Ecological functions of bamboo forest: Research and Application

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Abstract: Bamboo forest is an important forest type in subtropical and tropical areas. Due to its biological characteristic and growth habits, bamboo is not only an ideal economic investment that can be utilized in many different manners but also has enormous potential for alleviating many environmental problems facing the world today. This review describes ecological functions of the bamboo forest on soil erosion control, water conservation, land rehabilitation, and carbon sequestration.

Keywords: Bamboo forest; Ecological function; Environment; Review

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Introduction

Bamboo is a group of plants that belong taxonomically to the subfamily of Bambusoideae under the family of Gramineae. There are approximately 1 500 species under 87 genera of bamboo worldwide (Ohrnberger 1999; Li and Kobayashi 2004). Bamboo forest is an important forest type in tropical and subtropical areas, with a total area of 22 million hectares at present (Zhou 1999; Lei 2001; Liu 2001). Although the total forest areas in many countries have drastically decreased, bamboo forest area has progressively increased.

China, with over 500 species in 39 genera, has the richest bamboo resources in the world in terms of number of species, area and reserve of bamboo, and has long been known as the "Kingdom of Bamboo". In over 50 years since the founding of the People's Republic of China, particularly in the last 20 years since China's economic reforms, the bamboo industry has witnessed rapid development. The area of bamboo forests is steadily increasing, extending to 5 million hm^2 currently (Xiao 2000; Lei 2001).

Bamboo is known to be one of the fastest growing plants in the world, with a growth rate ranging from 30 to 100 cm per day in growing season. It can grow to a height of 36 m with a diameter of 1–30 cm (United Nations 1972). A culm can reach its full height in a matter of two to three months. Considering the above characteristics, it is easy to believe that bamboo is the fastest growing, highest yielding renewable natural resources (Lessard and Chouinard 1980).

Bamboo is not only an ideal economic investment that can be utilized in many different manners but also has enormous potential for alleviating many problems, both environmental and social, facing the world today. The increasing rate of tropical deforestation makes the search for alternative natural resources important. The characteristics of bamboo make it a perfect solution for the environmental and social consequences of tropical deforestation. Its biological characteristics make it a perfect tool for solving many environmental problems, such as erosion control (Austin *et al.* 1970) and carbon dioxide sequestration. On account of extensive shallow rhizome-root system and accumulation of leaf mulch, bamboo serves as an efficient agent in preventing soil erosion and conserving moisture, reinforcement of embankments and drainage channels, etc.. Additionally, its qualities of strength, light weight and flexibility make it a viable alternative to tropical timbers that typically supply the furniture and building materials industries.

Bamboo for erosion control

Soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture. It is a worldwide problem approaching disaster proportions in many countries. It is estimated that the world's arable land is lost at a rate of more than 10 million hm^2 per year. Seventy-five billion metric tons of soil is removed from the land each year, causing up to US\$400 billion in damage worldwide (Pimentel *et al.* 1995). One analysis of globe soil erosion estimates that, depending on the region, topsoil is currently being lost 16 to 300 times faster than it can be replaced (Barrow 1991). Soil is eroded by wind, water, and gravity aided and hurried by tillage and poor soil management.

In addition to many industrial and construction uses, bamboo also is valuable for controlling soil erosion. It grows well on steep hillsides, road embankments, gullies, or on the banks of ponds and streams. In Hakone-yama mountain of Japan, the bamboo community of *Sasa* and *Indocalamus* distributed in the high mountainous area, 1 000 m above the sea level, resulting in little water and soil loss. The Brazilian introduced *Bambusa blumeana* and *Phyllostachys pubescens* for controlling soil erosion, preventing nutrient loss and improving soil structure (Fu *et al.* 2000). The valuable features of bamboo for controlling soil erosion are its extensive fibrous root system, connected rhizome system, the leafy mulch it may produce on the soil surface, its comparatively dense foliage which protects against beating rains, and its habit of producing new culms from underground rhizomes which allows harvesting without disturbing the soil.

