Sustainable agriculture in the semi-arid tropics: Agroforestry and the suitability of bamboo

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Climate, population and food security

The regions of the world classed as semi-arid tropics (SAT) are home to 1.4 billion people (Thurston, 1997). Of these, 560 m people are classed as 'poor' (i.e. they have a daily income of less than $1 US), of whom 70 % live in rural areas and lack food security (Ryan and Spencer, 2001). The problems faced by populations in the SAT stem from the environmental, economic and social constraints which characterise these regions; environmental constraints include low and unpredictable seasonal rainfall, high mean annual temperatures and high evaporative demand, which severely limit water supplies for agricultural use. Poor soil fertility or condition may also limit productivity (Bramel-Cox *et al*., 2000). Staple crops include cereals (e.g. maize, sorghum and millet) and legumes (e.g. French beans, pigeonpea and chickpea), although many other species are grown for on-farm consumption or local sale.

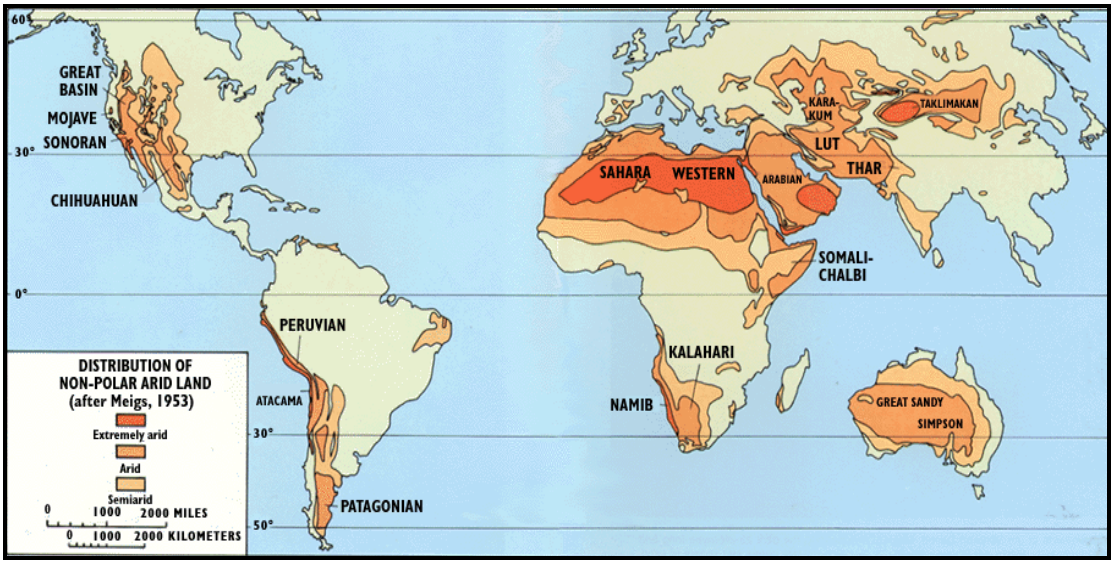

Figure 1. Global distribution of the arid and semi-arid tropics (from www.cnr.vt.edu).

Socio-economic factors also influence the ability of farmers to produce sufficient food. Populations in semi-arid regions have increased rapidly in recent decades and this trend is expected to continue. The populations of Ethiopia, Nigeria and Pakistan and India are predicted to double from 1.1 billion today to 2.5 billion by 2050, a combined population exceeding that of Africa in 1950 (Dar, 2001). This surge in numbers will greatly increase the strain on land resources already under substantial pressure to produce sufficient food. It is expected that poverty will increase and food security will decrease for both rural and urban communities. Moreover, existing constraints are likely to be exacerbated by climate change, with temperatures expected to rise and water supplies to become increasingly

scarce (Rosenzweig *et al*., 2004; IPCC, 2007), particularly in Africa (Orindi and Murray, 2005).
Rapidly increasing populations have caused traditional systems of shifting cultivation (slash and burn) to be abandoned in favour of intensive arable farming (Ong *et al*., 2006). However, intensification of land use has not been accompanied by increased mechanisation or application of organic fertiliser, leading to degradation of the natural resource base and a decline in *per capita* food production (Sanchez *et al*., 1997). Farmers in the SAT have been forced to adapt their farming practices to cope with the prevailing constraints.

