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The Potentials of Bamboo-Based Agroforestry Systems in Improving the Productivity of Tropical African Agricultural Systems

A. Addo-Danso[1] and P. Amankwaa-Yeboah[1]
[1] Council for Scientific and Industrial Research – Crops Research Institute

Corresponding Author: a.addo-danso@cropsresearch.org

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Abstract
Agricultural productivity is important for food security and income generation among other benefits. In tropical Africa, agricultural productivity is generally perceived as low. This low productivity can be increased through means such as crop improvement, integrated pest management, horticulture, livestock and fodder crops, agroforestry, modernization, technology adoption, irrigation and mechanization. This paper is focused on how agroforestry systems, more especially, bamboo-based systems can improve the productivity of tropical agricultural systems. Analysis of relevant literature was carried out to bring together existing information on tropical African Agricultural Systems, present a brief history of their evolution and analyze ways of increasing their productivity. The bamboo-based systems approach is highlighted as a potential means to improve tropical African Agricultural Systems.

Keywords: Agricultural productivity, Agricultural systems, Bamboo, Bamboo-based systems, Tropical Africa

Le Potentiel des Systèmes Agroforestiers à Base de Bambou Dans L'amélioration de la Productivité des Systèmes Agricoles D'afrique Tropicale

Résumé
La productivité agricole est importante pour la sécurité alimentaire et la génération de revenus, entre autres avantages. En Afrique tropicale, la productivité agricole est généralement perçue comme faible. Cette faible productivité peut être augmentée par des moyens tels que l'amélioration des cultures, la lutte intégrée contre les ravageurs, l'horticulture, les cultures d'élevage et de fourrage, l'agroforesterie, la modernisation, l'adoption de technologies, l'irrigation et la mécanisation. Cet article se concentre sur les systèmes agroforestiers et plus particulièrement sur les systèmes agroforestiers à base de bambou. L'analyse de la littérature pertinente a été effectuée pour rassembler les informations existantes sur les systèmes agricoles tropicaux africains, présenter un bref historique de leur évolution et analyser les moyens d'augmenter leur productivité. L'approche des systèmes à base de bambou est mise en évidence comme un moyen potentiel d'améliorer les systèmes agricoles d'Afrique tropicale.

Mots-clés: Productivité agricole, les systèmes agricoles, bambou, systèmes à base de bambou, Afrique tropicale

Introduction

Agricultural or farming systems consists of combinations of crops and animals managed in various production systems with their component cultural practices and technologies. It is also made up of mixtures of traditional and introduced elements adapted to the requirements of different ecological zones and people of different cultures (Okigbo, 1997). Hendrickson *et al.* (2008) define agricultural systems as complex and rapidly changing systems in which conflicting social, political, economic, technological and environmental issues must be balanced with traditional production goals. According to Okigbo (1997) the rapidly changing systems are as a result of changes in the natural and socio-economic environment, and some of these changes have made traditional systems unsustainable and outdated. Caldwell (2015) also defines agricultural systems as the relationships which exist within and between farmers or producers, natural systems involving climate, geology, soil, air, pests and water; and human systems such as politics, land-use planning and infrastructure, law, finance and marketing.

An agricultural system can consist of six main elements namely: farms, natural environment, governance, agribusiness, technical and professional expertise and non-profit and community sector (Caldwell, 2015). Farms may be of different sizes and they produce a range of crops, livestock and services such as carbon sequestration and aesthetics. The natural environment impact on the viability of the system. Services and programs, policy directives and regulations from different levels of government impact on-farm activities such as production and infrastructure and off-farm activities such as marketing and distribution. Agribusiness includes wholesale and retail companies who buy, process, package, store and/or distribute goods and services to or from farms. Labour and services rendered by technical and professional people such as accountants, lawyers and information technology experts make up the technical and professional expertise element. The non-profit and community element includes a range of organizations like those involved in research, innovation and knowledge transfer. Organizations and agricultural associations which render organizing, programmatic and advocacy support for agricultural communities are also part of the non-profit and community sector element (Caldwell, 2015). Caldwell (2015) also reports that different components of agricultural systems have different levels of importance in various locations or regions. These components must be seen as interconnected with each other; affecting or with the potential to affect the other. Example, fertilizer use may produce lush and soft crops which may be more susceptible to pests and diseases. The use of pesticides can also kill earthworms and other soil microorganisms that promote organic matter turnover, nutrient cycling and soil fertility (Edwards, 2001).