Holding soil

Bamboo can form a closely woven mat of roots and rhizomes under ground, which are effective in holding soil. The soil around bamboo plants is permeated by a mass of intertwining roots. A lot of studies showed that most of the rhizomes and roots, around 80%, were present in the upper 0–30 cm soil layer that is the area where roots and rhizomes serve best in controlling soil

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erosion. The bamboo species studied in this aspect include *Phyllostachys pubescens* (Xiao 1983; Wu 1984; Zhou *et al.* 1985; Wang *et al.* 2000), *Pseudosasa amabilis* (Chen 2002), *Phyllostachys praecox* (He *et al.* 1995; Hu *et al.* 1994), *Qiongzhuea tumidinoda* (Dong *et al.* 2002), *Phyllostachys makinoi* (Huang *et al.* 1994), *Phyllostachys bissetti* (Zeng *et al.* 1998), *Dendrocalamus latiflorus* (Lin *et al.* 2000), *Dendrocalamopsis oldhami* (Lin *et al.* 1998) and *Bambusa tulda* (White and Childers 1945) and etc. The root and rhizome of bamboo grow shallowly into the soil but they can horizontally extend widely. The root of *Bambusa tulda*, a sympodial species with a shortened rhizome, can extend horizontally to a distance of 5.2 m (White and Childers 1945). For monopodial species with running rhizome, there are a large amount of rhizomes under ground. The total length of living rhizome per one hectare of *Phyllostachys heterocycla*, *Phyllostachys viridis* and *Phyllostachys nigra* ranges from 50 to 170 km, 90 to 250 km and 200 to 320 km, respectively (Xiao 2001).

The extensive underground root and rhizome system has a significant capacity to bind the topsoil. A study estimated that a single bamboo plant can bind up to 6 m^3 of soil (Anonymous 1997). Because of this, it is perfect for arresting the ravages of water erosion in areas prone to it (such as slopes and lowlands). It is reported that the *Guada* bamboo in Colombia has been the one that prevented millions of tons of mountain soil from reaching the ocean bottom (Anonymous 1997). Bamboo is so effective in binding soil on steep slopes that Malaysia has started planting bamboos on hillsides to block mud and stones sliding onto roads. In the north-central Andes, the rich volcanic soils have been under cultivation for thousands of years, even on steep hillside (Judziewicz *et al.* 1999). *Chusquea scandens* and related species appear to aid the control of erosion naturally by stabilizing the soils surrounding their intricate rhizome system and by protecting the soil surface from insolation through shading and deposition of leaf litter (Stern 1995b).

The bamboo forest soil has a high ability of anti-scouribility and anti-erosion. It is reported that the index of anti-scouribility and anti-erosion in the upper soil layer (0–40 cm) of *Phyllostachys pubescens* forest are 0.998 and 1.051, respectively, higher than those in black locust (*Robinia pseudoacacia*) (0.92 and 0.98, respectively), those in *Metasequoia glyptostroboides* (0.93 and 0.52, respectively) and those in poplar (*I-69*) (0.95 and 0.38, respectively). *Pleioblastus argenteostriatus f. albostriatus*, a dwarf bamboo, demonstrated a even higher ability of anti-scouribility and anti-erosion due to its well-developed rhizomes and root system. The index of anti-scouribility and anti-erosion for the dwarf species are 1.404 and 1.413, respectively, 40% and 34% higher than those in larger sized *Phyllostachys pubescens* (Luo *et al.* 1999).

Protecting riverbanks

Bamboo planted along stream and river banks, grows particularly well because of a more even and abundant supply of moisture. The fibrous mass of roots binds the soft banks, and the thick culms arrest strong currents during flood periods. Bamboo's efficacy as a soil binder was successfully used in Puerto Rico. A river used to cause great damage at regular intervals to the trial crop fields at the Mayaguez Federal Experiment Station. Before the bamboo was planted, large areas of the adjoining experimental field were washed away, especially on the sharp curves. At these critical points a bamboo revetment was constructed. A sympodial bamboo species, *Bambusa vulgaris*, was used in this case (White and Childers 1945; Anonymous 1997). The soil behind the revetment is reinforced further by plantings of bamboo, thus building a solid wall of living plant material on the banks of the river, and solved the problem forever.