The high external-input agricultural systems used in economically developed countries rely on the widespread use of chemical inputs, hybrid or GM seeds, fossil-fuel powered machinery and irrigation. These approaches depend on non-renewable resources, are highly capital-intensive and market-orientated, and are available only to a small proportion of comparatively wealthy farmers in the SAT, but not to the great majority of poor subsistence farmers. They also have significant environmental impacts, including soil degradation and release of pollutants to the biosphere.

In the low external-input agricultural systems typical of the SAT, environmental constraints and poor commercial and economic infrastructure preclude the use of expensive inputs such as fertilisers and specialised machinery, with the result that farmers are forced to overexploit their land to produce sufficient food and other essential commodities such as fuel, timber and fodder to support livestock. This is particularly true when farmers are forced onto marginal land after being ousted from higher potential land or as a result of traditional land tenure systems. As a consequence, land becomes subject to deforestation and soil degradation and increasingly vulnerable to drought and erosion (Reijntjes *et al.,* 1993).

Sustainable Agriculture & Agroforestry
In view of these constraints and pressures, adoption of sustainable agriculture is vital to food security for local populations, even at the most basic subsistence level (Ong *et al*., 2006, 2007). Particularly relevant to the SAT is the concept of low external-input sustainable agriculture (LEISA), which is feasible for subsistence farmers because capital is not required to provide expensive external inputs. LEISA seeks to integrate all farm components (trees, crops and livestock) in order to optimise the use of available resources and achieve stable, sustainable and adequate long term production of all essential commodities (Reijntjes *et al.,* 1993). As average land-holdings decrease, smallholder farmers can no longer afford to allocate separate areas for crops and trees. In such cases, agroforestry, the practice of integrating trees into cropland, may provide viable land use systems to sustain the productivity of smallholdings while supplying fuel and other tree products.

Agroforestry is a form of LEISA in which trees or shrubs are grown in mixtures with crops or pasture species (Azam-Ali and Squire, 2002). A key objective is to optimise the capture and efficiency with which natural resources such as water, nutrients and light are used; Figure 2a below summarises the potential benefits. However, the integration of trees with crops may exert both complementary and competitive effects; in the former case, the trees have little effect on crop yield but overall system yield is increased, whereas crop yield and food production may be unacceptably reduced when significant competition occurs.
Appropriate agroforestry systems offer numerous potential benefits, including provision of multiple products and services, such as food, fuel and building materials, conservation of soil and water resources and improved food security (Ong *et al*., 2006, 2007). When trees provide economically valuable products

such as fruit, nuts, timber or carbon credits, they may generate significant income. However, an inappropriate choice of tree species may result in competition with crops, for example, shallow-rooted or excessively vigorous species such as *Eucalyptus grandis*; Ong *et al*., 2006, 2007).

(a)

(b)

