environmental protection requirements for guadua related products, services, processes and systems. Seven standards have been published during these 6 years of work (2003-2009): NTC 5300, NTC 5301, NTC 5407, NTC5405, NTC 5458, NTC5525, and Pre-NTC 209-08 (see References). They are not mandatory, but contribute to standardize and homogenize the quality of the products and processes. CBS has conducted training workshops to generate awareness about these standards among NFGLE members and the different actors involved in the Guadua chain of Colombia.

In the social aspect, a cooperation agreement was drawn with the principal authority of the Pueblo Tapao Township, in the Municipality of Montenegro, to promote the creation of a handcraft center for women-bread providers (head of the household). NFGLE provides the raw materials and the government, through SENA (the national training services) provides the training. A total of 12 women have become involved in this project.

In Research aspects, the CBS has worked since 2002 with various universities and research centers of the region (Cenicafé, Universidad Tecnológica de Pereira and Universidad Nacional de Colombia), making NFGLE available to them and providing financial and logistic support to undergraduate students. The resulting research work contributes to the sustainable management of the guadua stands and to improve the quality of the guadua products extracted.

Objectives for success when establishing the nucleus

1. Environmental objectives: a) Assemble and educate farm owners so they value the environmental benefits of the guadua ecosystem; b) Preserve and reforest the watersheds in the area of the NFGLE with guadua plantations; c) Minimize environmental impacts during the exploitation process; d) Establish new areas planted in guadua to develop soil and watershed recovery projects with the objective of having a compensation for environmental services in the future; e) Identify and protect the habitats of the different fauna and flora registered in the area.

2. Social objectives: a) Generate employment sources in the zone; b) Improve the environmental and touristic offer in the zone; c) Strengthen the principle of association among the members of NFGLE to carry out other activities that contribute to the improvement of the nucleus and of the township; d) Exchange knowledge and contribute with the research being done on guadua at different universities of the country; e) Train the communities neighboring NFGLE in the sustainable management of the guadua stands and in the handling of the raw materials to stimulate the establishment of business that help dynamize NFGLE.

3. Economic objectives: a) Perform productive activities related to the guadua stand that generate aggregate value, b) Provide guadua stands that yield higher productivity and profitability to the farm owners; c) Guarantee the supply of guadua through time, being able to supply high quality raw materials suitable for the different processes of transformation and industrialization; d) Supply quality guadua to the Guadua chain; e) Open and consolidate new domestic and foreign markets.

Activities carried out within the NFGLE

To begin any activity within the NFGLE a forestry exploitation plan must be prepared. This is a requirement of the local environmental authority, who must grant an exploitation permit by means of an official resolution. This plan consists of a study done by a forestry professional, whereby he determines the area of the native guadua stand, the number of culms in the stand, and their corresponding status of health and maturity. He defines the number of culms that can be harvested; taking into consideration the harvesting intensity, i.e. the number of culms harvested can't exceed 38% of the mature culms counted, without including sick, warped or dead culms.

After the local authority approves the plan, the following activities begin:

Weed control: It consists of eliminating weeds that prevent access and movement through the guadua stand. This activity must be carried out before extraction of the guadua to facilitate guadua cutting and transportation activities. Trees over 10 cm in diameter must not be cut down (NTC5300). Vines must be cut at least two weeks before harvesting the culms to facilitate harvesting and extraction. For this task, a machete and a "garabato" or hook are used in addition to the personal security equipment (helms, gloves, goggles, leather leggings).

Eliminating branches with thorns: In its morphology guadua develops thorns on the lower third portion of the culm (the first 2-3 meters of the culm). These branches are cut off taking care not to wound the culm with the machete. For this task, a machete, pole pruners, and a "garabato" or hook are used in addition to the personal security equipment.

Extraction and elimination of low quality culms: The dead, low quality or sick culms of guadua segments must be cut into small pieces to contribute to organize the guadua stand, facilitate circulation, and promote the birth of new shoots. The segments might be arranged as a barrier in the perimeter of the guadua stand or in existing gaps, so that the direct action of the sun and water may accelerate the decomposition process. For this task machetes, chain saw, and "garabatos" or hooks are used in addition to the personal security equipment.

Marking: Consists of marking the number of mature culms (5-6 years old) to be extracted according to the harvesting intensity recommended in the harvesting plan. This task is done by an experienced person, in a subjective manner, because to date, no quantitative method has been found to establish the culm's age. After the culms are marked, the cutting team proceeds to harvest them. This activity aims to prevent the cutting of immature culms and an excessive exploitation of the stand. The exploitation of immature culms is a serious problem for any transformation process, to overcome it, the new shoots are marked in the NFGLE placing the year of the new shoot eruption using a permanent ink marker.

Harvesting plan: It consists of quantifying the mature culms harvested so as not to surpass the volume of culms to be extracted as authorized by the regional environmental authority. The sustainability and productivity of the guadua stand will depend on a good harvesting plan.

Harvesting of the culms: The cuts are done above the first node of the culm, avoiding the rupture of the node's membrane and the accumulation of water in the internodes. The harvest of the culms is distributed in a uniform manner, trying to avoid the forming of gaps or an excessive exploitation of the guadua stand. When the cutting of the culm is taking place, it is important to direct its fall and avoid hitting the new shoots or other immature guadua stems that remain standing. Experienced people are required for this task, and they must use security equipment.

Correcting culms that don't have a good cut: After the harvesting plan is carried out, the old imperfect cuts from earlier harvests or caused by climatic phenomena such as the wind must be corrected by making a new cut at the base of the node. This task is made easier using a chain saw. The culm segments and the branches that remain in the stand after the harvest and which at that time are not of commercial interest, must be cut into small pieces and arranged in small piles inside the stand.

Transportation and storage: After the harvest, the culms are transported by workers to the border of the guadua stand, and from there they are transported with beasts of burden (horses or mules), taken to the collection area where the truck arrives, and sent on to their final destination. The storage of the cut culms is done in an open yard because we don't have a warehouse to store them yet.

The culms are stored horizontally, avoiding piles or laying them in tiers not higher than 3 meters and keeping the tiers in layers, separated by uniform wedges placed crosswise (NTC 5300). Storage is also done vertically. In this case the culms are leaned on a frame, with space between them, or leaned on trees; because of the strong winds in the area of the NFGLE, some of the culms must be tied to the frame to prevent them from slipping off.

Commercialization: The products from the NFGLE are mainly sold to dealers from Bogotá and Armenia. They collect the guadua in the storage yard. The unit of sale is the linear meter, and the price per linear meter is $700 pesos (0.35USD) for culms having a height of 4, 5 or 6 meters, or $500 pesos per linear meter (0.25USD) for the 4 meter *esterilla* (culm that is split and forms a mat). The products that are being offered at present are pre-dried in the open yard and are not preserved or immunized. For the members of the CBS there is a 5% discount over the sales price, and the farm owners who are members of the NFGLE are only charged for the labor costs.

