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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 better than trees, and that, much more research is needed to establish the true potential of bamboo for carbon sequestration. The assumption of bambooís high sequestration potential is derived mainly from the fast growth of the individual culm during its expansion phase. However, the impressive biomass of 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 growing 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, 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 ëcarbon, capture, storage (ccs)í idea is considered, where plant communities sequester carbon dioxide by their assimilation and transform the gas

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into their biomass for longer storage. Bamboo is certainly among the plants that are to be considered in that context.

The impressive 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 ìtrees absorb the carbon we generate rapidly by photosynthesis, but bamboo does this five times faster than the othersî (Times of India, 2008). The internet-forum-bamboo-plantations provides statements like ìif we plant new forest and especially new bamboo plantations, we could cool the planet by purposeî. A National Workshop in Kerala, India, discussed in January 2009 as urgent topic ìBamboo - a global cooling agentî 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: ìforest includes areas with bamboo and palms provided that height and canopy cover criteria are metî (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 ìClimatic Change-Global Risks, Challenges and Decisionsî (10-12 March, 2009), with 2,500 delegates from nearly 80 countries, where no specific discussions were devoted to the (potential) role of bamboo.

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

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. Sesson 23 of the VIIth World Bamboo Congress (27th February- 4th March 2004) in New Delhi, on ìCarbon Sequestration and Tradingî 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 D¸king, 2009).

GROWTH OF BAMBOO CULM

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 period 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 (*Bambusa, Dendrocalamu*s, *Guadua*) about 40-60 cm, depending on species and the environmental conditions; measurements of a daily growth of 100 cm have been reported - but are not common. During its expansion, the young culm is protected by culms sheaths, which fall off with time. Leptomorph (sub-tropical) genera reach a length of about 5-15 m and tropical, mostly pachymorph genera about 20-30 m (max. 35m) with a diameter of up to 30 cm (Fig. 2).

Figure 2. Expanding culms, *Guadua angustifolia.*

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 leaves as its own power plant- but admittingly also grows much less during its seedling phase 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 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 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 per cent of the tissue) and are mostly transformed into compact starch globules (Fig.3). The starch content

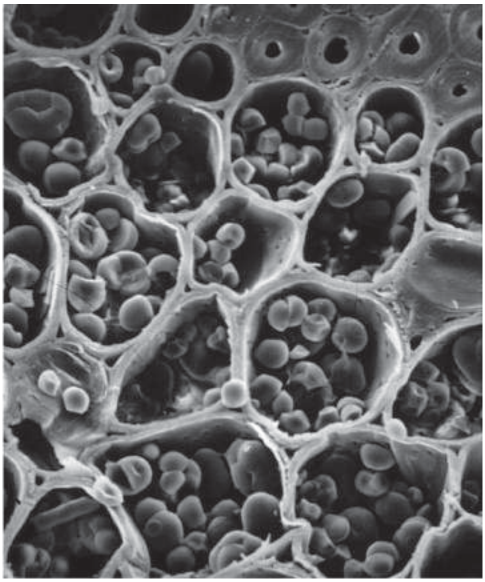

Figure 3. Starch granules in parenchyma cells store growth energy.

varies with species, site conditions and age; it may be up to 10 per cent 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 120 nmol 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, 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 per cent of the total tissue, young culms are called ìimmatureî and may break easier. 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. Data on the biomass production are found in a number reports, (Scurlock *et al.,* 2000; Kleinhenz and Midmore, 2001; Hunter and Wu, 2002). Like trees, it varies in a wide range, depending on species and site conditions, for bamboo between about 50 t/ha/year and 4 t/ha/year, with a considerable biomass also below ground. The carbon content amounts to about 45-50 per cent of the total dry biomass, equivalent to trees.

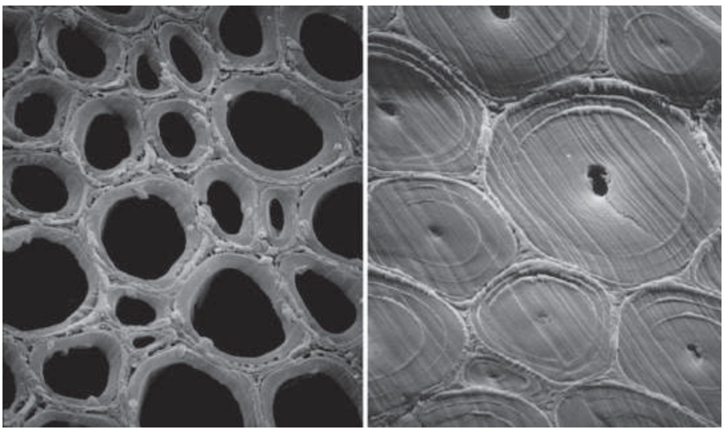

Figure 4. Cell wall of fibres, one and four years old.

LIFE CYCLE OF BAMBOO

A managed bamboo forest gives the impression of a continuous production of biomass. The ìmatureî 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 be 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; it is another research question in the context of bamboo stand dynamics.

An unmanaged, naturally regenerated bamboo forest, however, contains culms of all ages, including 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 per cent of bamboo are planted, but 70 per cent are naturally re-generated. Consequently, the additional storage of CO_2 by a bamboo ecosystem due to early fast growth may be quite limited because in a relatively short period such forest reaches an age when old culms start to die off and when the CO_2 captured by photosynthesis equals its release through biological deterioration.

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

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).

Flowering of bamboo

The apparent continuous growth of a managed natural bamboo stand with a replacement of the harvested dying culms by young ones can end abruptly by 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). *Melocanna baccifera,* the common species of northeast India has flowered in recent years in the Mizoram region, but also in Colombia (Liese, 2007) (Fig.7). The phenomenon was already observed in 1969 in Bangladesh, confirming the cycle of 45-50 years registered since 200 years

Figure 6. Flowering and death of a bamboo clump.

Figure 7. Fruiting cycle of *Melocanna baccifera*. a: 1969 Bangladesh, b: 2004 Colombia, c: India.

(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 die-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 sporadic 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.

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 biologically deteriorated or burnt. The commercial bamboo utilization is estimated to about 20 million t/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 per cent 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 (Quisheng *et al*., 2003; van der Lugt *et al*., 2009).

Construction

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 ìbamboo is the poor manís timberî 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 to invest in appropriate preservation technology and 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 than 15-20 years.

Furniture

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

Bamboo-based panels and boards of about 25 types are produced for an expanding large market (Ganapathy *et al.,* 1996). China produces around 1 million m^3 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 in 2004 in China.

Pulp and paper

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 considerably reduce 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 of bamboo.

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

Energy resource

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 bambooís high potential re-growth 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 are 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-term storage of bamboo. However, for an operational application, severe restrictions exist (Kˆhl and Fr¸hwald, 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 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 ñ 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 forestsë capabilities as a carbon sink to be any more relevant than those of tree forests regarding their role in halting global warming. Fact is that 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 than 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 analyzing the potential role of bamboo for carbon sequestration.

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