Future possibilities for bamboo in European agriculture

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Introduction

In the subfamily Bambusoideae (Poaceae) we find both woody and herbaceous bamboos but only woody bamboos have economic potential. Historically woody bamboos have been used for different applications but rather recently interest from paper and wood industries has increased, both for tropical and temperate woody bamboos. Temperate bamboos of the Northern hemisphere are used for agroforestry, mainly in China, and as ornamental plants in Europe and the U.S., although some preliminary trials to use bamboo as source of biomass are ongoing in these regions.

Bamboo is often advocated as an ideal renewable resource for biomass, useful for wood and paper industry. Positive arguments thus also include ecological arguments; indeed in the future forests and agriculture, water conservation and carbon cycling will become very important criteria. However, the classical economic criteria (profit and added value) will remain very important. Moreover, if bamboo is to be used as source of biomass, it will have to compete with other plants, not to speak about competitions with industrial powers. This will certainly impose much pressure on bamboo, e.g. regarding selection of elite genotypes, silvicultural methods, new approaches for harvesting and the production of quality biomass.

Given the worldwide interest in bamboo, this project aimed to look at possibilities to grow and use bamboo in Europe. While bamboos are not endemic in Europe, they have been introduced over 150 years ago and have since been an important part of ornamental horticulture, gardening and landscaping. Several bamboo products are already on the market in Europe and are imported mainly from Asia. The idea of cultivating and using bamboo in Europe and agricultural and industry poses several difficulties. First of all, we do not know if the varieties that grow so well in our gardens will grow equally well in the field. Secondly, prices of bamboo planting material in horticulture are too high and availability of plants too limited for large scale planting. Thirdly, harvesting of bamboo should be fully mechanized since wages are much too high in Europe to allow manual harvesting and selection of good quality culms. Fourthly, industry should be able to use bamboo without adaptation of their machinery. And last but not least, the incorporation of bamboo into various products made by European manufacturers should preferably improve product quality.

The Bamboo for Europe Project was conceived as an integrated project. The whole downstream process of bamboo production and transformation consists of many different steps. Each of these steps is important, and as in any successful industrial enterprise or chain of processes, optimization in each step as well as integration of steps and feedback is important. And the whole production scheme should be aiming at the market, to the European market. While there are various niche markets in which exotic bamboo products can play a role, the challenge here is to adapt bamboo to Europe, not vice versa.

This challenge was taken up by 9 partners from industry, universities and research institutions. The project was coordinated by Mr. Joris De Vos of Cobelgal, Portugal and consisted of two work packages. Work package 1 concentrated on bamboo as a plant, with propagation, eco-physiological aspects, silviculture and harvesting and was coordinated by Oprins Plant. Work Package 2 focused on industrial transformation of bamboo, in wood industry and bioenergy and was coordinated by Cobelgal.

Table 1 Various uses of bamboo

Use of bamboo as plant	*Use of bamboo as material*
Ornamental horticulture	***Local industries***
Ecology	Artisanat
	Furniture
Stabilization of the soil	A variety of utensils
Stabilizing	Houses
Uses on marginal land	
Hedges and screens	***Wood and paper industries***
Minimal land use	
	Stand Boards
	Medium Density Fiberboard
Agro-forestry	Laminated lumber
	Paper and rayon
Natural stands	Parquet
Plantations	
Mixed agroforestry systems	***Nutritional industries***
	Young shoots for human consumption
	Fodder
	Chemical Industries
	Biochemical products
	Pharmaceutical industry
	Energy
	Charcoal
	Pyrolysis
	Gasification

Large and mass scale propagation of bamboo using tissue culture

Bamboos can be propagated via seeds, via rhizome, culm cuttings or branch cuttings, via clump division or offset planting, via marcotting or layering. Some bamboos can be propagated only through 1 of these methods, while other species can be propagated through different methods. But the efficiency of these classical propagation methods varies greatly.