Conclusions

1. After 2 years, the NFGLE associative project was able to achieve profitable productive scales, giving *Guadua angustifolia* culms a higher aggregate value, and giving the guadua stand owner a higher percentage of the profits, increasing their participation in the final price from 10% to 37%.

2. By increasing the productivity and supply availability both in quantity and quality at the NFGLE, competitivity in the local and national markets is improved, and the planting of new areas of guadua inside the nucleus is stimulated.

3. This associative scheme facilitates the transfer of science and technology, makes improvements of the plantations possible, increases the volume supplied and lowers the cost for negotiation and thus increases competitiveness.

4. The permanent availability of guadua culms for the NFGLE members has stimulated the use of this raw material in the various agricultural and livestock tasks, and in the construction of rural infrastructure at the farms, contributing to rescue the traditional use of guadua in Colombia's coffee growing region.

5. The water volume of the Tres Palitos and La Esmeralda creeks, affected by deforestation in the headwaters and by the urbanization process of the area, has increased with the improvement of the guadua stands in the NFGLE.

6. The establishment of the NFGLE has given permanent jobs to 5 people in the area, and the process of entrepreneurial association of the group of women who are the heads of their household (bread winners) at the Pueblo Tapao Township has been strengthened.

7. The supply by NFGLE of quality raw materials has contributed to the improvement of all the transformation processes in the guadua supply chain.

Acknowledgments

I would like to thank the farm owners and the Colombian Bamboo Society for believing in and supporting this project; Natalia Morales Noreña for her contribution to consolidate this associative scheme and for her work in the voluntary certification process; Bosques FLEGT for their donation of equipment; and the Corporación Autónoma Regional del Quindío for their support.

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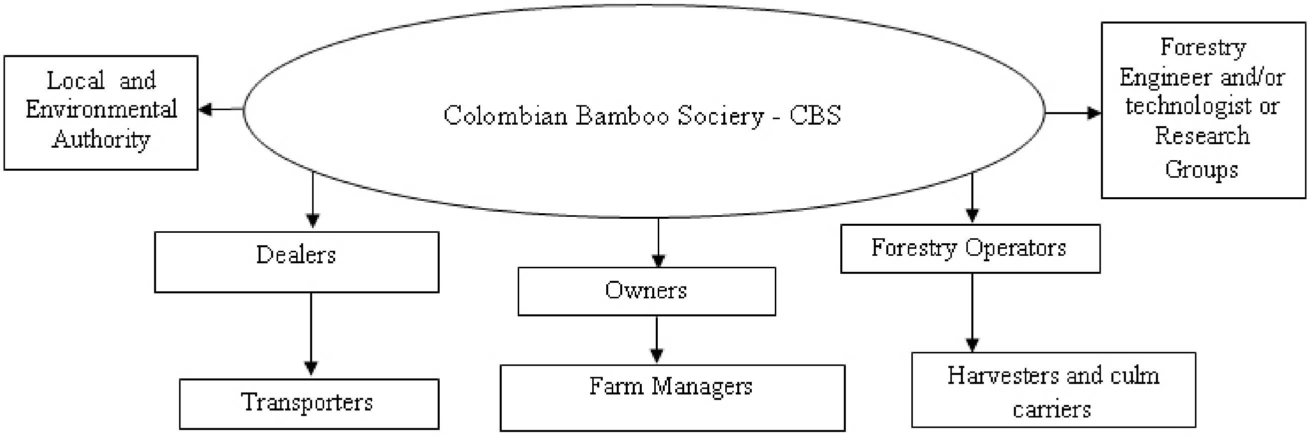

Diagram 1. Organizational Chart of the NFGLE

Oxygen Oasis

Tim Fisher
FisherGreen Communications

Imagine importing rich, life sustaining oxygen into your local community to combat high concentrations of air pollution from traffic clogged streets, backed up highways, multiple train lines and airplanes flying overhead.

Introducing OXYGEN OASIS – a completely new, innovative way to increase oxygen emission by 35 percent and help to combat pulmonary disorders such as asthma. OXYGEN OASIS is a simple and economical project designed to bring lush, green environments to abandoned urban lots.

Properties of Bamboo

1. emits 35 percent more oxygen than other plants
2. a renewable plant resource –
3. replicates quickly – a grove can mature in as little as three to five years
4. has minimal water requirements
5. grows in sun or light shade
6. thrives in temperate zones and can stay green year round

Benefits of an OXYGEN OASIS

Bamboo has superior properties that set it apart from other plants (shade trees and perennials) that would typically be used to green an urban environment:.

1. increased oxygen emissions
2. sequesters carbon
3. reclaims toxic soil and brownfields
4. controls soil erosion
5. green garden spaces:
    a. beautify and vitalize a neighborhood
    b. strengthen community bonds
    c. improve quality of life
    d. provide recreation, exercise, learning, therapeutic experiences
    e. cut heat absorption
    f. help to foster economic development

Getting OXYGEN OASIS in the Ground

In order to bring an OXYGEN OASIS to your community, the following requirements are needed:

1. empty dirt lot (brownstone size and above) with sun exposure
2. neighborhood site manager and community gardeners
3. debris removal and soil amendment
4. security fence
5. landscape design
6. bamboo plants
7. watering, maintenance
8. event planning and site administration

Bamboo as Carbon-Sink - Fact or Fiction?

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Abstract

Bamboo is often considered as a plant with an extraordinary potential for carbon sequestration and therefore for mitigating climatic change. This paper argues that bamboo is not likely to be significantly better than trees, and that much more research is needed to establish the true potential of bamboo for carbon sequestration.

For example, the assumption of bamboo's high sequestration potential is derived mainly from the fast growth of the individual culm during its expansion phase. However, the impressive biomass of such a young culm does not originate from its own photosynthesis, but derives from the energy produced by older culms in previous years and stored as carbohydrates in their culms and rhizome system. At the beginning of the growth season this energy will be mobilized and transported to the growing culm.

The individual culm has a limited lifetime of 7-10 years, and thereafter its biomass and the carbon contained will be deteriorated biologically into its origins, among them also CO_2, released into the atmosphere. Furthermore, the gregarious flowering of some species, often world-wide and followed by their death, can constitute a massive CO_2 production. On the other hand, prolonged sequestration of carbon is provided through the great variety of bamboo products that range from the manifold constructions to pulp; many of these uses serve the daily needs of over 1.5 billion people.

Although the carbon sequestration of bamboo forests is not likely to influence the mitigation of global warming as much as some protagonists have been arguing, the importance of bamboo forests and plantations for an environment-friendly and sustainable production of food, fibre and energy, and their environmental services including soil stability and waste-water management, important for adaption to climate change are undisputed.

