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The Potentials of Agroforestry Systems in East Africa: A Case of the Eastern Arc Mountains of Tanzania

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Authors' contributions

This work was carried out in collaboration with both authors. Author MYM designed the study, wrote the first and final draft. Author XH checked the first and final draft. Both authors read and approved the final manuscript.

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ABSTRACT

The optimization of crop yields and environmental services need a proper selection and adoption of sustainable farming systems. Agroforestry is a farming system which involves the integration of trees and crops in the same plot. It is a climate-smart environmental conservation system that aims at increasing crop yields as well as environmental services. The Eastern Arc Mountains (EAM) of Tanzania, which cover Usambara and Uluguru Mountains, have a significant potential for agroforestry. They are characterized by potential biophysical resources such as fluvial, vertisol and xerosols soils with the annual rainfall exceeding 1200mm per year. We reviewed over 40 peer reviewed publications to assess the ecological significance of the agroforestry system in the EAM with clear focus on Usambara and Uluguru Mountains and found that the agroforestry system has

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been in practice on a small scale for a couple of years. The agroforestry has significantly increased crop yields by 50% in few areas where it is practised and has protected the environment by improving soil fertility, enabling the carbon sequestration and protecting water resources. As a result, this study recommends further researches on the same to reveal its potential in improving the conditions of small-scale farmers in East and Sub-Saharan Africa.

Keywords: Agroforestry; climate change; Tanzania; East Africa.

1. INTRODUCTION

There is a great demand for optimal production of food by today's global population [1,2], where the production needs to be not only high, but also stable and sustainable. This type of production is required urgently to feed the millions of undernourished people in sub-Saharan Africa [2,3]. However, this type of food production necessitates good farming systems that can optimally increase yields to curb hunger and famine in the region. In this respect, agroforestry which has a number of economic, social and ecological significance is seemingly to be the solution since it has significantly increased stable yields in various areas where it was adopted [4,5]. Agroforestry not only increases the crop productivity, but also restores the degraded environment and improves the environmental services in the area. Therefore, the people in the area can adopt agroforestry system more to curb the problems related to hunger, poverty and environmental stress [6,7,8,9].

East Africa has some potential ecosystems that can accommodate agroforestry systems to increase the yields and food security [10]. The study area, which includes the Eastern Arc Mountains of East Africa is characterized by biophysical characteristics that favour agroforestry systems [10]. The area has a wide range of plant species and can accommodate the integration of diverse trees [8,9]. A number of large-scale international donors like World Wildlife Fund (WWF) and Alliance for Green Revolution in Africa (AGRA) have also earmarked the area to be significant for agroforestry system. These international donors believe that investing in agriculture (including agroforestry) is the surest path of reducing poverty and hunger in the region.

On the other hand, the people in the area are subject to a number of environmental challenges which simultaneously need immediate and long-term remedies [6,7,8,11,12]. According to Intergovernmental Panel on Climate Change [13], Tanzania, which includes the study area of Eastern Arc Mountains, is among the thirteen countries to be affected the worst by the impacts of climate change [14]. The impacts of climate change have also increased the vulnerability of Eastern Arc Mountains [13]. Basing on that juncture, the country is at risk of failing to feed the increasing population because more than 70% of the population, especially in rural areas, depend on rain fed agriculture and have weak purchasing power to have access to imported food from the market [10].

Therefore, this study aims at reviewing the potentials and economic importance of the agroforestry systems as well as the threats to them in the Eastern Arc Mountains. Since agroforestry is a climate-smart system that sustainably protects the environment and offers socio-economic benefits to farmers, it is considered as a tool that raises the resiliency of the vulnerable communities posed by the impacts of climate change in the study area and across the whole country. Its adoption should be significantly supported [3,10].