In Europe, bamboos are propagated almost exclusively via division of clumps. Propagation using seeds, branch or culm cuttings or marcotting are not possible for temperate bamboos. Indeed, almost all temperate bamboos today in horticultural and agricultural practice today, are propagated through division. But classical propagation techniques are insufficient, in view of the need for quality planting material at a very large scale. To meet increasing demands for bamboo planting material it is necessary to develop suitable propagation methods, that are commercially viable and that can give added value to plant producers, foresters and those who transform the biomass harvested.

A special problem arises in temperate bamboos in Europe. Prices of bamboos in horticultural trade are high compared to many trees and shrubs. In current horticultural trade bamboos are becoming increasingly popular and because of the high demand remains on the market, effectively preventing a build up of mother stock in nurseries. Because of this situation there is no incentive at all for growers to consider large scale propagation for agroforestry in Europe. Considering prices of at least 10 EURO for *Phyllostachys* plants (e.g. aurea, the most widely distributed species, in sizes pot of 5l) in trade at present, and given the still restricted availability, there are few prospects that large numbers of bamboos, combined with a broad range of genotypes (at least 5 different types e.g.), will be produced in the near future in mass quantities. The incentive for the production will remain in horticulture for a considerable number of years.

In the laboratory of Oprins Plant a very efficient technology has been developed for the mass scale propagation of different temperate and tropical bamboos based on axillary branching (Gielis and Oprins, 1998). This allows to overcome one of the major bottlenecks namely availability of planting material at a large and even mass scale. Mass scale production of high quality plants, which are easy to transport and to deliver on site, disease-free, and vigourous growers (e.g. 10 000 plantlets occupy a volume of 2 boxes and can be shipped within 24 hours to any place in the world). Moreover micropropagation is very flexible and rapid upscaling is possible (within 1 year several 10^5 plants can be produced from any genotype). *Fargesia rufa,* a new selection from China, can be produced in large numbers starting from one single plant only. Such short time frames or large numbers cannot be rivalled by any conventional method.

Another objective was a reduction of prices of bamboo plants by 40-60%, compared to conventional propagation. In horticultural trade, *P. aurea* plants with 1 culm only in 4 l pots are sold at about 9 EURO, retail prices being at least 30-50% higher. And this is by far the cheapest species of *Phyllostachys*. Other bamboos like *Phyllostachys nigra* cost at least double this price. Both P*hyllostachys* species are in high demand. *P. aurea* plants produced in tissue culture in 4 l pots, height 40-50 cm cost 5.5 EURO for small quantities. For large quantities prices may go down to 3.8-4 EURO, which is an effective price reduction of 40-60% (Oprins, 2000).

It is very important to remark that these figures are based on real data. Indeed, we have developed the technology beyond the R&D stage and are producing the plants commercially

The technology has proved powerful enough for a rapid upscaling of bamboo genotypes for forestry or other application outside horticulture. The technology allows yearround production of quality plants in large quantities at reasonable prices. Given the rapid growth and uniformity of the plants, logistics are improved and transportation becomes more profitable.

Growth and development under field conditions

The set-up of the plantations was primarily to find out which bamboos that perform well in the garden and were used already in temperate climates for industrial purposes, could be used for biomass production in Europe. At three sites in Europe (Belgium, Portugal and Spain) bamboos were planted at different planting densities to assess survival rates and growth under field conditions. At each of these sites about 10 different genotypes were used for evaluation. The species used in Belgium were mainly *Phyllostachys praecox, P. vivax, P. aureosulcata* 'Spectabilis', *P. aurea, Sasa palmata* and *Pseudosasa japonica.*

The experiments also have to be considered as initial trials like never been done before in Europe. Moreover, from the outset it was known that 3-4 years is too short for full monitoring, because establishment of plantations typically would take 5-6 years in bamboo. While from the outset larger plants have been selected, 3 years proved not sufficient for a good evaluation, and therefore a fourth growth season has been included. That is that the growth of bamboo shoots, which occurs mainly in June has been monitored for the 3rd growing season in the spring of 2000. Planting in 1997, followed by three main shooting periods in late spring of 1998, 1999 and 2000.