Keywords: bamboo, CO_2 sequestration, biomass, carbon, life cycle, bamboo products

Introduction

Global warming, its causes and possible counter-measures are a major global concern and numerous international conferences and initiatives, both in research and politics, strive to identify viable approaches to mitigation and adaptation. Among these approaches the „carbon, capture, storage (ccs)" idea is considered, where plant communities sequester carbon dioxide by their assimilation and transform the gas into their biomass for longer storage. Bamboo is certainly among the plants that are to be considered in that context, and this is also indicated by the title of our Conference „Bamboo, the Environment and Climate Change".

The impressively fast growth of a bamboo culm and the annual re-growth of new culms point to a sustainable high biomass production and thus carbon sequestration. This is also expressed by numerous statements in public media like „Trees absorb the carbon we generate rapidly by photosynthesis, but bamboo does this five times faster than the others“(Times of India 4.08.2008). The internet-forum „bamboo-plantations“ provides statements like „ if we plant new forest and especially new bamboo plantations, we could cool the planet by purpose“(26.01.09).A National Workshop in Kerala, India, discussed in January 2009 as urgent topic „Bamboo - a global cooling agent“. To mention are also considerations to include bamboo plantation projects and the sustainable management of bamboo forests as eligible CDM projects for the post-Kyoto period.

Although a bamboo plant is biologically a grass and not a tree, a bamboo forest is considered a forest by UN-FAO definition (FAO 2004); there it reads: “forest includes areas with bamboo and palms provided that height and canopy cover criteria are met” (Fig. 1). Bamboo forests are able to store large amount of carbon which is later released by its natural biological deterioration. The discussions about relevance of forests in the context of global warming are mainly about the tree-forest and ecosystems, not about specific plants or (agro-)forestry species, such as for example at a recent conference in Copenhagen on “Climatic Change-Global Risks, Challenges and Decisions” (10-12 March 2009), with 2.500 delegates from nearly 80 countries, where no specific discussions were devoted to the (potential) role of bamboo.

In principle, of course, a bamboo forest has relevant characteristics like a tree forest regarding its role in carbon sequestration, but many questions are still open regarding the carbon dynamics in bamboo forests.

On the past VIIth World Bamboo Congress 27th February- 4th March 2004 in New Delhi, Session 23 “Carbon Sequestration and Trading” discussed in four papers mainly the issues of biomass production and carbon sequestration (Singh and Dadlani 2004). This paper follows with some biological aspects of the bamboo life cycle which are relevant for determining the storage of its biomass. Corresponding considerations and conclusions were published recently in a German Journal (Liese and Düking 2009).

The Growth of a Bamboo Culm

In order to consider bamboo as an extraordinary carbon-sink influencing atmospheric conditions, the carbon dioxide used for photosynthesis would have to be captured as biomass for a longer period than the period for comparable trees in the ecosystem under consideration. But what are the biological facts, which were apparently not much considered so far?

The bamboo culm impresses by its fast growth within a short time of only 3-4 months. Its daily growth amounts in a sub-tropical, temperate climate (*Phyllostachys, Pleioblastus*) on average to 20-30 cm and for tropical genera (*Bambus, Dendrocalamus, Guadua)* about 40-60 cm, depending on species and the environmental conditions; measurements of a daily growth of 100 cm are reported - but are not common. During its expansion the young culm is protected by culms sheaths, which fall of with time. Leptomorph (sub-tropical) genera reach a length of about 5-15 m and tropical, mostly pachymorph genera about 20-30m (max. 35m) with a diameter of up to 30 cm (Fig. 2).

The considerable amount of carbohydrates needed for the expanding culm cannot be produced by the culm itself. This is quite contrary to a germinating tree seed, which produces with the little energy of the seed first germination leaves as its own power plant- but admittingly also grows much less during its seedling year than bamboo. A bamboo culm, however, can grow so fast, because it is connected by its rhizome system with its older culms. Consequently, the energy for the culm shoot originates from the carbohydrates of previous years stored in their culms and rhizome. By the well-known photosynthesis process the leaves produce carbohydrates by uptake of CO_2 and release of oxygen. The resulting soluble sugars (saccharose, glucose, fructose) are transported in the phloem of the vascular bundles from the leaves to the culm and further down to the rhizome and roots. They diffuse in the surrounding parenchyma (about 50% of the tissue) and are mostly transformed into compact starch globules (Fig.3). The starch content varies with species, site conditions and age; it may be up to 10% of the biomass. Only few investigations exist so far about the molecular and physiological processes during culm growth. Observations on *Sasa palmata* (Magel et al. 2006) have shown that at early development stages the starch content in the rhizome and in older culms is much reduced, transformed into soluble sugars and transported to the expanding culm. In its early phase an older culm contains about 120nmol saccharose/mg dry weight which is reduced to 10 nmol during expansion. The hydrolysis of the carbon hydrates leads to a 50 times increased sugar concentration, so that due to the high osmotic pressure the cells expand and consequently growth results.

At a later stage of culm expansion the sheaths fall off and the epidermis appears often greenish coloured by their chloroplasts. In how far these chloroplasts contribute by photosynthesis to the culm tissue below has hardly been investigated (Poudyal 2006). It is one of the many questions for research on bamboo growth and the photosynthesis and respiration of the developed culm.

After the few months of expansion the fully elongated culm has all cells and tissues developed to be functional. However, the fibres of the vascular bundles contain still a small cell wall of few layers (Fig.4). Since the fibres amount to about 40% of the total tissue, young culms are called “immature” and may break easier, e.g. by storm. During the following years their wall will be strengthened by formation of additional lamella. Also the wall of the parenchyma cells will be thickened (Liese and Weiner 1996). It can be assumed, that this additional biomass stems from the culms ongoing photosynthesis.

The production of total biomass/ha/a is not to be addressed within this paper. Data about the biomass are found in a number reports, such as Scurlock et al. (2000), Kleinhenz and Midmore (2001) and Hunter and Wu Junqi (2002).Like trees, it varies in a wide range, depending on species and site conditions, for bamboo between about 50 t/ha/a and 4 t/ha/a, with a considerable biomass also below ground. The carbon content amounts to about 45-50 % of the total dry biomass, equivalent to trees.

Life Cycle of a Bamboo Culm and Stand

A managed bamboo forest gives the impression of a continuous production of biomass. The “mature” culms harvested commonly after 3-5 years are replaced by the young culms, so that the bamboo stand appears to be in biological balance. With such a regular management hardly any older culms are left, the more as their outer appearance makes them unfavourable for use. Significant is the fact, that a bamboo culm has a limited life span of only 7-10 years, which will hardly be recognized in a managed forest. An old culm looses its leaves, dries up and breaks down after a while. Its biomass will de decomposed then by micro-organisms and insects into its origins with an uptake of oxygen and a release of the captured carbon back into the atmosphere. The biochemical and structural modifications at the culms natural death are still unknown and need to be analysed urgently; another research question in the context of bamboo stand dynamics.