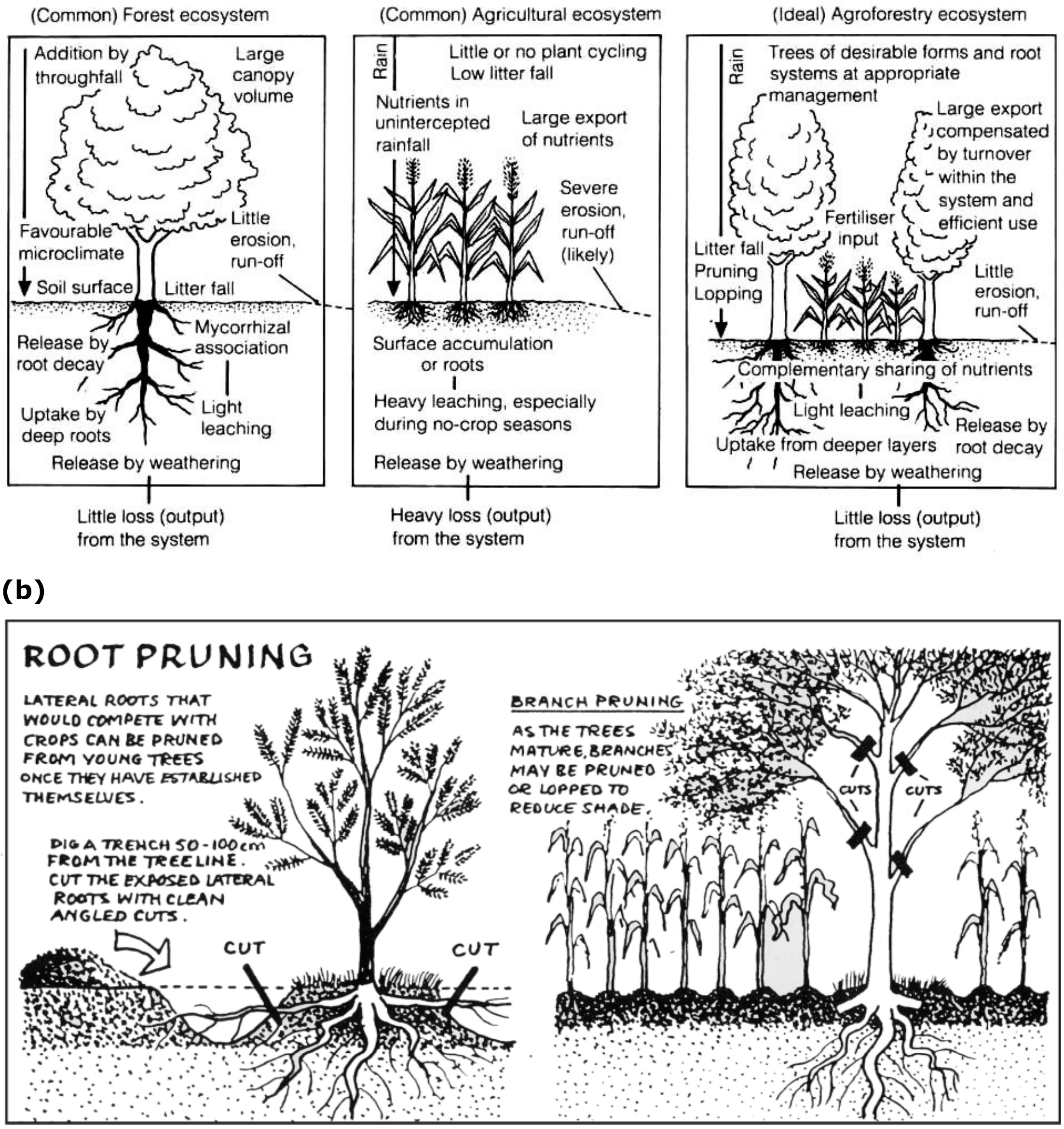

Figure 2. (a) Nutrient advantages of agroforestry systems compared to common forestry and cropping systems (from Reijntjes *et al*., 1992); (b) root and shoot pruning of trees to minimise competition with crops (from Assmo and Eriksson, 1999).

Competition in agroforestry and potential solutions

As noted above, competition may pose significant problems. As biomass production is closely linked to the quantity of light, water and nutrients used, dry matter production is reduced when their capture and conversion to produce dry matter is impaired (Ong *et al*., 2006, 2007). Competition is most intense when trees and crops compete for the same resource pools, so exhibiting overlapping niches, and are therefore unable to coexist effectively in the same community (Ong *et al.,* 1996). For example, some tree species promoted for use in agroforestry in East Africa such as *Grevillea robusta* and *Eucalyptus* species have root systems with similar vertical distributions to crops and so compete with the species they are intended to complement (Chirwa *et al*., 2007; Ong *et al*., 2007). Efforts to minimise the adverse effects of competition on crop yield have not always been successful. One approach involves shoot and/or root pruning to manage the competitiveness of the above and/or below-ground canopies of trees (Fig. 2b). Some studies have shown that repeated shoot pruning may increase root density and competitive interactions in soil horizons occupied by crop roots and so is ineffective in reducing competition (Govindarajan *et al*., 1996), whereas others have shown shoot and/or root pruning to be effective in controlling competition, although labour requirements are increased (Ong *et al*., 2007). The potential for using tree species with appropriate leafing phenology to promote temporal complementarity between trees and crops has also been examined. Trees used in agroforestry may be evergreen, semi-deciduous or fully deciduous (Broadhead *et al*., 2003a, b). As evergreen species retain their leaves during the annual cycle, they may be more competitive with crops than those which lose some or all of their leaves during the annual cycle as this reduces their activity, and hence competitive impact, particularly if this occurs during the cropping season. An example of temporal complementarity, where trees and crops make their main demands on available resources at different times, involves *Faidherbia albida*; this species enhances crop production because its reverse phenology causes leaves to be shed at the beginning of the rainy season, so supplying nutrients to the soil, while leaf flushing (production of new leaves) occurs at the start of the dry season when annual crops are approaching maturity (Sanchez, 1995). Broadhead *et al*. (2003a, b) provided a detailed consideration of the role of trees with differing leafing phenologies in agroforestry systems.

Suitability of bamboo for agroforestry
Bamboos are perennial grasses native to all continents except Europe between latitudes of 40° North and South (Fig. 3; El Bassam *et al*., 2000).