Of the genotypes tested the best performers in Belgium were *Phyllostachys aureosulcata* 'Spectabilis' and *Phyllostachys aurea*. Also *P. nuda* performed very well. All plants of these species survived and showed good development and uniform growth througout the trials. Other species like *P. praecox* were less interesting because the mortality of the plants was very high. This would require replanting and substituting, which is far too expensive. Other species like *P. vivax* developed much less evenly in the first years, then grew very tall in the fourth year. None of the *Sasa* and *Pleioblastus* species performed well in these experiments. The mortality of *Sasa palmata* was very high, up to half of the plants died in field conditions, and *Pleioblastus* and *Sasaella* types did not grow very well. Although weeding was done regularly competition with weeds was very hard for these species.

The denser planting was 1.5 by 1 while the widest planting distances were 2.5 by 3 meters. Samples from the stands were cut, allowed to air dry for 14 days. The results of weight of culms for Spectabilis and P. aurea are as follows:

1. Spectabilis

The average fresh weight of the culms is for Spectabilis :

1998 culms, 2.2 m high, 100-150 g
1999 culms , 2.8-3.2 high, 450-500 g
2000 culms, 2.5-4 m high, 550-630g

For P. Spectabilis, given a culm density of about 20 culms per m_, early 2000 we arrived at about 300g (average of 1998 and 1999 taking into account number of shoots)*20 being 6kg per square m for the high planting densities. This means that fresh weights of the culms amount up to 60 tonnes per hectare.

2. Phyllostachys aurea:

The weight of culms is for aurea

1998 culms, 2.5-2.7 high, 300- 400 g
1999 culms 3.5 m, 500-600g
2000 culms 4 m, 600-630 g

Phyllostachys aurea has an even denser growth than P. Spectabilis. This results in more new shoots in the fourth year, at the periphery of the plant and may attains higher values amounting up to 14 kg/m_ or 140 tons per hectare of standing biomass if planted very close together. In comparison, in high density planting of *Sasa palmata* with about 100 culms per m_ at present, 5 culms taken together weigh approximately 200g making up 4 kg/m_. In *Sasa palmata,* leaves make up the bulk of the biomass.

The ultimate yields will also depend on the planting density. When the initial spacing is small, like 1*1 (10 000 plant per hectare), the development of the stand will be very rapid and in the fourth years harvest can yield up to 100 tonnes of fresh material. If planting density is lower like 3.3 * 3.3 m (900 per hectare), investment in planting material will be lower, but development of the stand will be at least one year longer. A golden solution is planting distance of 2*2.5 with 2000 plants per hectare. It is also very important to remark that these yields were obtained on land which was only fertilized with organic fertilizer prior to planting. With additional fertiliser yields could be considerably higher.

From an economic point of view higher density planting also requires a much higher investment so that a balance will have to be found. In the future, when planting prices can be cut further denser planting will become more feasible. From an investment point of view, bamboo will yield returns much faster then forest trees, but later than agricultural plants. However, unlike agricultural plants, bamboo only requires a one time planting and little care and maintenance, combining the best of agriculture and forestry worlds.

Four years is too short to make final evaluations. In this study it was not possible to study silvicultural systems related to harvesting either. Theoretically bamboo can be clearcut after four years, but one has to test regrowth. Parts of the trial plantation have been cut early Spring 2001 and regrowth has defveloped fast from the rhizomes. It will have to be shown that regrowth from clearcuts will be sufficiently fast. An alternative, which has been performed before in the US is strip harvesting, in which only strips of the plantation are harvested. This is a rotation systems and every third year the same strip is cut again. In this way the rhizomes in the strips will still be attached to living culms which can provide sugars and phytohormones for regrowth.