An unmanaged, naturally regenerated bamboo forest, however, contains culms of all ages, including a great many dying and dead ones (Fig.5). Also the connected rhizome system appears to become deteriorated, equivalent to trees. Such forest is often situated far from human settlements and poorly described. It may be assumed, that most of the 37 millions ha bamboo forest are not utilized, so that their biomass will follow the biological cycle between growth and deterioration. According to FAO (2007), in Asia about 30 % of bamboo are planted, but 70% naturally re-generated.

Consequently, the additional storage of CO_2 by a bamboo ecosystem due to early fast growth may be quite limited because also in a relatively short time period such forest reaches an age when old culms start to die of and when the CO_2 captured by photosynthesis equals its release through biological deterioration.

Such calculation assumes a complete biological deterioration, so that no un-rotten material remains on the ground to form thicker humus or even coal layers, as often postulated for the tree forest. This situation has still to be clarified. Also recent reports from Australia about the formation of long lasting phytoliths with a high carbon content in old bamboo stands merit further investigations (ABC 2008).

The Flowering of Bamboo

The apparent continuous growth of a managed resp. natural bamboo stand with a replacement of the harvested resp. dying culms by young ones can end abruptly by a gregarious flowering. Quite a few bamboo species flower in regular intervals, often with a cycle of 30-50 years. The flowering occurs worldwide for all individuals of the given species and is regularly followed by the death of culms (Fig. 6).The common species for northeast India *Melocanna baccifera* has flowered in recent years in the Mizoram region, but also in Colombia (Fig.7).The phenomenon was already observed 1969 in Bangladesh, confirming the cycle of 45-50 years registered since 200 years (Liese 2008, Shibata et al. 2008). In Europe the common *Fargesia murieliae*, although not really a high biomass producer, has flowered around 2006 followed by a general dye-off. However, for the widely distributed *Bambusa vulgaris* no flowering was seen since 1810. Other species do not exhibit the natural property of gregarious flowering, but show spontaneous flowering of individual plants or culms, followed often by the death of the culm or group of culms that flowered.

After flowering the culms and most of the rhizome die off, they become brittle, collapse and decompose biologically. Consequently the stored carbohydrates will be released into the atmosphere as a big CO_2 eruption. Also the fire of a bamboo forest can produce large amounts of CO_2, as it also occurs for the trees by fire, insect calamities or windbreak.

The occurrence of a coming flowering is indicated by smaller and lesser foliage, so that the culms might be harvested in time by clearing and storing for the material requirements in coming years. However, the strength of the dying culms becomes much reduced; details of these changes in the culm structure are yet to be researched.

It might be noted, that reforesting a new bamboo stand on a large area either by seed or with a plantation program will take about 4 - 6 years until the regenerated culms reach their final productivity and dimensions; harvesting of mature culms will then take another 2-3 years. While this is usually quicker than for a tree plantation, the manpower for planting and maintenance as also the energy input through fertilization and watering during establishment should be taken into consideration when calculating the carbon sequestration balance of bamboo- and of trees or other carbon sequestration crops for hat matter.

Bamboo Products for CO_2- storage

The natural carbon cycle in bamboo is being interrupted by the utilization of mature culms as products. There are about 1.500 kinds of products for manifold purposes. These products store the carbon until the product is either biological deteriorated or burnt. The commercial bamboo utilization is estimated to about 20 million tons/year, but much more can be assumed to be consumed by rural life, not being accounted for in national statistics (Scurlock et. al. 2000). Bamboo contributes between 4-7% of the total tropical and subtropical timber trade (Jiang 2007). During the last decade, production, utilization and trade of bamboo have increased considerably, mostly due to improved and new products, but also by the higher esteem for bamboo products as part of the natural scenery (Zhang Qisheng et al. 2001; van der Lugt et al. 2009).

Construction is the main field for bamboo use. In rural areas bamboo is often the only material readily available. It is estimated that at least 1 billion people live in bamboo houses of different kinds and quality. Prefabricated elements and international programs have fostered the construction of modern house-types, as in Costa Rica by UNHABITAT. The slogan “bamboo is the poor men’s timber” embraces both the fact that bamboo is a good replacement for wood and cement available to the poorest in society, as well as the unfortunate fact that poor people do not have access and the financial means in invest in appropriate preservation technology and that therefore their bamboo constructions often face deterioration by fungi and insects. Adequate constructions will be helped by chemical protection, although with its potential significant side-effects (Liese and Kumar 2003).With the present status of bamboo preservation technology use in bamboo constructions the storage time of CO_2 should be considered limited and is estimated to be in the order no more then 15-20 years.

Furniture products from round or split bamboo are much appreciated; some are designer pieces for long lasting use, but mostly bamboo is used for daily life products in the bamboo-countries often with a limited use time. In compact flat packs they are increasingly exported to North-America and Europe in spite of various obstacles regarding production, transport and commercialization (van der Lugt and Janssen, 2008).

Bamboo-based panels and boards of about 25 types are produced for an expanding large market (Ganapathy et al. 1999). China produces around 1 million cbm boards in about 200 factories for manifold applications. Their service life may be in the range of decades. Also bamboo flooring should be mentioned with a production of 17.5 million m^2 2004 in China.

Pulp and paper are big consumers of bamboo (and wood), but do not have great value for carbon sequestration. Their production in large mills requires a steady and huge amount of raw material. In a few cases an over-cutting of bamboo stands has led to a shortage and therefore a change of the material source, or even to the closure of these factories. Also imports became partly necessary. The use of bamboo for cardboard or paper is short term use, and most of the products if not recycled will rapidly deteriorate and return to the atmosphere as CO_2.

Pulp mills require a continuous intake of raw material. Bamboo however can be harvested in most regions only during about 6 months due to the sprouting season and weather conditions. Consequently large amounts of culms have to be stored at least for several months. Often fungal infections and borer attack occur which can reduce considerable the pulp quality and also quantity (Fig. 8).The loss of biomass during storage and the corresponding immediate carbon release is an additional factor determining the limited carbon sequestration value of most pulp/paper products made out from bamboo.

As an **energy resource** bamboo has a most important function. In rural areas bamboo is often the only material for cooking and heating, especially where firewood is not available. Also the bamboo waste from processing often serves as energy. A large amount of bamboo biomass is being used this way, often replacing wood because of bamboo's high potential regrowth after cutting, which can help to prevent deforestation. The potential of bamboo biofuels is intensively investigated (El Bassam et al. 2002)

Another way for using bamboo biomass is the production of bamboo charcoal. This process leads to products with a better heating quality. Bamboo charcoal is lighter, can be stored and transported easily and they is absorbent and not susceptible to insects and fungi. A recent project by INBAR and the EU for Ethiopia and Ghana sees plans for a total of about 1.000 production centres for bamboo charcoal to meet the energy demand of 30.000 families on a sustainable basis.