2. MATERIALS AND METHODS

2.1 Profile of the Study Site

The study focuses on the Eastern Arc Mountains due to their biophysical characteristics such as soil, vegetation and rainfall. Such characteristics create the conditions that are favorable for agroforestry in comparison to other parts of the country. The Eastern Arc Mountains are comprised of thirteen separate blocks which are located from South-East Kenya to South-Central Tanzania (Fig. 1). They are situated between 3° 20′ to 8°45′S latitude and 35° 37′ to 38° 48′E longitude, covering an area of around 3300 km^2 of sub montane, montane and upper montane forests. The current timberland in the Eastern Arc Mountains is less than 30% or approximately 1440 km^2 of the original timberland. About 70% of the area has been deforested through anthropogenic activities such as charcoal making and extensive agriculture. The mountains exhibit connectivity and isolation among themselves

(specifically the Usambara and Uluguru). Connectivity is where the mountain blocks were formed as sister blocks that were separated by a narrow gap without much difference in forest types. North and South Pare, West and East Usambara, North and South Uluguru and the Udzungwa are the examples of connected mountain blocks of the Eastern Arc Mountains. On the other hand, there are isolated mountain blocks such as Nguu, Nguru, Ukaguru, Rubeho, Mahenge, Malundwe and Uvidunda. Taita Hills in Kenya are the only part of the Eastern Arc Mountains with an estimated remnant forested area of 6 km^2 (see Fig. 1). The mountains are ecologically quite distinct from adjacent highlands, grasslands, savannas and woodlands in East Africa. The Eastern Arc Mountains have been proposed as one of the several *refugia* in Africa during geologic periods when the tropical climate was generally adverse for forest development [15].

2.2 Methodology

More than 40 peer reviewed, scientific articles as well as the reports of government and international organizations were selected for this study. The studies that were conducted either in the area or in similar ecosystems and published in international journals were taken into consideration during the selection. We used data base system to select the publications issued between 2003 and 2015. In other words, the priority was given to authentic journal articles and reports that were published recently while a conceptual framework (Fig. 2) was designed to synchronise the important aspects of the study.

3. THE CONCEPTUAL FRAMEWORK OF AGROFORESTRY SYSTEMS

Agroforestry is a multipurpose agricultural system which produces more yields from different crops. These yields may come from different crops embraced in agro-silvopasture, the integration of tree or shrubs with cattle in the same site) or agri-silviculture (the simultaneous husbandry of forest tree crops and food crops) or other related forms of agroforestry systems [16]. Agroforestry not only provides varieties of food crops, animal feeds and building materials, but also serves for forest management, carbon sequestration and developing the adaptive capacities to the impacts of climate change (Fig. 2).