Another alternative is to clearcut bamboo only after 7 to 12 years. The standing biomass will then be very high, and if clearcut, the yields calculated on annual basis may be comparable with other harvesting methods. The advantage of this is that bamboo can be planted for ecological reasons (soil stabilisation for example) in land that is not used for anything else, but still economic profits can be gained by harvesting biomass facultatively. While several decades will be needed to evaluate the best silvicultural system, a major advantage is that bamboo can be cultivated in very flexible systems of production and harvesting, with a one time planting and relatively little care and maintenance, only in the first years.

Mechanical harvesting of bamboo

The main advantage of smaller bamboos is that a large number of culms grows in dense stands with up to 20 culms per square meter and these culms are very similar in height and width. The age structure was such that the thicker culms made up about 60% of the total number of culms. In tests in wood industry however it was shown that the age of the culms did not have significant effects on the product quality. So at the end of the growing season of the third year after planting, harvests are possible.

The uniformity of the culm's width and height provides a major advantage for mechanical harvesting (comparable to corn and sugarcane e.g.). Unlike the selective harvests of big mature culms in tropical bamboos and some *Phyllostachys* used for timber and parquet, mechanical harvesting can be used in such stands. The structure of the stands and the sizes of the culms allow various ways of harvesting. Chipping is possible, in which small or big chippers cut down the culms and chip them directly. The chips can then be transported to the industry of choice. The disadvantage however of chips is that moulding starts immediately after harvest. If the material is left in chips for more than 1 week material deterioration by biological agents will be serious.

An alternative however is to harvest in bundles. The culms are cut, collected and bound with chords or strings into bundles. These bundles can be trimmed in length to any desired size. In bundles material deterioration is much more limited and bundles can be kept in dry conditions. Unlike chips, they can be stored for several months before they are transported to industry, according to Prof. Liese, advisor of this part of the project. This aspect makes bamboo very interesting for wood industry. For both chipping and bundling existing harvesting machines can be used without adaptations (CRA, 2000).

Harvesting of bamboo stands can be done from the end of the growing season to early Spring, from October to March, over a period of about 6 months. The bundles can be kept for another 3 months. This means that bamboo can be supplied as raw material to the industry for about 8-9 months per year, which is very important from a logistic point of view. For example, harvester used for corn in September through November, can be used in the following months for bamboo harvesting. In this respect it is very important is that the rhizome system can support considerable loads of harvesting machines. A tractor for chipping equipped with rubber tyres exerts a load of 0.5 kg/cm_. Harvesting machines in forestry, weighing up to 14 tonnes exert 1 kg/cm_, which leads to serious compaction of wet soils.

Wood industry

Today several bamboo products are on the market in Europe. Bamboo poles and sticks are used for a variety of applications, such as in tree nurseries and orchard as supports for trees, as sticks for young plants of tomato and begonia, in niche markets like broom and exotic furniture (Liese, 1985). In recent year there has been a considerable increase in bamboo parquet sales in Europe. Throughout the world suppliers are trying to sell parquet in the high end of the market. Bamboo parquet has excellent qualities regarding hardiness and durability, and is used today in various major buildings in Europe. The market for wood flooring is estimated at 80 million m_ per year in Europe.

The production of bamboo material for utensils, handicrafts or parquet is not feasible in Europe. The main sources of raw material today are to be found in Asia, to a lesser extent in South America. But given the potential to grow bamboo in Europe under field conditions, and the possibility of mechanical harvesting, bamboo could be used in a variety of other ways in wood industry. Technically bamboo can be used for the production of plywood, boards and panels. This has been done in various countries in Asia like India, Malaysia and China and also in America (Lee *et al*., 1996; Dagilis and Turcke, 1996).

In the Bamboo for Europe project raw bamboo material was supplied to industries to use it in their existing production chain. The idea was that the equipment used to chip round wood should also be able to take bamboo. If industry would have to adapt its machinery to bamboo they would not use bamboo. On the contrary, if bamboo could be chipped in the same machines as for round wood, bamboo could be used as a substitute. Experiments showed that existing mills could chip bamboo for the production of fiber boards and panels.