Its biological resistance also promotes intentions to use bamboo charcoal for long lasting improvements of degraded soil.

For wood a permanent carbon dioxide sequestration by a burial process was recently proposed by Scholz and Hasse (2008) and also considered for long time storage of bamboo. However for an operational application severe restrictions exist (Köhl and Frühwald 2008).

Conclusions

The fast growth rate of bamboo culm and the apparent sustainability of its forests favours considerations about a very high potential as a carbon sink with potential beneficial impact on global warming. However, a closer look indicates that there are no reasons to assume that bamboo would outperform trees in carbon sequestration. For example, the impressive production of biomass during the growth phase is based on carbohydrates produced in prior growing seasons. Since a bamboo culm has a lifetime of only 7-10 years, the biomass accumulated through assimilation will relatively rapidly start to degrade into its origins. Thus, a natural bamboo forest in biological balance is not likely to be an exceptional CO_2-sink. Also the gregarious worldwide flowering rhythm of decades of some species, followed by their death is likely to lead to a massive sudden carbon release.

A prolonged capture of carbon in bamboo is possible whenever the culms are processed into products with long life cycles, such as construction material, panel products and furniture; also the use as an energy resource and as activated charcoal - reducing resources of fire-wood - may contribute to a sink effect of bamboo stands or may help halting deforestation and its related release of captured carbon. However, it must be noted that the lifespan of bamboo products rarely exceeds decades.

Consequently and despite other expectations, it does not appear justified to consider bamboo forests` capabilities as a carbon sink to be any more relevant than those of tree forests regarding their role in halting global warming. Fact is though because of bamboo´s high level of re-growth promoting increased usage of bamboo forests reduces the pressure on other forest resources, and thus protects and maintains the carbon sink function of ordinary tree forests.

Bamboo forests have many positive environmental effects: They stabilize steep slopes and water ways, prevent soil erosion and contribute to waste-water management (Ndzana and Otterpohl 2009). Bamboo as a plant and as a basis for thousands of uses does indeed secure the existence of more then a billion people on this planet. Bamboo plays a great role as an environmental friendly way to produce food (bamboo shoots), it is essential for the construction of houses as scaffolding as well as building material mostly in rural areas. Also bamboo is increasingly used as raw material for the production of countless articles and as an energy source for cooking and heating, where there is no alternative thus making it a frequent substitute for wood (Hunter 2002).

The facts presented in this paper are well known; it is clear that a lot of knowledge is still missing when analysing the potential role of bamboo for carbon sequestration.

Acknowledgement

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Figure 1. Bamboo forest in Colombia, *Guadua angustifolia*