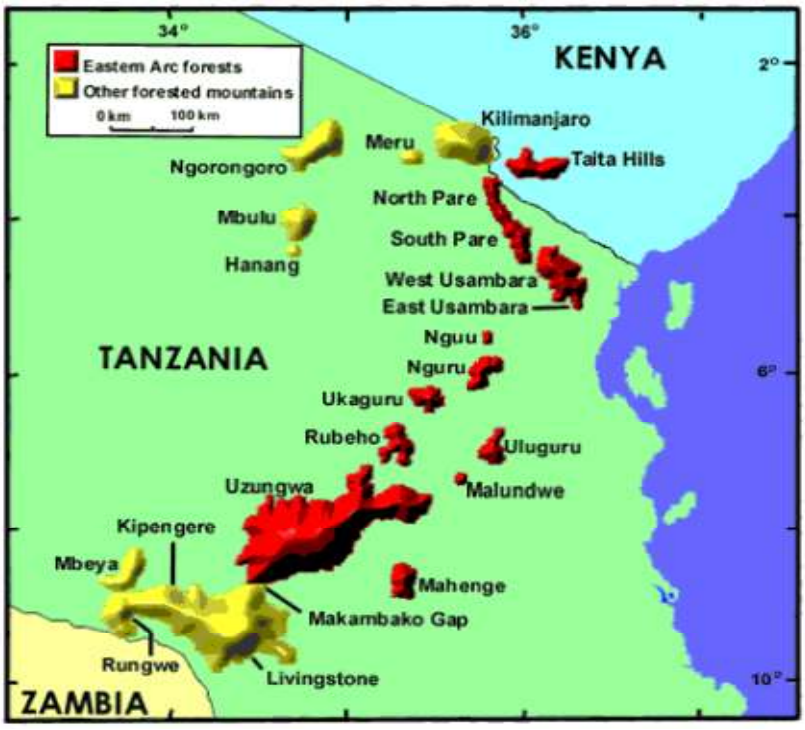

Fig. 1. Twelve Eastern Arc Mountain blocks in Tanzania and one in Kenya
Source: Adopted from Burgess et al. [10]

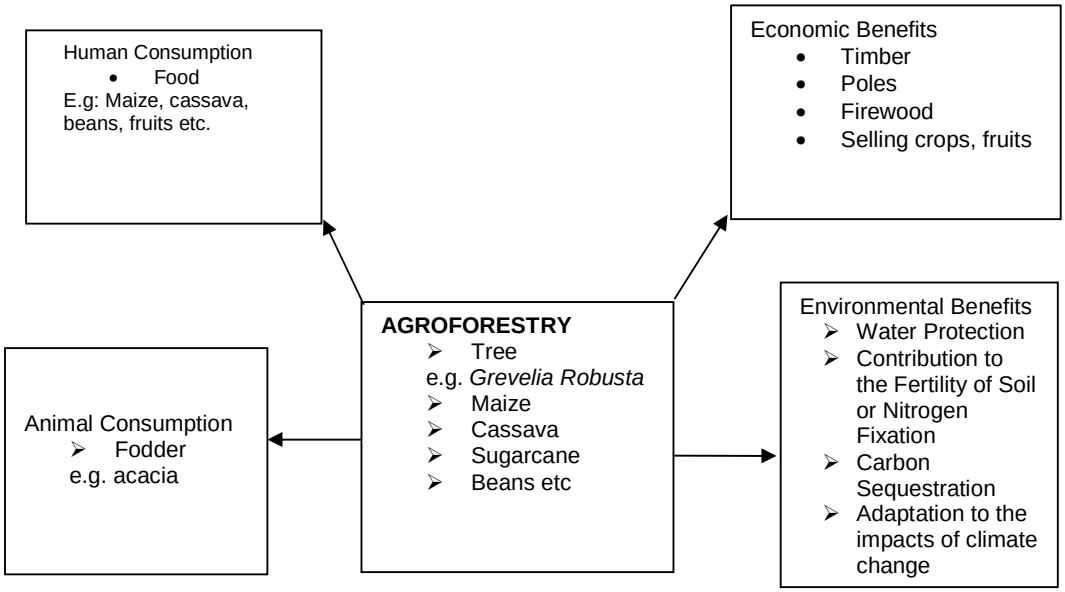

Fig. 2. The conceptual framework of agroforestry
Source: Created by the authors, 2017

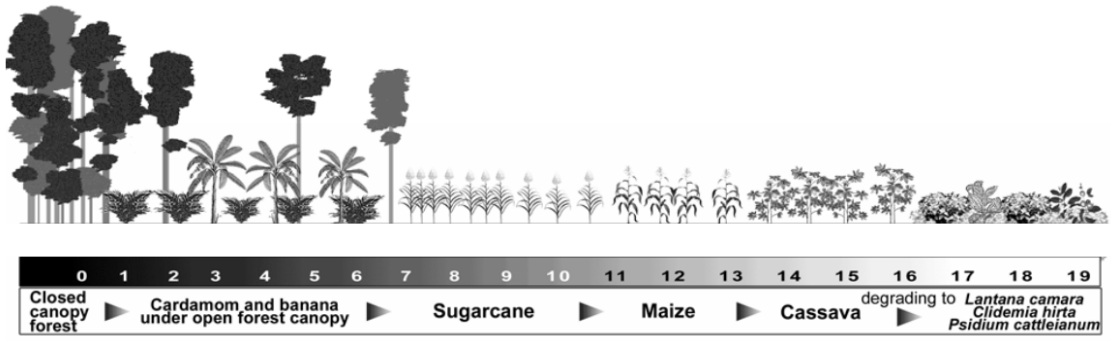

Fig. 3. Agroforestry system
Source: Adopted from Reyes, [15]