Several trials were done to produce bamboo particle board and Medium Density Fibreboard MDF. It was shown that partial substitution of spruce with bamboo did no affect quality and properties of particleboard and MDF panels (Van Acker *et al*., 2000). Testing of these boards showed that in MDF fiberboard the introduction of 10% of bamboo fibres with 90% of spruce did improve material characteristics (CTBA, 2000).

The use of bamboo as a (partial) wood substitiute for manufacturing medium density fibreboard MDF panel production gives good perspectives. Particle board production amounted up to 32 million m_ and MDF production was 7 million m_. More than 10% of this capacity is in smaller countries like Belgium and Luxembourg and Portugal. (EPF, 1999). Given a density of 0.75 to 0.8 tons per m_ for panels this means about 25 million tonnes of dry material. If only 1% of this amount would be bamboo, it would be 250 000 tonnes of dry bamboo. In the assumption that bamboo fields can produce 5-10 tonnes per hectare, this would mean 25 000 to 50 000 hectares of bamboo would be needed.

Another applications is Light Natural Sandwich LNS that can be used for floors, partition wall and exterior walls. They can provide an acoustic and thermal insulation (Joris Devos, pers. comm.). Uses of raw material in paper and pulp industry may also be possible in the future. If raw material is available to these industries, there are few technical difficulties.

Renewable energy

In the past century most of our fuel demands have been met with fossil fuels, including petroleum and natural gas, to a lesser extent also with nuclear energy. However, oil and its derivatives and nuclear energy present a great threath to health and the environment. Nuclear energy is being subjected to a die-out scenario. Also the availabity of fossil fuels is not indefinite. The main drawback of fossil fuels is that it harms the environment and our health. The costs of fuels do not include the ecological cost and cost to the health. Increase of CO_, highly carcinogenic effects of certain compound of exhaust gases of cars and trucks are but two examples. Annually thousands of people die from the direct effects of these carcinogenic effect. Renewable can contribute to a solution of many of these problems.

In its White Paper the Commission targets a doubling of the renewable energy production by means of renewable energy sources to 12 % of the total energy demand and a trebling of the production of electricity from renewable energy sources by 2010. This includes a variety of techniques like geothermal, wind, solar, hydro-energy (rivers and seas) and biomass.

Bioenergy is characterised by numerous resources of different origin and chemical composition. It can be classified by its origin in the following broad areas:

- agricultural products (such as energy crops) and wastes (such as straw and olive stones from the agro-food industry)
- forestry products and wastes (such as thinning and tops and branches left in the forest, short rotation forestry and also waste, products and by-products from wood based industries and operations such as bark, sawdust, fibre sludge and paper materials)
- waste streams which are generated by the consumer society (such as sorted biodegradable fractions of municipal and industrial solid waste and sludge)
- peat products.

In Europe there will be differenences between regions, owing to different geography (climatic and edaphic factors) as well as industrial activities. In the future it is expected that various sources of bioenergy will be valuable to supplement energy demands of local communities or companies. Wood waste, animal manure and so on can all be used to generated energy to power plants or companies, large buildings. Several conversion technologies can produce energy in the form of electricity and/or heat as well as gaseous, liquid and solid fuels that could be sold in the market. These include among others thermo-chemical processes such as combustion (and in the case of waste incineration), gasification, pyrolysis and biological processes such as aerobic digestion, anaerobic fermentation and others for liquid bio-fuels (bio-ethanol, bio-diesel etc.).

Europe has been building a portfolio of energy corps in the last decades (El Bassam, 1998). Research has been performed on the potential of crops such as Miscanthus, willow, Arundo donax, several other perennial grasses and bamboo. These energy crops can be converted into energy by combustion, gasification or pyrolysis. Another advantage is that energy from biomass generates 3 to 4 times more employment than natural gas and petroleum. (In developing countries this ratio will be 10-17 times according to an FAO study).