The productivity of agricultural systems can be increased through land management and sustainable agricultural practices. Several studies such as Benin *et al.* (2016), Pretty (2011) and Pender *et al.* (2003) have looked at improving the productivity of tropical agricultural systems. In these studies, expanding lands for crop production, increasing cropping intensity, yield-enhancing technologies such as fertilizer usage, large expenditure, regional agricultural policies, investments into agriculture research and development, location-specific strategies, opening new markets for crops which are restricted to small domestic markets and increasing tree crops in productive agroecologies are considered as some of the means to increase agricultural productivity in the region. The focus of this paper is however on agroforestry, particularly, bamboo-based agroforestry for the tropical African region.

Methodology

A review of relevant literature was carried out from 48 published sources. These included peer reviewed journal articles, reports, manuals, online resources, theses, training guides and conference proceedings. The review leaned more on examples from Asian countries such as China, India and Indonesia because these countries have abundant bamboo resources and bamboo-based systems have been practiced for several years. Moreover, the qualities, uses, production, management and potentials of bamboo are very conspicuous in these countries (Christanty *et al*., 1997; Mailly *et al*., 1997; Chongtham *et al*., 2011; Nath *et al.,* 2016; FAO and INBAR 2018; Sharma *et al.,* 2018) and lessons can be learnt and applied to the tropical African context. Lessons were also drawn from some tropical African countries such as Ghana, Ethiopia, Tanzania, Kenya and Cameroon. The study spanned from sources from 1972 to 2020 to allow for the consideration of historical perspectives of tropical African agricultural systems. With these in mind, a brief history of tropical African agricultural systems is presented. The productivity of agricultural systems and how agricultural systems can be improved are examined. Potential of agroforestry to improve agricultural productivity is presented with emphasis on bamboo-based agroforestry systems.

Agricultural systems in tropical Africa

Two major agricultural systems existed in tropical Africa in the early 20th century. These were the shifting cultivation (a practice where parcels of land are farmed temporarily and left to regain their normal vegetation, at which point the farmer moves on to farm another land) which was considered indigenous and the plantation system which resulted from European colonization (Benneh,1972). There was also the subsistent system in which the cultivator farmed his land for himself and his household, and the commercial system in which the cultivator produced for the market. In his paper, Benneh (1972) reported that agricultural systems in tropical Africa can be classified based on what they are and how their constituent elements interact to make them function as production units. He also noted that the organization of agricultural systems are based on pressure of population on agricultural lands, economic crises, increases in knowledge of social and economic opportunities to be gained by adopting new systems of agriculture, government directives and an awareness and availability of superior technology for solving problems of agricultural production. Agricultural systems in tropical Africa were also broadly considered as traditional systems (example; bush fallow and compound farms), transitional systems (example; smallholder cocoa and coffee plantations) and the then modern systems and their local adaptations (example; large-scale plantations, poultry farming and market gardening) (Okigbo, 1997).

In tropical Africa, agricultural systems have evolved over the years to include the cultivation of cash tree crops by subsistent farmers, the application of technology in commercial farming, sustainable agriculture and land management systems such as soil nutrient management, tillage and residue management, agronomic practices, agro-forestry, soil and water conservation, integrated pest management and improved livestock management (Benneh, 1972 and Recha *et al*., 2014). These changes resulted from the introduction of Asian and New World crops, population expansion, the need for spices and agricultural raw materials for industry, improved means of transportation and communication, introduction of mechanization and adoption of new techniques (Kaufmann *et al.*, 1983). Furthermore, Okigbo (1997) noted that agricultural systems in tropical Africa resulted from several years of experimentation to give rise to extensive production systems such as shifting cultivation and nomadic herding. These systems were seen as sustainable under the then low population densities in that they were economically viable, ecologically sound and culturally acceptable. However, intensive fallow systems dominated as the populations grew. Evolution of agricultural systems in tropical Africa can also be looked at considering inputs of technologies used (Table 1). Today in the 21st century, issues concerning climate change and food security are paramount in organizing agricultural systems.

Productivity of agricultural systems

Agricultural productivity is the relationship between the production of a commodity (good or service) and the inputs needed to produce that commodity (FAO 2017). The Organization for Economic Co-operation and Development (OECD) (2016) describes agricultural productivity as the improvements in the efficiency with which farmers combine inputs to produce outputs. According to Benin (2016) agricultural productivity across Africa has increased at a moderate rate over time, although there are variations in the rate of growth in land productivity, labour productivity and total factor productivity.