Different forms of agroforestry such as agri-silviculture and agro-silvopasture have already been practiced in the study area [16]. The *Chagga* 'home garden' in Kilimanjaro and the *Ngitiri* 'silvopastoral system' in Shinyanga are their examples [4]. With respect to the Eastern Arc Mountains, a number of trees and cereals are grown together. These can be mangoes, oranges, coconuts, maize, cassava, beans and sugarcane (Fig. 2).

4. THE POTENTIALS OF AGRO-FORESTRY SYSTEM IN THE STUDY AREA

The Eastern Arc Mountains are endowed with plenty of biophysical resources, such as diverse tree species, animals, and fertile soil and water sources [17,18]. It is a source of water supply for more than 3.5 million people, the storage of more than 100 million tonnes of carbon, the habitat of more than 800 endemic plant species, 100 endemic vertebrates, 10 endemic mammals, 19 endemic birds, 31 endemic reptiles and 40 endemic amphibians [10].

The mountains have been globally ranked among the top biodiversity 'rich hotspots' in the world [3]. However, this characteristic of the mountains is threatened by not only the anthropogenic activities taking place around, but also the impacts of climate change. This is supported by the studies by Mumbi et al. [4], Reyes [15], Charles et al. [19], Mbwambo et al.

[20] and Milledge et al. [21]. Therefore, there is a need for sustainable use of available resources.

On the other hand, the cultivated tree crops such as mangoes, oranges and guava provide fruits to the people [10]. These fruits (wild and cultivated trees) are a good source of food during a food scarcity, especially when there is a maize shortage. On this basis, agroforestry systems from both the wild and cultivated tree crops can curb hunger and malnutrition in the study area since they provide enough food varieties ranging from vitamins (vegetables) and proteins (beans) to starch (maize) and oil (coconuts). Therefore, agroforestry systems are good sources of food and they can increase the resilience threshold of the vulnerable local communities during hunger. Indigenous fruits are changed into a main food source instead of a snack food especially during a crisis [16].

Moreover, the mountains host many endemic plant and animal species [10,22]. The unique characteristic of isolation and connectivity of the mountains play a crucial role in shaping the current distribution of species diversity in and around the mountain blocks.

5. THE THREATS TO THE ECOSYSTEMS OF THE STUDY AREA

Despite a large number of biophysical resources, the Eastern Arc Mountains are vulnerable to anthropogenic activities taking place in the area such as the conversion of forest lands into farming, deforestation for charcoal, forest fires, shifting cultivation and monoculture [23,24]. Poverty issue is the main driver of this degradation in the study area. More than 12% of all forest resources in the Eastern Arc Mountains have been cleared by small-scale farming, charcoal production, collecting forest resources and extensive grazing [24,25,26]. Since the 1970s. All these practices have been inserting more pressure to the already stressed ecosystems. Massive degradation has been taking place at the higher potential zone of Uluguru, Nguru, Usambara and Udzungwa Mountains [15,27].

This degradation involves the destruction of water resources and soil erosion. Practicing shifting cultivation, collecting fuel woods, building materials and producing charcoal are among the key issues disturbing the ecology of the area [26]. These practices lead to deforestation and extinction of the endangered species. For instance, *Mussaenda microdonta*, *Memecylon cogniauxii, Syzygium micklethwaitii, Coffea mongensis, Allanblackia ulugurensis*, *Lasianthus pedunculatus, Zenkerella capparidacea* and *Polyscias stuhlmannii* are only some of the endangered natural plant species in Nguru Mountain. Similarly, climate change is another significant challenge towards the sustainable use and protection of the available resources [28,29,30].