In China, about 90% of bamboo forest naturally occurs in the headstreams of rivers, lakes and reservoirs or along the banks. The bamboo forest area accounts for 5% of total forestland area in the Yangtze River Valley, 4.5% in the Pear River Valley and 2.5% Huaihe River Valley (Li 1998). Bamboo forest has been playing a significant role in protecting riverbanks in these areas. A study sponsored by INBAR also has documented two instances. One in Dayingjiang River in Yunnan Province and the other in Jiulongjiang River in Fujian Province, where bamboo succeeded in protecting river banks after soil-rock engineering efforts and planting of other trees failed to yield results. It was also observed that the mixed bamboo forests that adorn the southwest mountains area were instrumental in ensuring that the quantity of soil that reaches Yangtze River through sheet erosion is just half that of the quantity washed out into the Yellow River. There are many undestroyed high mountain bamboo forests with the major species of *Fargesia* growing in the upper reaches of Yangtze River (Anonymous 1997; Fu *et al.* 2000).

Preventing Landslides

Landslide is one of the most severe types of land degradation, which causes serious topsoil loss and greatly threatens the land productivity. Puerto Rican researchers, who experimented with several plant species, found bamboo to be one of the most effective in controlling landslides. Puerto Rico has many winding roads through the mountainous interior of the Island. Landslides are a problem both above and below the hillside roads. The Department of Interior has used planting of bamboo with considerable success to maintain fills and steep road embankments. The bamboo generally used for this purpose is the common species, *Bambusa vulgaris* (White and Childers 1945; Anonymous 1997). It develops large thick clumps, makes a rapid dense growth, and planting material has been readily available.

For erosion control purpose, bamboo is generally planted in the specific places vulnerable to erosion. However, this is not the only way to do it. In southwestern Japan, the introduced *Bambusa multiplex* is widely planted in coastal areas facing the Pacific Ocean. Especially in Kagoshima prefecture, it has been utilized as the materials of culm weaving works, a kind of hillside fencing, called 'Karami' for erosion control for more than 100 years (Shibata 2001).

Bamboo for water conservation

Litterfall accumulation

Bamboo creates a lot of biomass, up to 10 $t \cdot hm^{-2}$ or more each year, mostly in the form of foliage. Ueda (1960) pointed out that bamboo leaves usually fall when they are between 12 and 18 months old, and they are quickly replaced with new leaves. The total aboveground litterfall (litter, sheath, and branches) was estimated to be 4.7 $t \cdot hm^{-2}$ at 72 months. Fu *et al.* (1989) observed the seasonal dynamic of litterfall of *Phyllostachys pubescens*. They suggested that *Phyllostachys pubescens* produces the most litterfall during two periods, i.e. during April to May and November, although the litterfall occurs around the year. Rozanov and Rozanov (1964) reported values for total aboveground litterfall for bamboo plantation of 6.6 $t \cdot hm^{-2}$ per year for bamboo forest under thinned tropical forest, and of 10.6 $t \cdot hm^{-2}$ per year for bamboo forest under thinned monsoonal forest. Tripathi and Singh (1994) reported aboveground litter values ranging from 4.1 to 7.2 $t \cdot hm^{-2}$ per year for mature bamboo savannas. Seth *et al.* (1963) reported the aboveground leaf litter production of 3.2 $t \cdot hm^{-2}$ in a bamboo plantation in India. A 4-year-old *Bambusa longispiculata* forest can accumulate to 2–10 cm mulch in Puerto Rico (White and Childers 1945). Wu *et al.*(1992) suggested that the litterfall amount varies with the composition of the mixed forest, the stand density and human activity. The pure *Phyllostachys pubescens* forest accumulated litterfall of 5.8 $t \cdot hm^{-2}$ per year, while the bamboo forest mixed with broadleaf and with *Cunninghamia lanceolata* produced litterfall of 7.2 $t \cdot hm^{-2}$ and 9.4 $t \cdot hm^{-2}$ per year respectively. The annual litterfall of *Dendrocalamus latiflorus* forest, with a density of 825 $culm \cdot hm^{-2}$, is measured to 3.6–3.9 $t \cdot hm^{-2}$ (Xie 1999).