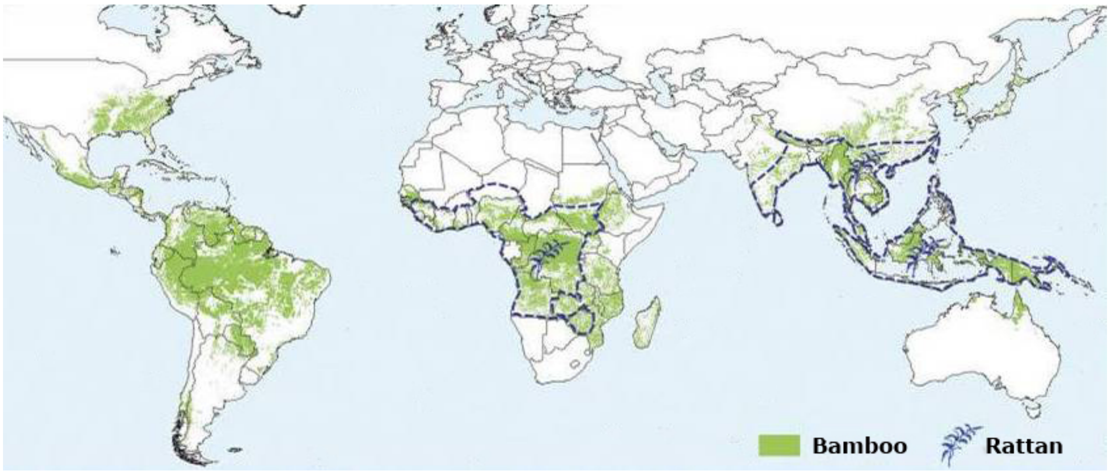

Figure 3. Global distribution of bamboo (modified from Lobovikov 2003, www.fao.org).

Bamboos have the potential to be incorporated into agroforestry systems in the SAT in place of conventional tree species due to their adaptability and diverse range of raw and manufactured goods which they produce. They are among the world's most important and versatile plants (Kleinhenz *et al*., 2003) and are the fastest growing woody species (Bosire, 2007), partly because their large leaf canopies (Fig. 4) are highly effective in capturing light. Their stems may extend by 40-90 cm d^{-1} (El Bassam *et al*., 2000) to reach heights ranging between 10 cm and 40 m, and may achieve basal diameters of 15-20 cm (Scurlock *et al*., 1999).

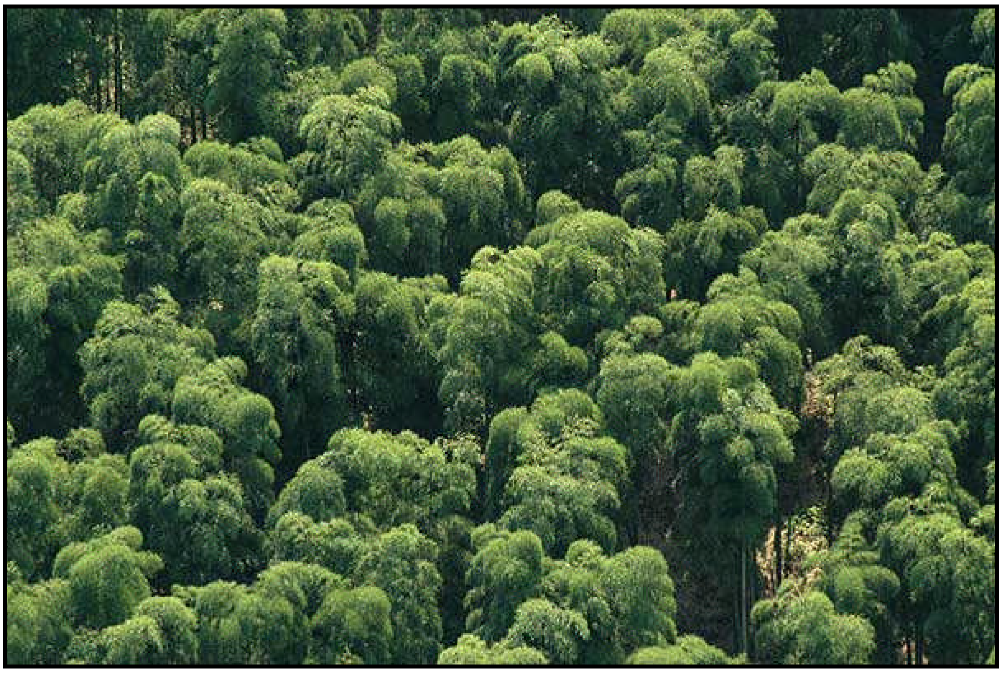

Figure 4. The large leaf canopy of *Phyllostachys pubescens* allows it to absorb 95% of available sunlight (from bambooweb.org).