6. THE ECONOMIC BENEFITS OF AGRO-FORESTRY

This section describes the link between the adoption of agroforestry and the socio-economic benefits of people. Communities that adopt agroforestry systems can improve their livelihoods because agroforestry makes a significant contribution to the socio-economic development. It provides income by means of selling different agroforestry products, such as timber, fruits and crop yields. Agroforestry also enables women in the study area to form social groups and/or to be employed in small enterprises dealing with agroforestry products. In this regard, women may earn some income from the production, processing and marketing of fruits.

On the other hand, farmers have been doing well in agroforestry in Kilimanjaro Region. They are well engaged in *chagga home garden (a type of agroforestry in the area)* which mainly involves coffee, bananas, beans and maize. Since the yields from home gardens appeared to have significantly increased, it had given a maximum economic return to the farmers [19,31,32]. The people in this area have been earning more income than before and their living standards, such as building houses and affording school fees of their children have been improved. In other words, agroforestry systems have improved people's livelihoods in Tanzania [8,10,15,27,31].

Moreover, agroforestry system also contributes to the increase in crop yields because the system provides favorable conditions for crop growth [33]. Since both the fertility and the moisture of soil are among the basic requirements for crop production in the tropic biome, the assurance of these aspects can guarantee the increase in crop yields. As expressed in Table 1, a number of trees used in agroforestry is good at fixing nitrogen which is necessary to grow crops, whereas other trees like *Gravelled robusta* are

good at providing organic matter to improve the fertility of soil [6,7,8,24,26]. While the overall production of maize was 466 kg per acre before the adoption, it was elevated to 783 kg per acre afterwards [4,34]. Along with these economic benefits, agroforestry has also ensured the food security to the majority households especially from crops like banana, beans, cassava and maize. The regions like Tanga, Morogoro, Kilimanjaro and Coast are among the regions that have fairly benefited from agroforestry systems [15].

7. THE ENVIRONMENTAL BENEFITS OF AGROFORESTRY

When nature is protected sustainably, it always remains at its state [17,31]. However, many anthropogenic activities are destructive to the natural environment. In this regard, agroforestry systems facilitate the protection of soil fertility particularly in hedgerows. For example, *Grevellia robusta, Tamarindus indica* and *Balanites aegyptica* are successful in forming organic matter [35,36]. Moreover, some trees are environment-friendly to water sources, hence, they conserve it. Therefore, such trees increase the sustainability of water sources [26]. Likewise, *Artocarpus heterophyllus, Persea americana and Mangifera indica* are very good at controlling soil erosion and protecting it from degradation (Table 1). Furthermore, shading, forming windbreaks and providing construction materials for houses are among other significant environmental benefits of the agroforestry system that cannot be quantified.

7.1 The Fertility of Soil or Nitrogen Fixation

The Eastern Arc Mountains are dominated by hundreds of plant species and nitrogen is the most important source of nutrient for the plants. As shown in Table 1, plants like *Markamia obtusifolia, Acacia species* and *Albizia schemperana* are very useful in fixing nitrogen.