Figure 2. Expanding culms, *Guadua angustifolia*

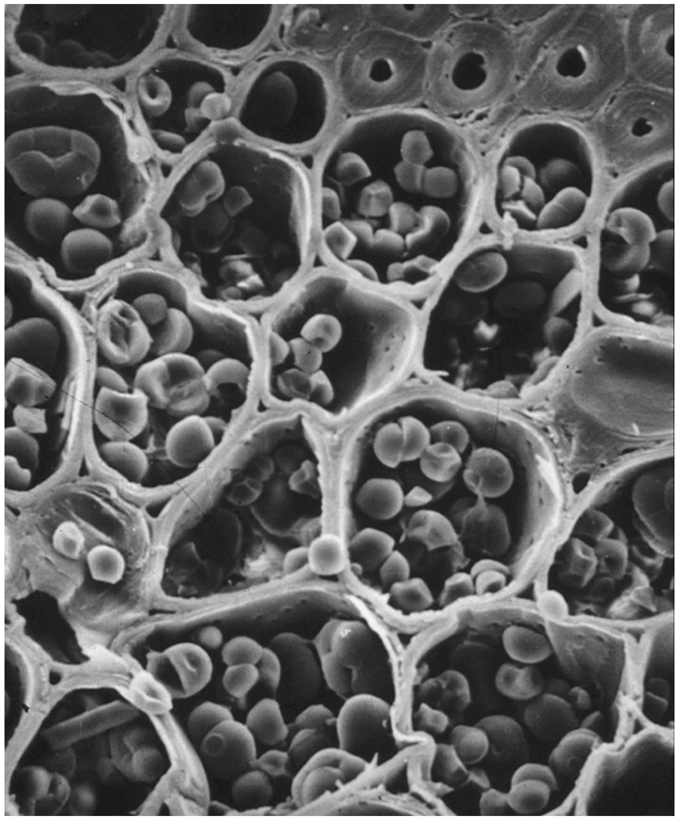

Figure 3. Starch granules in parenchyma cells store growth energy

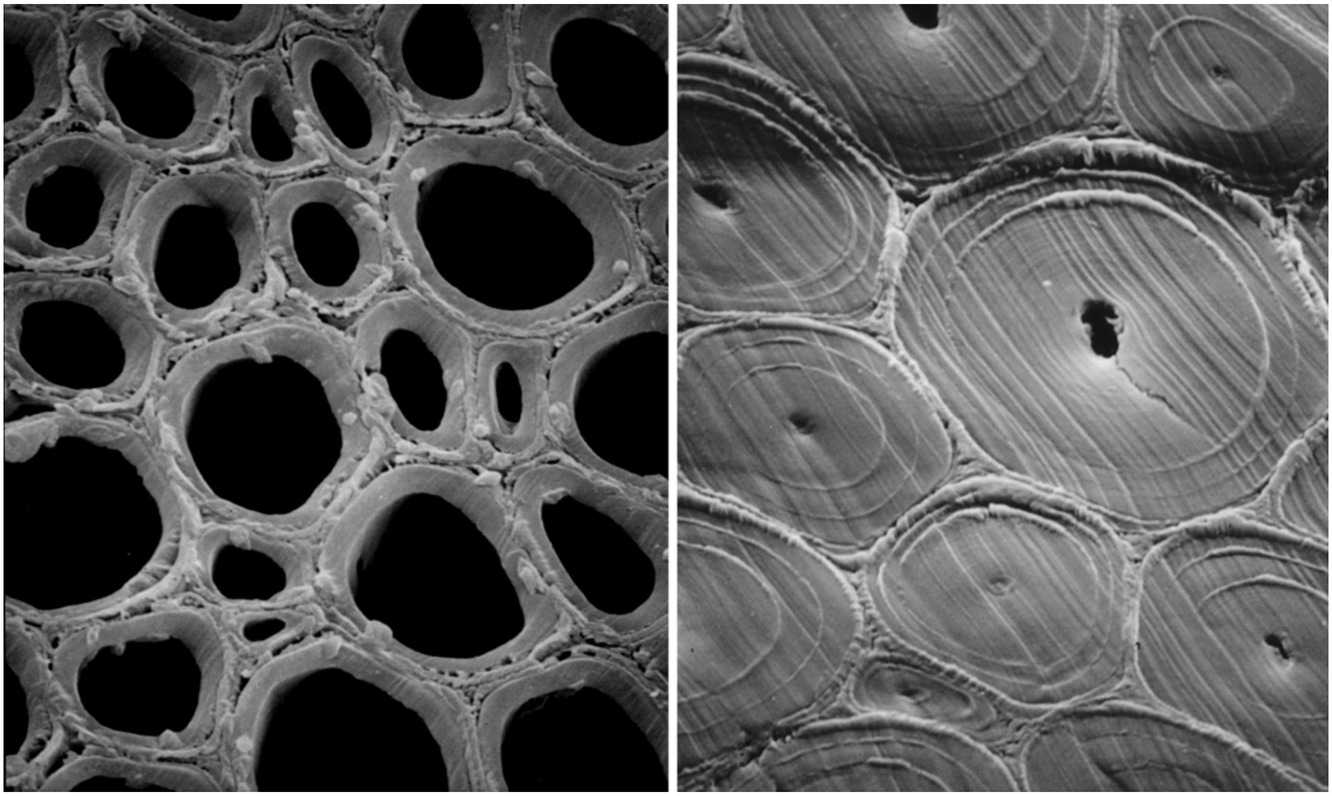

Figure 4. Cell wall of fibres, one and four years

Figure 5. Bamboo stand in balance between growing and dying culms.

Figure 6. Flowering and death of a bamboo clump.

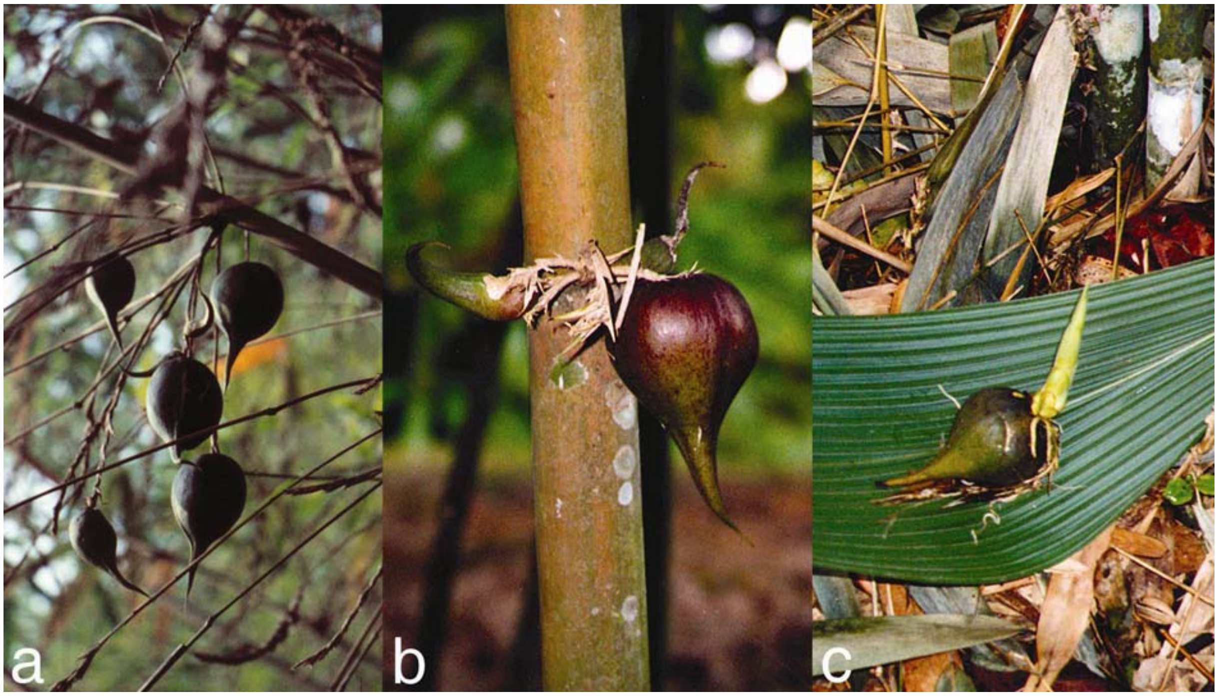

Figure 7. Fruiting cycle of *Melocanna baccifera* . 1969 Bangladesh, 2004 Colombia, India.

Figure 8. Fungal deterioration of a bamboo pile at a pulp mill.

Bio-sequestration of Carbon within the Phytoliths of Economic Bamboo Species

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Abstract

The rates of carbon bio-sequestration within silica phytoliths of the leaf-litter of ten economically-important bamboo species indicates that a) there is considerable variation in the phytolith occluded carbon (PhytOC) content of the leaves between different bamboo species, b) this variation does not appear to be directly related to the quantity of silica in the plant but rather the efficiency of carbon encapsulation by the silica. The PhytOC content of the species under the experimental conditions ranged from 1.6% and 4% of the leaf silica weight. The potential phytolith carbon bio-sequestration rates in the leaf litter component for the bamboos ranged up to 0.709 tonne e-CO_2 $ha^{-1}y^{-1}$ for these species. The data indicates that the management of bamboo forests to maximise the production of PhytOC has the potential to result in considerable quantities of securely bio-sequestered carbon per annum.

Keywords: Soil Organic Carbon; Phytoliths; PhytOC; Terrestrial Carbon Sequestration; Occluded carbon; Organic Matter Decomposition

Introduction

The world's soil carbon stocks have previously been estimated to accumulate at ~ 2.4 g C m^{-2} yr^{-1} (Schlesinger, 1990). However, quantifying soil carbon changes is difficult due to differences in methodologies currently employed and rates of decomposition resulting in both spatial and temporal variability (McKenzie et al., 2000; Skjemstad et al., 2000; García-Oliva and Masera, 2004). Current methods of carbon quantification in soil include determination of total carbon (TC). Total carbon measures all carbon fractions and is unable to distinguish between the more volatile soil carbon fractions and the stable soil carbon forms.

One inert form of organic carbon that is biosequestered within plants (and hence can be measured whilst in standing vegetation) and that accumulates in soil after the decomposition of that vegetation is the phytolith occluded carbon (PhytOC) fraction (Parr and Sullivan, 2005). Phytoliths are found in many plants species but are particularly prolific in grasses such as bamboo species. Also referred to as 'plantstones' or 'plant opal', phytoliths are silicified epidermal cell structures that occlude carbon (Wilding et al., 1967). The silicified epidermal cells of the leaf and stem within all grasses are particularly good at occluding carbon (Parr and Sullivan, 2005). This carbon fraction is likely made up of the internal cytoplasmic organic cellular material

(Wilding et al., 1967). Upon maturity the leaf material is deposited onto the soil surface: phytoliths later become incorporated into the soil matrix during decomposition of this organic material.