Moisture retention

The leafy mulch which accumulates beneath bamboo collects and conserves moistures in addition to preventing soil erosion. The mulch facilitates the intake and retention of moisture. The thick leafy blanket also assists the earth to absorb and retain moisture more effectively, and to reduce the rate of evaporation. Leaves, being organic matter, also help increase the organic content of the soil. Bamboo litter has a high water retention capacity. The moisture that bamboo litter can hold weighs 2.75 times as much as its dry weight itself, topping the other 8 types of vegetation studied in Hunan province of China (Huang *et al.* 1997). The litter of *Dendrocalamus latiflorus* stand, with a density of 825 $culm \cdot hm^{-2}$, has the capacity to absorb the moisture 2.7-2.9 times of its dry weight (Xie 1999). The maximum water-holding capacity of *Phyllostachys pubescens* forest mixed with *Cunninghamia lanceolata* could be 21.29 $t \cdot hm^{-2}$, much higher than that for pure *Cunninghamia lanceolata* forest, which is measured to be 7.37 $t \cdot hm^{-2}$ (Chen 2000). Similar conclusion has been made by other researchers (Wu *et al.* 1992; Zheng *et al.* 1995; Zheng *et al.* 1998; Zheng 1998; Lin 2002).

The soil under bamboo forest also has a high capacity of water conservation, which is closely related to the type of bamboo community. The total moisture capacity of forest soil for bamboo forest mixed with broadleaf is the highest, followed by the pure bamboo forest, and that for bamboo forest mixed with *Cunninghamia lanceolata* is the lowest. But for the non-capillary moisture capacity, the pure bamboo has the highest, followed by bamboo-broadleaf mixed forest and bamboo-conifer mixed forest has the lowest (Wu *et al* 1992). The reason for this is because larger quantity of culm stumps, dead rhizomes and roots remain in bamboo forest after felling, leaving lots of non-capillary pore which can retain large amount of moisture. The experiment results show that total capillary moisture capacity within the depth of 0–60 cm in the bamboo forest watershed is measured to be 430.5 mm, and the valid water storage capacity 312.73 mm, which are higher than those in *Cunninghamia lanceolata* plantation and natural broadleaf forest, especially for the valid water storage capacity, it increases by 28% than the control (Wu 1997).

Rainfall Interception

Bamboo has evergreen leaves, dense canopy and numeral culms, which can help to intercept considerable amount of rainfall. Falling raindrops change their direction and ways, and reduce velocity, and therefore decreases its direct soil erosion after multiple interception by tens of shoot layers and larger amount of culms. A research in China conclusively proved that the canopy of bamboo stands can intercept up to 25% of rain throughfall, value much higher than those for conifers and pines. The canopy interception is dependent upon quantity of standing culms and leaf area index in a bamboo forest. For example, the average interception is 0.95 mm with interception ratio of 21.3% in a *Phyllostachys pubescens* stand with 2 190 standing culms per hectare, average DBH of 8.12 cm and leaf area of 35 100 $m^2 \cdot hm^{-2}$. The average interception (1.80 mm) and ratio of interception (31.3%) increases by 89.4% and 47.0% respectively in a dense bamboo forest with 6720 standing culms per hectare, average DBH of 7.35 cm and leaf area of 100 000 $m^2 \cdot hm^{-2}$, compared to the previous sparse bamboo stand (Wu *et al.* 1992).