Hendrickson *et al.* (2008) explain the productivity of agricultural systems as presented in Figure 1. As the agricultural system becomes more complex with more production components, economic risks, may be lowered due to diversified market opportunities and the avoidance of price cycles. Management inputs in such systems increase because of the need to understand not only the components but their potential interactions too. As the agricultural production systems increase productivity, there is an increase in complexity both in structure and management of the system. There is also an increase in sustainability. As the agricultural systems progresses in the hierarchy, economic, environmental and social-community dimensions are considered. The inclusion of more components up the hierarchy lower production and economic risks whiles increasing adaptability to contribute to long-term sustainability. Moving up the hierarchy, more production components or enterprises are involved, best available information and technology are employed and decisions are made in a dynamic manner to result in reduced income uncertainty.

Agricultural systems whose productivity are improved whiles conserving and enhancing natural resources can lead to sustainability. Sustainable agriculture demonstrates long-term maintenance of natural resources and agricultural productivity, minimal environmental inputs, adequate economic returns to farmers, optimal production with minimal chemical inputs and provision for food and social needs of farm families and communities (Edwards, 2001). Whereas agricultural intensification is increasing yields per hectare, increasing cropping intensity using two or more crops per unit of land or other inputs and changing land-use from low-value crops or commodities to higher market priced crops or commodities; sustainable agricultural intensification is producing more outputs from the same area of land while reducing negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services (Pretty, 2011). According to Okigbo (1997), “the overall objective of agricultural or farming system design and management should be the creation of environmental

Table 1: Inputs of technologies used in traditional and modern conventional agricultural systems

Input of Technologies	Traditional Systems	Modern Systems
Land	Small (<1-5 ha)	Large (10-100 ha or more)
Tools	Simple: fire, axe, hoe, digging sticks, machete	Complex: tractors and implements, threshers, combine harvesters, etc.
Crops	Many species (5-80), land races, no genetic improvement, wide genetic base	Few species (1-3), improved narrow genetic base
Animals	Several species (2-5)	1 or 2 species
Labour	Manual, human energy, or animal power	Mechanical, petroleum fuels, electrical energy
Soil fertility maintenance	Fallows, ash, organic manures	Inorganic fertilizers, sometimes manures, soil amendments, example lime and gypsum
Weed control	Manual, cultural	Mechanical, chemicals (herbicides and petroleum-based products)
Pest and disease management	Physical / cultural	Mainly mechanical, chemicals (insecticides, fungicides, bactericides, nematocides, rodenticides)
Crop management	Manual	Growth regulators for defoliation, control of flowering, fruit drop, etc.
Harvesting	Manual or with simple tools	Mechanical, tractors plus implements: pickers, balers, threshers, combine harvesters
Post-harvest handling and drying	Simple sun-drying and over fires	Mechanical forced-air artificial drying using petroleum fuels, sometimes refrigeration

Source: Okigbo 1997

conditions that remain favorable to crop and animal production or even increase their productivity while at the same time minimizing adverse impacts on the resource base or, where possible, enhancing it".

Increasing the productivity of agricultural systems

The productivity of agricultural systems can be increased through sustainable agricultural and land management practices such as soil

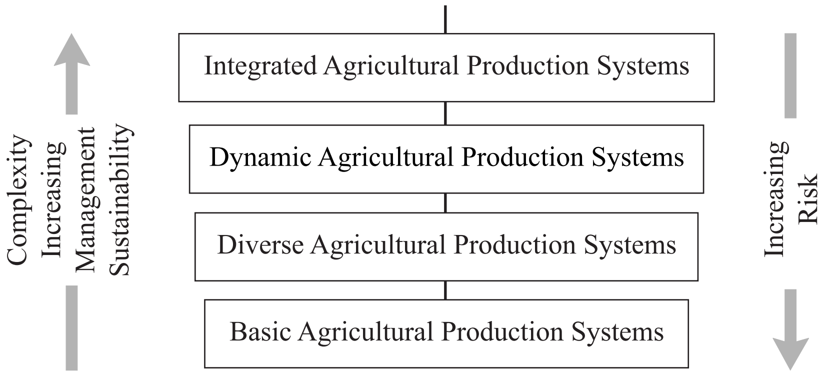

Figure 1: Hierarchical arrangement of agricultural production systems (Adapted from Hendrickson *et al*., 2008)