The occlusion of carbon within phytoliths has been demonstrated to be an important long-term terrestrial carbon fraction (Parr and Sullivan, 2005) representing up to 82% of soil carbon in some buried topsoils after 2000 years of in situ decomposition depending on the overlying vegetation type and drainage regime. Moreover, it has been demonstrated that relative to the other soil organic carbon fractions that decompose over a much shorter time scale, the carbon occluded in phytoliths is highly resistant against decomposition (Wilding et al., 1967; Wilding and Drees, 1974; Mulholland and Prior, 1993; Parr and Sullivan, 2005). Our research has demonstrated (using radiocarbon dating of the phytoliths themselves) that phytoliths extracted from palaeosols and peat sediments reach ages of at least 8000 years BP (Parr and Sullivan, 2005) and in another study a date of 13,300 ± 450 BP was acquired (Wilding, 1967). While under some circumstances bioturbation may move them up or down a soil profile, or erosion and dust storms may transport phytolith assemblages over some distance, or they may be burnt in a grass fire, or pass through the digestive system of an animal, the durability and persistence of phytoliths against such processes has been well documented (Baker, 1959; Baker, 1961; Baker et al., 1961; Bowdery, 2007; Hart and Humphreys, 1997; Humphreys, 1994; Jones and Handreck, 1967; Jones and Milne, 1963; Parr, 2006; Pearsall, 1989; Piperno, 1988; Rovner, 1986; Sangster and Parry, 1981; Wilding, 1967; Wilding et al., 1967). Moreover, the ability to radiocarbon date the phytoliths themselves demonstrates that they can remain stable sequesters of carbon over millennia despite being subject to the above circumstances.

Bamboo is known to be particularly proficient silica accumulators and hence also at the production of phytoliths (Drees et al 1989). Bamboo forests cover approximately 22 million ha worldwide and at least 7.2 million ha are currently growing in China (Jiang, 2004). There has been a significant increase in the use of bamboos for economic purposes such as crafts, charcoal and gas (for fuel), human consumption, housing construction including flooring, panelling, roofing and veneers as well as paper, oil and the production of textiles for the clothing industry which will result in an increase in demand for bamboo plantations (Lobovikov et al., 2007). While the culms are harvested for these various applications the leaf litter is often overlooked in carbon inventories (Zhou et al., 2008). In this study we examine the PhytOC content in the leaf litter fraction of ten economically-important clumping bamboo species in China. While PhytOC has been shown to be an important long-term soil carbon fraction (Parr and Sullivan, 2005), the potential of bamboo, a known silica accumulator plant, to securely biosequestrate carbon through this process has not been examined previously.

Materials and methods

Plant material

In this study bamboo species were used to examine the variability of the yields of plant silica and PhytOC within ten economically important species and to examine the relationship between these two characteristics. The importance of variability of PhytOC content within different cultivars of the same species is that such variability would allow, by the selection of a high PhytOC yielding species or cultivars over a lower yielding species or cultivars, to increase the rate of terrestrial carbon securely sequestered in PhytOC (Parr et al 2009).

Living leaf samples were collected from ten different sympodial (clumping) bamboo species of economic importance that had been established for approximately eight years.

Sampling of plant material

In most commercial bamboo applications the shoots and culms are harvested for consumption, the production of building materials or textiles. The leaf litter from new growth and the harvested culms generally is returned to the soil. In this study we have focused on the PhytOC component contained within the leaf litter. The accumulation of silica has been found to be greater in plants at maturity than in juvenile plants (Motomura et al., 2002; Norris and Hackney, 1999; Parr and Kerr, 2007), so to ensure valid comparison and to gain maximum accumulation contents, only the mature leaf samples from each bamboo species were collected and analysed (Table 1). Soil under each species were acidic (pH 4.0 to 5.5).

Phytolith occluded carbon analysis

The method used in this study for the isolation of phytoliths from duplicate leaf samples is a microwave digestion process described in (Parr et al., 2001). The basic method adopted here is a modified version of a stepped microwave digestion process (Parr et al., 2001) for plants and for soil samples (Parr, 2002) this process was followed by a Walkley-Black type digest (Walkley and Black, 1934) to ensure extraneous organic materials in the samples were removed. The absence of extraneous organic materials in the samples was checked by optical microscopic examination. This is a similar method to that used in the preparation of phytoliths for radiocarbon dating (Parr and Sullivan, 2005; Wilding, 1967). The phytolith isolates were then dried and weighed to obtain plant silica yields. The phytolith isolates were then combusted in an Elementar CNS analyser to determine carbon contents. The PhytOC results for duplicate leaf samples were combined and the mean percentage calculated.

Annual leaf litter deposition rates were not available for the study sites. Published data describing typical yields of two of the bamboo species were used in conjunction with the relative PhytOC yields (% biomass by weight) to provide estimates of the potential annual PhytOC yields in tonnes e-CO_2 ha^{-1}. Published data of annual leaf litter deposition rates for the remaining bamboo species consist of highly variable leaf litter accumulation rates for different geographical locations and species. Estimates of leaf litter accumulation rates in mature bamboo stands range from 1 to 37 t/ha (Kleinhenz and Midmore, 2001; Peng et al. 2002; He et al. 2003). Using the published data for two species and the potential range based on the above leaf litter accumulation rates, the PhytOC percentages per hectare were then quantified and compared (Parr and Sullivan, 2004).

Results

The phytolith extraction methods used in this study are designed to completely remove all organic material from the leaf-litter of each bamboo species and all available organic material from soils apart from that within the phytolith fraction give (Parr, 2002; Parr et al., 2001; Walkley and Black, 1934). Both the silica content and the PhytOC content of leaf-litter show significant variation between species (Table 2). The phytolith content for the ten bamboo species varied from between 8% and 28% of the original mass of leaf-litter material (Table 2).

There was considerable variation in the phytolith carbon contents of leaf-litter material for each bamboo species, ranging between of 1.60% and 4.02% (Table 2).

The total carbon (TC) content of soil samples taken from the base of each bamboo species ranged from 0.26% to 6.80% and the PhytOC content of the soil samples ranged from 4% to 100% of the total soil carbon content (Table 3).

Discussion

Both the silica content and the PhytOC content of the leaf-litter show significant variation and there was a relatively strong negative correlation between the two variables (Figure 1). These results suggest that it is the efficiency by which carbon is encapsulation within the phytoliths rather than the quantity of silica uptake by the plant that determines the relative PhytOC yield.