With respect to the fact that a tree leaf biomass of 400kg.ha^{-1}.yr^{-1} of dead matter has a potential of returning 80-120 kg.ha^{-1}.yr^{-1} nitrogen, 8-12 kg.ha^{-1}.yr^{-1} phosphorus and 40-120 kg.ha^{-1}.yr^{-1} calcium to soil by means of litter fall, this flow of nutrients enriches the soil [10]. Even though nitrogen is the main nutrient responsible from plant growth, its amount in the soil is insufficient especially in Tanzania and its use as a fertilizer is also limited in comparison to other developing countries. For example, a Tanzanian farmer uses an average of 9 kg of nitrogen fertilizer.ha^{-1} while Malawian and Vietnamese farmers use 27 kg.ha^{-1} and 365 kg.ha^{-1} respectively [29]. For this purpose, the World Agroforestry Centre recommends the use of four options which are possible in agroforestry. These are: i) Sequential fallow rotation of nitrogen fixing trees with cereal crops, ii) Fertilizer/cereal intercropping managed as cropped fallow, iii) Annual relay fallow intercropping of shrubs with cereals, and iv) Biomass transfer by using *Gliricidia* or *Tithonia* leaves.

Therefore, agroforestry can be adopted by small scale farmers because it provides organic materials (plant leaves) which are useful for litter decomposition and facilitates the formation of organic matter (soil nutrients) for crop growth [20, 31,34,37]. The National Agroforestry Strategy is an approach established by the Government of Tanzania in 2004 aimed at increasing the number of rural households to adopt agroforestry systems and benefit from them from about two to four millions of people by 2025 [30]. This approach also pre-determines that agroforestry technologies will be adopted by the majority of small scale farmers in Tanzania to improve the livelihoods of about 60% of the country's resource-poor households which are mainly located in the study area and nearby regions by the year 2020.

7.2 Carbon Sequestration

Carbon sequestration entails the sinking of carbon dioxide by the plants [10,19,36,38]. The industrialized countries which are big polluters, provide funds to developing countries for afforestation aiming at increasing carbon sinks. This is done to adhere the 1997 Kyoto protocol. In developing countries, there are big projects that work on this aspect such as reducing emissions from deforestation and forest degradation (REDD). REDD is a mechanism that has been under negotiation by the United Nations Framework Convention on Climate Change (UNFCCC) to mitigate the impacts of climate change at the global level. A great concern about the increasing levels of Green House Gases (GHGs) in the atmosphere has awakened the majority of stakeholders to think about the whole issue and its remedies. Due to the fact that about 50% of the forest biomass is carbon, forest degradation and afforestation have different impacts [19,38,39]. While deforestation will lead to an increase in emission levels and

concentration of carbon dioxide in the atmosphere, afforestation will increase the level of atmospheric carbon sequestration (carbon filter).

A number of REDD projects related to the climate change has been in practice in most of the developing countries like Tanzania as a solution brought by the Kyoto Protocol in 1997. The projects intend to reduce the carbon emission and emphasize the use of clean development mechanism (CDM) as a carbon elimination mechanism.

On the other hand, indigenous people should be asked for the consent of a project funded under CDM. Otherwise, lack of consent may bring unbearable opposition from the natives [41]. The construction of a hydroelectric plant in Panama, a waste incinerator in India and a palm oil plantation in Indonesia were all the examples of projects that were opposed by indigenous people. Therefore, the implementation of various projects needs to have some consent from indigenous people even in Tanzania (for sustainability). Tanzania, the CDM projects give directives on the prices and procedures about how the people can be compensated for their planted trees.

Afforestation, reforestation and forest restoration are good practices because they increase the earthly capacity to sequester atmospheric carbon as well as reducing terrestrial carbon emission [12,36,37]. The reduction of terrestrial carbon creates favourable conditions for agricultural systems to improve crop yields. In this connection, the forests in the Eastern Arc Mountains have a significant contribution to carbon sequestration since they act as a filter to atmospheric carbon (CO_2). Similarly, agroforestry also offsets other dangerous greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) to mitigate climate change impacts.