nutrient management, soil and water conservation, tillage and residue management, agronomic practices, agro-forestry, integrated pest management and diversified rotation involving crop varieties and species with different temperature requirements. Increasing agricultural productivity and sustainability could also mean using technologies that make the best out of both crop varieties and livestock breeds and their agroecological and agronomic management (Lipper *et al.* 2010; Pretty, 2011). Also, according to Pretty (2011) increasing agricultural productivity involve understanding how agricultural inputs such as seeds, fertilizers and pesticides either compliment or contradict the biological processes and ecosystem services that inherently support agriculture. To add to these, Okigbo (1997) notes that the characteristics of the resources used in production, how the resources are managed and manipulated in the production process and the technologies and practices which make the production system unsustainable should be considered. The drive to increase agricultural productivity must be backed by political will, policies and regulation. Reporting on sustainable intensification projects in Africa in the 2000s, Pretty (2011) noted that where there was political and economic domestic recognition of agriculture, food outputs not only increased without harm to the environment but also with increased flow of beneficial environmental services. Although increasing the productivity of agricultural systems involve different technologies and practices, it should also include approaches to farmers like agricultural research, building social infrastructure, working in novel partnerships and developing new private sector opportunities (Pretty, 2011).

There are however, conflicting thoughts on the results of increases in the productivity of agricultural systems. For example, OECD (2016) report that increase in productivity results in affordable food, feed, fuel, fiber, increased household income, improved competitiveness and contribution to national growth. Hendrickson *et al.* (2008) add that increasing the productivity of agricultural systems results in increasing the complexity, management and sustainability levels whiles decreasing the risk levels of the system. Moreover, Pretty (2011) reports that increasing the complexity and efforts in agricultural systems lead to net benefits in productivity and income. Contrarily, de Prada *et al*. (2003) report that increasing the productivity of agricultural systems through for example; intensive land use, corporate land leasing and large farm sizes, may increase revenues but at the expense of sustainability. They explain that although corporate land leasing for agricultural modernization results in increased crop revenues, it may also lead to the adoption of simple mono-cropping systems that reduce long-term productivity and increase off-farm damage. Also, from a policy perspective, de Prada *et al*. (2003) argue that market forces may increase short-term agricultural productivity but have negative effects on sustainability. Striking a balance between efforts at increasing agricultural productivity and their resulting effects must therefore always be considered. Agroforestry is one means to achieve this, as agroforestry has the intention of developing more sustainable land use forms that ensure diversification and increased productivity in farming systems for social, economic and environmental benefits for land-users at all levels (Leakey, 1996).

Potential of agroforestry for improving agricultural productivity

The complexity of agroforestry presents challenges for the evaluation of impacts although agroforestry has potentials to simultaneously contribute to a number of the Sustainable Development Goals (Miller *et al.* 2019). Example; agroforestry has the potential to improve farming systems by providing a means to put unsuitable lands for crop production into woody perennial crop production. Over years when the woody perennials mature, the soil is replenished for crop production. This may be achieved through aboveground ecological interactions such as shading and evapotranspiration. There are also belowground interactions such as root interactions with respect to water and nutrients and interactions through biomass transfer when tree litter or prunings are added to the soil (Nath *et al.* 2009). Agroforestry can also help improve agricultural productivity through its service functions. This is expressed in the role of woody perennials in soil management like erosion control and maintenance and improvement in soil fertility for improved crop production (Nath *et al*. 2009). Again, the productive functions of agroforestry provide a range of products (food, fruits, fodder, fuelwood, fiber, gums, resins, thatching, medicinal products, etc.) which diversify outputs from farming systems to give broader economic base and improved food security (Nath *et al.* 2009).

According to Nair (1993) all agroforestry systems possess 3 attributes - productivity, sustainability and adoptability. This author explains that most agroforestry systems have the goal to maintain or increase production of preferred commodities, example food crops, and productivity of the resource base, the land. Agroforestry achieves and maintains conservation and fertility of the resource base through the beneficial effects of woody perennials on soils, thus enhancing the sustainability of the land. New agroforestry technologies introduced are to conform to existing local practices which have already been accepted by farmers to satisfy the adoptability attribute.