The high variability of PhytOC content for the different species used in this study provides some opportunity to increase the amount of bio-sequestered carbon. For example, the PhytOC content of leaf-litter for the lowest yielding species contained 1.60% and the highest yielding species 4.02%, a relative difference of 251% (Table 2). For the two species of which the leaf-litter data per hectare have been determined in a study, *Dendrocalamus latiflorus* and *Phyllostachys pubescens* the PhytOC accumulation rates were 0.030 t-e-CO2 ha-y^{-1} and 0.102 t-e-CO2 ha-y^{-1}, respectively, a relative difference of 340%. These data indicate that if 1) high PhytOC yielding bamboo species are grown over lower PhytOC yielding bamboo species under 2) conditions that are conducive to the production of biomass, then the amount of carbon being securely bio-sequestered (in phyoliths) could be substantially increased.

There are several factors a land manager would need to take into account (e.g. location, disease resistance, yield and the end use or application of the bamboo etc) prior to planting a bamboo plantation. If for example a land-manager chose to grow *Phyllostachys pubescens* over *Dendrocalamus latiflorus* there would, assuming the published leaf litter deposition rates apply, be as a direct result of that decision, an increase of 0.072 t-e-CO2 ha^{-1} of additional securely sequestered carbon in phytoliths each and every year for that plantation.

The ability to isolate and accurately quantify this carbon fraction for each bamboo species prior to its incorporation into soils is a distinct advantage for carbon accounting purposes because it bypasses many of the potential problems discussed earlier that are associated with the measurement of soil carbon (García-Oliva and Masera, 2004; McKenzie et al., 2000; Skjemstad et al., 2000).

In this paper we have 1) discussed methods of plant and soil carbon quantification and 2) demonstrated that the ability to accurately quantify the PhytOC carbon fraction in the leaf litter fraction for each bamboo species prior to incorporation into soils is possible. This latter point provides a distinct advantage for bamboo plantation and/or land managers wishing to quantify and trade in soil carbon. The results also show that the quantity of carbon occluded in phytoliths varies considerably between different bamboo species. This indicates that substantial quantities of carbon could be sequestered securely by choosing to grow bamboo species that have high PhytOC yields over those that have low PhytOC yields as well as by maximising biomass production. For example, if a land-manager chose to grow *Phyllostachys pubescens* over *Dendrocalamus latiflorus* (assuming the published leaf litter deposition rates apply), an increase of 0.072 t-e-CO2 ha^{-1} of additional securely sequestered carbon in phytoliths could be achieved annually. Thus the selection of specific species of bamboo with high phytolith occluded carbon levels and/or the appropriate management of that bamboo to maximise biomass production, could substantially increase the terrestrial sequestration of carbon .

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more authors only the first three should be listed, following the et al.

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Table 1. Corresponding sample number for each bamboo species and sample collected at the Fuzhou City, Fujian China site.

Sample	Scientific name
1	*Dendrocalamopsis basihirsuta* (McClure) Keng f. et W. T. Lin
2	*Bambusa pervariabilis* McClure
3	*Bambusoideae cerosissima* McClure
4	*Thyrsostachys siamensis* (Kurz ex Munro) Gamble
5	*Bambusa ienta* Chia
6	*Phyllostachys pubescens* Mazel ex H. de Lehaie
7	*Dendrocalamus latiflorus* Munro
8	*Dendrocalamus minor* var. *amoenus* (Q.H.Dai et C.F.Huang) Hsueh et D.Z.Li)
9	*Bambusa multiplex* cv. *fernleaf* R.A.Young
10	*Bambusa vulg*aris var. *striata* Gamble

Table 2. Bamboo species, percentage of silica (Si) post-digestion to original plant sample dry weight and percentage of phytolith occluded carbon (PhytOC) post-digestion.

Bamboo species	**Si** (%)	**PhytOC/Si (%)**
Dendrocalamopsis basihirsuta	21.27	2.40
Bambusa pervariabilis	28.03	1.60
Bambusoideae cerosissima	9.34	4.02
Thyrsostachys siamensis	21.56	1.83
Bambusa ienta	13.71	3.82
Phyllostachys pubescens	15.82	3.00
Dendrocalamus latiflorus	8.15	2.99
Dendrocalamus minor var. *amoenus*	13.01	3.18
Bambusa multiplex cv. *fernleaf*	13.19	3.35
*Bambusa vulg*aris var. *striata*	11.33	3.39

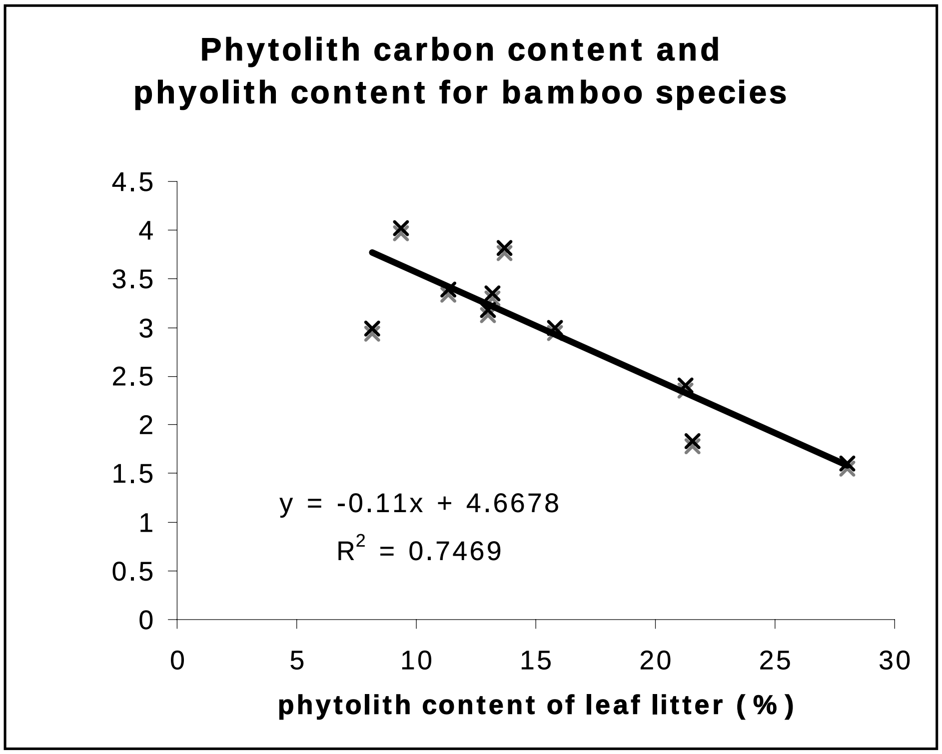

Figure 1. Phytolith carbon content and phytolith content.