8. THE CONSTRAINTS REGARDING AGROFORESTRY SYSTEMS

There is a wide range of constraints facing agroforestry systems in Tanzania. These range from social and economic to political and technological challenges. It is worthwhile to examine the constraints related to the small-scale farmers than those that are caused by the government policy and large-scale investments. Numerous small-scale farmers have the mind-set that agroforestry systems are new farming approaches that do not comply with their lives. These small-scale farmers believe that monoculture and other single cropping systems fit the bill and they expect to have more yields from single cropping than multiple cropping [6-8]. Only few of small-scale farmers are aware of the

Table 1. The potentials of available plant species in the Eastern Arc Mountain

Species name	Uses/Functions
Acacia species	Firewood, Fodder, Nitrogen fixation, shade
Albizia schemperana	Timber, firewood, nitrogen fixation, fodder,rain indicator
Anona muricata	Fruits, shade, live fence
Artocarpus heterophyllus	Fruits, shade, control soil erosion
Balanites aegyptica	Timber, firewood, organic matter
Commiphora eminii	Firewood, fodder, shade, organic matter
Cordia africana	Timber, shade, firewood, soil improvement, fodder
Cordia sinensis	Firewood, organic matter, shade
Croton macrostachyus	Firewood, Fodder, Nitrogen fixation, shade
Eucalyptus saligna	Poles, firewood, wind break, erosion control
Faidherbia albida	Firewood, nitrogen fixation, fodder, shade
Ficus species	Firewood, shade, windbreak, soil erosion control
Grevellia robusta	Timber, shade, firewood, adding organic matter
Kigeria africana	Fruits, shade, Nitrogen fixation
Mangifera indica	Fruit, erosion control, windbreak, firewood
Markamia obtusifolia	Firewood, Fodder, Nitrogen fixation, shade
Persea americana	Fruits, Firewood, shade, soil improvement
Salvadora persca	Firewood, Fodder, Nitrogen fixation, shade
Syzigium cordatum	Timber, fruits, firewood, organic matter, shade
Tamarindus indica	Timber, Fruits, firewood, organic matter

Source: Modified from Charles et al. [4]

benefits of agroforestry and have adopted it, while most of them are *laggards* to adopt it and they are not ready to change their mindset of monocropping [19,23,40]. Furthermore, agroforestry system needs experienced farmers to undertake it. It also needs time and effort regarding the care for seedlings and pruning. This is because the systems require different types of trees and food crops to be integrated, the selection of the best trees and crop varieties has financial implications [6-8]. Similarly, labour and some chemical inputs can also be grouped among the economic constraints.

Besides, the poor quality of soil in most areas does not enable farmers to significantly adopt agroforestry. In most cases, the government doesn't propose agroforestry intensively, but rather leaves the farmers to proceed with their usual farming practices. Thus, it is high time for the government to make positive intervention towards this particular farming system.

9. CONCLUSIONS

This study aims to explore the potentials of agroforestry system in the Eastern Arc Mountains of Tanzania by highlighting its ecological and socio-economic importance. In areas where agroforestry has been practiced, has improved the socio-economic development of the people by increasing crop yields and developing strong adaptation measures to the impacts of climate change. Therefore, the Eastern Arc Mountains can be put in the group of high potential zones (rich areas) for agroforestry system in Tanzania. Meanwhile, other areas with forest resources in Tanzania like Tabora, Shinyanga and some parts of Mbeya regions should also adopt this farming system since they have similar biophysical characteristics with the study area. Since agroforestry systems encourage multiple cropping rather than single cropping, farmers receive more yields and they can earn a livelihood. Therefore, Agriculture and its allied ministries should endorse agroforestry in their policies, plans and programmes to support its adoption and implementation as it serves both socio-economic and ecological functions.

The organizations, such as World Wildlife Fund (WWF) and Alliance for Green Revolution in Africa (AGRA) have been giving funds for agricultural production, climate change and sustainability of the environment. It is essential that these large-scale international organizations to significantly support the agroforestry system in the country. Thus, it is seemingly that, the Tanzanian government and private sector as well as the large-scale international organizations are needed to support agroforestry for socio-economic and ecological benefits. The research priorities can involve the identification and quantification of all stakeholders involved in EAM and their over-all welfares.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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