The sympodial also has a high interception capacity. Xie *et al.* (1999) reported the rainfall interception of *Dendrocalamopsis latiflorus* forest in South China. The annual canopy interception is 128.1mm for the bamboo forest with the planting spacing of 3m x 4m, 6 culms within a clump and the overall density of 5 000 culms per hectare. And the interception ratio is 14.5%, annual throughfall 689.1 mm, throughfall ratio 78.02%, the runoff coefficient 7.47%. It was found that the canopy interception has a positive correlation with stand density and with total precipitation. The interception varied with season and precipitation intensity. Stemflow has a close positive relation with throughfall but a negative relation with stand density.

Bamboo for land rehabilitation

The globe store of arable land and grazing lands is under increasing pressure from varied causes, including overuse of fertilizers and pesticides; salinization, acidification or alkalinization, nutrition depletion and etc. In the last five decades or so, 1.2 billion hm^2 of land (11% of the earth's total vegetated land) is reported to have become degraded to the extent that their original biotic functions are damaged (Oldeman *et al.* 1990). According to a UNEP report (1992), at least one-quarter of the degradation of agriculture lands is human induced (agricultural practices, overgrazing, deforestation, etc.). Bamboo is healer of lands wounded through human enterprise. The ability to grow in a wide variety of soils, from marginal to semi-arid, makes bamboo perfect for rehabilitation; it also serves to conserve soil and manage water flows. Bamboo is also a prolific generator of biomass, ideal for regenerating soil. The plant is thus well-positioned to be used as an instrument for land repair and maintenance.

With its evergreen canopy, large biomass accumulation and abundant litterfall, bamboo has been playing a great role in rehabilitation of degraded land. In China, India and Thailand, appropriate bamboo agro-forestry modes for cultivation on degraded lands have been developed. In China, three types of bamboo-agroforestry models have been established, which includes agro-silvicutural system, (bamboo + tea, bamboo + coniferous or broad-leaves tree for timber, bamboo + crops), silva-pastoral system (bamboo (+ crops) + fish pond (or poultry)) and special agro-forestry system (bamboo + edible fungi, bamboo + medicinal plant) (Fu *et al.* 2000). With the establishment of the agro-forestry model, rehabilitation effects on land have been attained. Theses bamboo agro-forestry model improve the microclimate in the stands, helping increase the formation and accumulation of the photosynthetic product. Meanwhile, the community composed of several different plant populations strengthens its resistibility to calamities such as frost and heavy snow or reduces the attack of disease and pests.

In these models, since the subterranean root systems of different components in the community have different distribution, both horizontal and vertical, the bamboo agro-forestry system can fully use the soil fertility, which increases the growth of the populations. The litterfall also increase greatly, resulting in the increment of organic matter, nitrogen, phosphoresces, potassium etc. especially, if the nitrogen fixation plants are planted in the models, a much better effects will be obtained.

In Jabalpur, Madhya and Pradesh of India, farmers were willing to plant *Dendrocalamus strictus*, *Bambusa bambos* and *Bambusa nutans* on farm bunds and degraded lands even if that were non-productive. Bamboo seedlings were intercropped with either maize or soybean. In Thailand, the bamboo species were intercropped with maize and peanut (Anonymous 1997).

In India, researchers have tried to develop bamboo-based technologies to rehabilitate land from which topsoil has been removed to depths up to three meters for producing bricks. Also, a novel research project, funded by IDRC and jointly undertaken by the Indian researchers, looked at the possibility of using bamboo and coal fly-ash to rehabilitate degraded land. The project successfully proved that using a soil + sludge + fly-ash combination, bamboo can be successfully cultivated to restore degraded land because it can produce the maximum biomass per unit area and unit time (Anonymous 1997).