Nath *et al.* (2009) defined agroforestry as a collective name for land-use systems in which woody perennials are grown with agricultural crops, pastures or livestock in a spatial arrangement, a rotation or both. Recently, Leakey (2017) has defined agroforestry as a dynamic, ecologically based, natural resource management system that through the integration of trees in farm- and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits. Although most agroforestry practices and technologies have trees or shrubs as the woody perennial component (Bekele-Tesemma, 2007 and den Herder *et al*., 2015), bamboo can also serve as the woody perennial component (Dev *et al.,* 2020 and Tewari *et al.,* 2015). Therefore, for the purpose of this work, bamboo-based agroforestry systems are defined as agroforestry systems which have bamboo as the woody perennial component.

The bamboo-based systems approach

Agricultural systems have evolved over the years and deciding on an option for production must necessarily be based on sound ecological, social, economic and environmental principles and bamboo-based cropping systems or agroforestry have the potential to satisfy these. Bamboo-based agroforestry systems can play important roles in enhancing productivity, sustainability and resource conservation in agricultural systems (Teweri *et al.,* 2015). Care should however be taken to include factors needed for their successful implementation and sustainability of effects during their design stage. For example; the overall goal of the systems, specific needs to be met, financial and technical capabilities, market availability for produce and secure tenure need to be considered. The successes of integrating bamboo into farming systems have been reported by several authors, example: Akoto *et al.* (2020); Bekele-Tesemma (2007); Christanty *et al.* (1997); Nirala *et al.* (2018) and Rahangdale *et al.* (2014) (Table 2). As noted by IFAD (2019) there are untapped indigenous bamboo species in Africa and conditions are also suitable for growing cultivated species. These fast-growing plants can therefore be taken advantage of to improve the productivity of agricultural systems which are mostly considered as low in tropical Africa.

Common bamboo species used in agricultural systems are *Bambusa balcooa, B. bamboos*, *B. bluemeana*, *B. membranaceae, B. multiplex, B. nutans*, *B. pervariabilis, B. vulgaris, Dendrocalamus asper*, *D. brandisii*, *D. hamiltonii*, D. *strictus,* and *Oxynanthera abyssinica,* (Nath *et al.,* 2009 and Tewari *et al.,* 2015). All these species are clumping bamboos (grow in clumps) and are well suited for tropical regions and hence tropical Africa. Clumping bamboos are unlike running bamboos which are invasive and difficult to manage and control (Lobovikov *et al.,* 2007). The agricultural crops commonly cultivated with bamboos are soybean, mango, rice, maize, wheat, oil seeds, chilies, sugarcane, pigeon pea, ginger, cashew nut, rubber, cucumber, cassava, potato, paddy, groundnut, cowpea and tomato (Nath *et al*. 2009 and Shanmughavel and Francis, 2001).

Bamboo-based agroforestry systems, like any agroforestry system can be grouped into zonal or mixed spatial arrangements where intimacy of associated plant components is restricted or encouraged; or rotational arrangements, where woody perennials are completely separated from the non-woody plant components or the agricultural crops in time (Huxley *et al.*, 1987). The authors further note that spatially-arranged systems can also be manipulated temporally, but within a seasonal time frame. Bamboo can be integrated into farming systems through mixed cropping, hedgerow cropping or alley cropping, intercropping, modified shifting cultivation, clusters or patches of bamboo on farm lands, scattered bamboo on farm lands, homegardens, shelter belts, windbreaks and fodder production (Akoto *et al.*, 2020; Christanty *et al.*, 1997; Nath *et al.*, 2009; Obiazi, 1995; Shanmughavel and Francis, 2001 and Tewari *et al.*, 2015). There is the potential for vermicompost with bamboo and bamboo-poultry or bamboo-dairy farms as practiced in some parts of India and the hilly regions of Southern China (Nath *et al.*, 2009).