There are *c*. 75 genera and 1200 species (Scurlock *et al*., 1999; Bystriakova *et al.,* 2004); variability in stem characteristics between important species is shown in Figure 5.

Bamboos may provide a sustainable solution to problems posed by harsh environmental and socio-economic conditions in the SAT as they offer a wide range of income and employment opportunities and consequently have the potential to alleviate poverty in rural areas (Gangopadhyay, 2003).

Bamboos have an estimated 1500 uses including food, flavouring for alcoholic beverages, construction, fuel, charcoal, medicinal products and the manufacture of paper, flooring, screens and clothing (Filho and Badr, 2004; Pilliére, 2008). Their potential for improving socio-economic conditions is illustrated by the wide gap between demand for bamboo products and the rate at which they are produced (Gangopadhyay, 2003), suggesting a unique opportunity for subsistence farmers in the SAT. Many species are well suited to semi-arid regions by their ability to adapt to a wide range of environments and may grow more rapidly than conventional agroforestry species such as *Eucalyptus* species, *Leuceana leucocephala* and pines (Embaye, 2001).

A major potential use is in soil conservation and improvement, as in Nepal, where agriculture may extend to altitudes of 3500 m and bamboo has proved effective in preventing erosion on steep hillsides and terraces (Bradshaw, 1997). Bamboo may also be planted on river banks to protect against erosion during floods, is a nutritious food source for local consumption, and provides a major source of revenue when exported in processed form, as in China.

Profitability for subsistence farmers may be greatly increased by 'adding value' through the manufacture of intermediate or finished products, including furniture, tourist goods, flooring, screens and charcoal for local sale or export. Bamboos also provide an eco-friendly substitute for timber due their rapid growth, excellent mechanical properties, durability, resistance to rot and insect pests and diverse uses. The high density of fibres in the stems results in a tensile strength exceeding that of steel, making bamboo one of the strongest known construction materials (Murage, 2008); buildings and bridges constructed using bamboo are highly resistant to earthquakes and other natural disasters due to their intrinsic strength and flexibility.

Bamboo also has potential applications in combatting environmental pollution and climate change, both of which have important implications in SAT regions. As a non-food species, bamboo may be irrigated with contaminated wastewater and harvested without risk to human health, providing an alternative income stream for subsistence farmers, while remediating soils contaminated by trace metals or other pollutants as a result of human activity (Bosire, 2007; Murage, 2008). Bamboo-based and other types of agroforestry also have the potential to be used to secure payments for carbon sequestration through carbon credit policies (TIST, 2008).