Bamboo for Bioenergy

Given the large amounts of biomass that bamboo can produce it provides a very interesting source of bioenergy in the tropics (Fielden, 1999). When grown as an agricultural crop the biomass produced by bamboo can be considered as a reenewable source of energy. The net calorific value of bamboo is comparable or higher than other wood species like beech, spruce, eucalypts and poplars, in the range of 18.3-19.7 MJ/kg.

In the Bamboo for Europe project two groups have concentrated on bioenergy aspects of bamboo. Centro da Biomass para a Energia (CBE) in Portugal has produced briquettes from bamboo. When chips of bamboo are ground to sawdust particles they can be compacted into briquettes that can be used for fireplaces and stoves. More than 98 % of the particles are smaller than 2 mm and 70% of the particles between 0.4 and 2 mm. About 30% is smaller than 0.4 mm (CBE, 2000). Briquettes are generally quite expensive in retail shops and add quite a lot of value to biomass. An alternative is a compaction method into pellets. When the material is harvested it is directly ground into small particles and compacted into cylindrical pellets of 2 to 4 cm long and 0.5 to 1 cm wide. Such pellets can immediately be used for burning (El Bassam, 1998).

Another useful technology for using bamboo for energy purposes is gasification in which a solid fuel is burnt at very high temperatures between 700 and 900°C in the presence of a gasification agent such as air. In this sense the energy present in the biomass is converted into a gaseous combustible, or chemical energy. Gas products are easier to handle, they can be used in combustion engines or gas turbines and combustion is clean and less polluting. The produced gas has a calorific value of 25-30% of natural gas and is a valuable source of bioenergy for a variety of purposes (CBE, 2000).

Carbonization experiments on bamboo were performed by Centre Genie Rural in Gembloux, Belgium. The result of carbonization is charcoal. The experiments show that the charcoal obtained from bamboo is of very good quality and can be used in industrial processes. The same group also showed that a bioenergy filiere would have a socio-economic impact with the creation of sustainable jobs, at least ten times as many as in fossil fuels. This includes the complete bamboo-to-energy supply chain and is very positive. An example is a 585 kW power plant used for heating buildings or greenhouses. Such a power plant would require 25 hectares of willow in short rotation coppice. For crops with potential higher yields, such as bamboo, less surface area is needed. In combination with the field organisation and mechanical harvesting a complete bamboo-to-energy production and supply chain is technically feasible (CRA, 2000; Gielis and Devos, 2001).

Conclusions

The major shift in view generated by the Bamboo for Europe project is that bamboo can be grown and cultivated as an agricultural plant in Western Europe, much in the same way as corn, sugarcane and wheat, or as other agricultural plants for bioenergy. The Bamboo for Europe project has studied various bottlenecks for the introduction of bamboo as an agricultural plant for tomorrow’s agriculture. The feasibility has been demonstrated. The next step is to set up different pilot plantations in different parts of Europe. Throughout Germany, 10 trial plots of 0.5 ha have already been established.

When bamboo will be used as an agricultural plant will depend largely on economic and political factors. Agriculture in Europe is very likely to undergo major changes in the future. The Common Agricultural Policy CAP reform aims at an agricultural sector which is much less subsidised than today, yet provides an important and long term revenu for the farmers, which is much less sensitive to short term market changes. At the same time agriculture and silviculture will have to safeguard landscapes and contibute to ecological goals, such as reduction of CO_2. A lot of emphasis will be placed on non-food crops. Energy crops for example can help Europe to become less dependent on the imports of fossil fuels.

In this framework bamboo provides a lot of opportunities. It is a hardy plant which a range of ecological advantages, and as a material can be supplied in a sustainable way to different industries. The use of bamboo as raw material for industry or bioenergy is a completely different approach compared to high end uses such as handicrafts, utensils and bamboo parquet. But when introduced into Europe, it may or will have a serious socio-economic impact in agriculture.

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