In Caldas of Colombia and Merida of Venezuela, *Guada angustifolia* has been widely used for reclaiming land degraded by deforestation and poor agricultural practices (Judziewicz *et al.* 1999). Vietnam has demonstrated the rehabilitation effects by regreening with bamboo vast tracts of land laid wasted by the war (Anonymous 1997). Dwarf bamboo (*Sasa*) is the most representative forest floor vegetation in Japan and covers 6 910 000 hm^2 of land throughout the country, accounting for 25% of the total forest area (Katoh 1979). It plays a significant role in preventing soil from acidification in mountainous area of Japan by acting as a biological pump to return basic cations from the lower layer of soil (20–30 cm) to the surface, and retaining them within the ecosystem (Takamatsu *et al.* 1997). In West Java of Indonesia, the bamboo "talun-kebun" agroforestry system made a great success. Bamboo is acknowledged so important that the farmers always kept the old saying "without bamboo, the land dies". The success of the talun-kebun system in maintaining soil fertility appears to be based largely on the "nutrient pumping" action of the bamboo, the slow decomposition, of its silica-rich litter, and the extremely high biomass of bamboo fine root (Christanty *et al.* 1996). Singh *et al.* (1999) suggest that *Dendrocalamus strictus* plantation has an efficient restoration potential and positive rehabilitation effect on mine spoil land in a dry tropical region in India. The bamboo plantation planted on this land has attained similar biomass and higher net production levers compared to that of native dry forest with a short time.

Bamboo for Carbon Sequestration

The globe environment debate, which has intensified considerably over the years from the Stockholm Conference on Environment in June 1972 to the Earth Summit in Rio de Janeiro in June 1992 and beyond, has seen international action being taken through the Framework Convention on Climate Change to reduce carbon dioxide in the ambient temperature of the earth. A focus of this climate change debate has been the role of the forests, and especially tropical forests – being they primary, logging and regenerating, secondary, or plantation forests – in sequestering carbon.

There are three carbon inventories in the global, ocean, atmosphere and terrestrial ecosystem. So far, we know little about the carbon cycle between ocean and atmosphere. Because we live in this terrestrial ecosystem, its complex and bigness, we know much about carbon cycle between atmosphere and terrestrial ecosystem. In terrestrial ecosystem, forest is the largest carbon inventory and it deposits 1146×10^{15} g carbon which occupies 56 percent of the carbon inventory of the total terrestrial ecosystem. Bamboo forest ecosystem is an important part of forest ecosystem and an important carbon source and carbon sink on the earth (Li *et al.* 2003).

In bamboo forest ecosystem, through the mechanism of photosynthesis, bamboo turn carbon dioxide into organic carbon and store it as their structure, part of which will store in the litters or in forest soil. Considering the respiration of bamboo organism and decomposition, the net primary production of bamboo forest is the key issue. In the natural forests of the tropics, bamboo spreads gregariously where there is disturbance by logging and shifting cultivation activities, and the bamboos are the fastest growing plants, reaching their full height in two to four months, and that branching begins as soon as culms reach their full heights. It is estimated that a bamboo clump can produce in its lifetime up to 15 km of poles of 30 cm in diameter. So, bamboo is very vigorous and dynamic in growth. Due to its rapid biomass accumulation and effective fixation of solar energy and carbon dioxide, the carbon sequestration ability of bamboo is likely to be second to none and if at all, only to a very few. According to an estimate, one quarter of the biomass in tropical regions and one-fifth in subtropical regions comes from bamboo Anonymous 1997). If one considers the fact that the great majority of bamboos occur in the tropics within the broad band circumscribed by the Tropics of Cancer and Capricorn, and that about 80% of the area containing bamboo is in the South and Southeast Asian tropical regions, the likely contribution to the globe accounting of carbon sequestration by bamboo alone could be quite significant.

Suggestions

Bamboo forest is an important forest type in many countries, especially in East and Southeast Asian and in African countries. Bamboo is versatile not only in industry utilization and in routine life but also in environment protection. There is an old saying, bamboo is the timber of the poor, indicating its status in the life of countryside people and its importance in poverty alleviation. Due to bamboo's economic benefits, the research emphasis has long been put to its biological characteristics and the techniques for its propagation, cultivation, management and utilization. In fact, bamboo possesses a great potential either in soil erosion control, water conservation, or in land rehabilitation and carbon sequestration, which is supposed to give it a promising future. More attention needs to be paid to the research on its ecological functions, with the focus on the hydrological and ecological process of bamboo forest ecosystem, the mechanism and its application of erosion control of bamboo, its capacity of carbon sequestration and etc. in the future.

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