Table 2: Success stories of bamboo-based agroforestry systems

Some bamboo-based agroforestry success stories
Intercropping bamboo with maize, cowpea cassava in Ghana - This example revealed a greater advantage of integrating bamboo with food crops over monocropping systems. Changes in soil properties, crop productivity and economic potential of a bamboo-based intercropping system was evaluated in the Sekyere Central District in the Ashanti region of Ghana over three years. This involved *Bambusa balcooa* with maize, cowpea and cassava. Results showed significant higher soil moisture, pH and crop productivity levels for the bamboo-based agroforestry over monocropping systems. Also, marginal profitability of the bamboo-based systems was estimated over the monocropping systems (Akoto *et al.*, 2020).
The bamboo cum cereal farming system in Ethiopia - Here bamboos are planted as farm boundaries, or fence rows between croplands and grazing lands and along farm plots. The bamboos are planted as a narrow strip of linear bamboo plantation and interspersed with barley, wheat, millet, tef, potato or thatching grass. The bamboo boundary plantations are established and maintained with minimum inputs (land, traditional digging tools, axe and sickle) by farm households. The major management input is protection against grazing and trampling damage. Bamboos are harvested all year round and used to make mats, carpets, broom, cover for baking plates, walking sticks, chairs, tables, fuelwood, etc. The bamboo leaves and twigs are also fed to animals as fodder. Normally family members help manufacture the products. Farmers are able to accrue uninterrupted cash income throughout the year without major financial and labour investments (Bekele-Tesemma, 2007).
The "talun-kebun" system in Indonesia - In the "talun-kebun" system (a modified shifting cultivation system practiced in West Java, Indonesia) a 6–7-year management cycle of a 4–5-year fallow period of perennial clumping bamboos is alternated with 2 years of food crop production. The success of the system is based on the ability of bamboo to reverse much of soil nutrients leached deeper into the soil profile during the 2 years of food crop production. The pumped-up nutrients are deposited at or near the soil surface as aboveground bamboo litter and dead bamboo fine roots for use by the food crops during the 2 years crop production period (Christanty *et al.,* 1997).
Bamboo as boundary plants around agricultural fields and for water and soil conservation in India. In Jharkland (India) bamboos are planted around agricultural fields as boundary plants to protect food crops from high wind speed. The bamboos are also used for water and soil conservation during water stressed periods. When the bamboos are harvested, they are sold to compensate the monetary losses of the agricultural crops. The bamboo leaves are also served to livestock as fodder. Therefore, the bamboo-based agroforestry practiced in the area is able to enhance the socio-economic conditions of farmers and also ensure ecological sustainability of their farming systems (Nirala *et al.*, 2018).
Bamboo-based agroforestry in wasteland conditions. Bamboo-based agroforestry was found to raise the overall production and productivity of farming systems in wasteland conditions in central India. The experiment involved 2 bamboo species (*Dendrocalamus strictus* and *Bambusa arundinacea*) with 4 kharif crops (moong, soybean, paddy and til). Economic analysis resulted in higher monetary returns of the bamboo-based agroforestry system over the sole cropping systems (Rahangdale *et al.*, 2014).

The possibility of integrating bamboo into food crop production as live stakes can also be considered. Live staking is where living trees or woody perennials are used as support for growing crops such as yam, potatoes and beans. Currently at the Crops Research Institute of the Council for Scientific and Industrial Research in Ghana, a trial where bamboo is being explored as live stakes for yam production is underway.

Comparing bamboo-based systems to tree-based systems, the former has the advantage of fast growth and early maturity. Within 3 to 4 years, bamboo comes into production, reaching maximum productivity in 7 to 8 years (Nath *et al.*, 2009). In comparison to similar agroforestry systems with a tree - *Acacia mangium* and a shrub - *Tephrosia candida*, intercropping with bamboo resulted in reduced run-off and lower erosion (Nguyen, 2004). In Northern Vietnam, bamboo accounted for higher percentage of household income (7-14%) than *Acacia mangium* and *Tephrosia candida* (1-10%) in an agroforestry system (Nguyen, 2004). In Jharkhand, India, bamboo culms from agroforestry systems are good alternatives for depleting and expensive timber resources, and these culms are also available at lower prices (Nirala *et al*., 2018). Although these examples are outside the tropical Africa region, lessons can be learnt and integrated.

Within the tropical African region, a number of Programmes and Projects have been executed or are on-going which address aspects of bamboo-based agroforestry. These include the Inter-Africa Bamboo Smallholder Farmers Livelihood Development Programme (IABSFLDP), the Mainstreaming Pro-Poor Livelihoods and Addressing Environmental Degradation with Bamboo in Eastern and Southern Africa Project (MPLAEDB) and the South-South Knowledge Transfer Strategies for Scaling up Pro-Poor Bamboo Livelihoods, Income Generation and Employment Creation, and Environmental Management in Africa Project (SSKTSSPBL). The IABSFLDP draws on China's bamboo industry history and expertise to help scale up climate-smart, smallholder-based value chains in Cameroon, Ethiopia, Ghana and Madagascar. The MPLAEDB aimed at developing livelihood and income generation options in a way that increased demand for bamboo planting, in turn reducing deforestation, reducing soil erosion, and contributing to environmental sustainability. Also, the SSKTSA aimed at optimization and scaling up of benefits to the participating communities and the environment through specific value-chain driven sustainable management and farming of bamboo for resilient rural livelihoods and robust environmental management in Ethiopia, Madagascar and Tanzania.