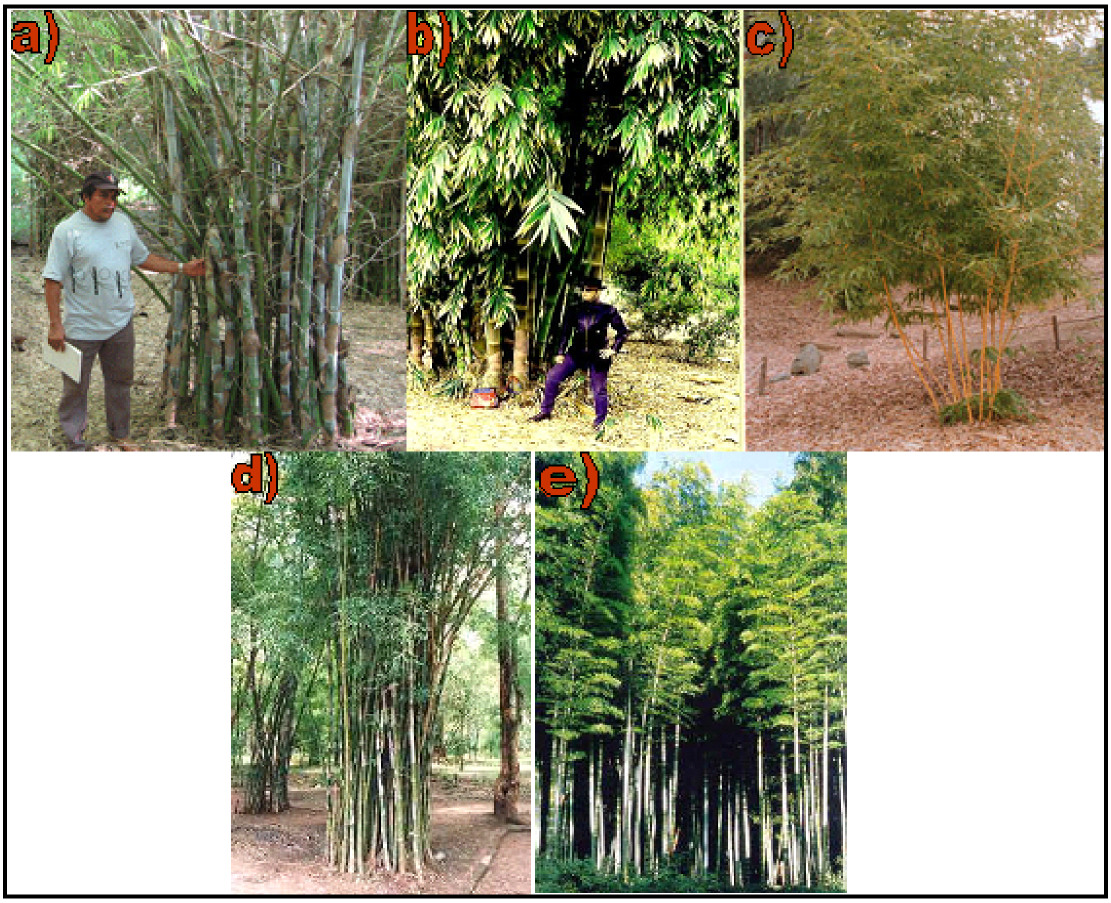

Figure 5. Important bamboo species: a) *Dendrocalamus strictus* (from www.bamboodirect.com); b) *Dendrocalamus asper* (from www.endangered species.com); c) *Phyllostachys bambusoides* (from www.bamboogarden.org); d) *Thyrsostachys siamensis* (from www.kyoto.zaq) and e) *Phyllostachys pubescens* (from www.bambuon line.it).

In addition, bamboo can provide habitat for endangered species such as the eastern mountain gorilla, panda and mountain bongo (Fig. 6).

Conclusions and further research
Agricultural production in the SAT is limited by a unique set of constraints, the most significant of which are limited water supplies, poor soil fertility and socio-economic factors, including rapid population growth. These pressures have caused increasingly large areas of marginal land to be brought into agricultural use and raised demand for food and commodities such as timber, fuel and fodder, resulting in the adoption of increasingly unsustainable farming practices and depletion of soil fertility, native forests and other ecosystems. Coupled with an under-developed infrastructure which cannot deliver fossil fuels and raw materials effectively, these practices have led to widespread poverty and starvation in both rural and urban areas. As climate change is expected to worsen the situation, it is essential that the sustainability of current production practices is addressed and solutions to soil degradation and water scarcity pursued.

Figure 6. Mountain bongo (left) and red panda (right) are among the many animals that feed on bamboo and depend on conservation of bamboo forests for their survival (from http://www.jphpk.gov.my/English/).

Sustainable low-external-input agricultural systems are well suited to the SAT as they aim to produce sufficient food and essential commodities in an environmentally beneficial and socially and economically acceptable way. They enable farming communities to produce food and other commodities whilst maintaining or restoring natural resources such as soil fertility. In such systems, the aim of short term profitability is over-ridden by the need for long term sustainability and environmental remediation. Agroforestry is a sustainable production system which makes more effective use of available resources when competitive interactions are effectively controlled and has proven environmental and socio-economic benefits. Moreover, bamboo has significant potential for use in agroforestry as it provides numerous environmental benefits including soil conservation and phytoremediation, together with diverse products ranging from food and fuel to tools and building materials. Bamboo also has industrial applications as a raw material for the production of paper, flooring, clothing and other commodities and 'added value' can be provided for smallholder farmers through the production of ornaments and furniture.

However, further research is essential to fulfil this potential. For example, it is important to determine the extent to which bamboos compete with crops in agroforestry systems. Studies of flowering and seed production are also important as vegetative propagation alone may be unable to provide sufficient planting material, as some species flower and produce seed only once during their 70 year life cycle. Finally, studies of a wide range of species are needed to ensure that those selected for use in agroforestry are well-suited to semi-arid areas and provide a favourable balance between environmental and socio-economic factors.

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Personal Profile

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