Aside the fast growth and early maturity, other qualities qualify bamboo as a good agroforestry component (Table 3). It must however be noted that bamboo can show promising results in agroforestry systems when each plant receives individual care (Nath *et al*., 2009). Like other mixed species planting systems, there is bound to be competition among the components of bamboo-based agroforestry systems. Bamboos may out-compete the agricultural or food crop components because of their higher root densities. To overcome interspecific competition in bamboo-based agroforestry systems, agricultural crops can be planted 8-9 m away from the bamboo clumps (Nath *et al*., 2009). In situations where shorter distances are desired, Nath *et al.* (2009) further recommend that bamboo roots can be spatially isolated from the crops through trenching (30-40 cm wide and 50-60 cm deep) at 5-6 m away from the bamboo clumps. To manage aboveground interactions, pruning of the bamboo canopy may be considered (Rao

Table 3: Some qualities of the bamboo plant that qualify it as a good agroforestry component

Agroforestry strengths of the bamboo plant
Bamboos are the fastest growing plants with a growth rate ranging from 30 to 100 cm each day within a growing season, reaching a maximum height of more than 36cm and a diameter of 1-30 cm. Within 2 to 3 months, the bamboo culm can reach its full height (Nath *et al*., 2009)
Bamboo has the ability to regenerate vegetatively, be harvested repeatedly and be grown on marginal lands unsuitable for forestry or agriculture (Anajuguma and Kigomo, 2008 and Liese and Kohl, 2015)
Bamboo has the ability to restore degraded lands (Anajuguma and Kigomo, 2008) Bamboo is used for a variety of purposes due to its strength, straightness, lightness, hardness, abundance, range of size and short maturation period (Anajuguma and Kigomo, 2008 and Nath *et al*., 2009)
Bamboo can substitute for timber. Bamboo can be used for construction, furniture, handicrafts, clothing, etc. Bamboo can help slow down depleting timber resources and deforestation (Bonsi, 2009 and Vogtländer *et al.,* 2010)
Bamboo is easily adaptable to different soil and climatic conditions (Lobovikov *et al*., 2007) Bamboos can maintain soil health (Nath *et al.,* 2009)
Bamboo has the ability to sequester carbon (Yuen *et al*., 2017 and Seethalakshmi *et al*., 2009) Bamboo can provide alternative livelihood support for farmers during off-farming season. Example, bamboo can be used for charcoal production to raise extra income (Kwaku, 2020) Bamboo can be used for erosion control and slope stabilization (Guillermo *et al*., 2018)

et al. 1998). According to Kittur *et al.* (2016) appropriate spacing for bamboo is important to optimize production of bamboo and associated crops. Thus, a possible tradeoff is required for bamboo-based agroforestry systems to optimize production of intercrops without compromising bamboo yields. Nirala *et al.* (2018) report that yields of intercrops in bamboo-based agroforestry systems are higher in wider spacings as compared to closer spacings. This is because the intercrops are able to utilize resources such as sunlight, soil moisture, space and nutrients better at wider spacings.

Since agricultural systems cannot effectively function on impoverished soils, the focus of all agricultural systems is to improve soil fertility whilst increasing or maintaining crop yields (Benneh, 1972). As Christanty *et al.* (1997) put it, the nutrient pumping action of bamboo, the slow decomposition of the silica-rich bamboo litter and the extremely high biomass of fine bamboo roots improve soil fertility and soil health to make bamboo-based agroforestry systems successful.

Conclusions

Bamboo-based systems approach have been highlighted as agroforestry systems for the improvement of agricultural productivity in tropical Africa. Aside the ability to improve agricultural productivity, bamboo-based systems are promising land management systems that can sustain the integrity of ecosystems. Agricultural systems are dynamic, lessons can be learnt from other regions, adapted and applied to improve productivity. Improving the productivity of tropical Africa agricultural systems can therefore learn from successful bamboo-based systems from elsewhere especially from some Asian countries like China, India, Myanmar, Thailand and Bangladesh where bamboo is abundant and bamboo-based systems have been practiced for several years.

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