Vol 4 | Issue 2 | Pages 368-375

Advances in Environmental Studies
ISSN: 2642-4231

Review Article

DOI: 10.36959/742/233

Agroforestry Systems: A Boon for Developing Country

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Abstract

An intensive practice of agroecosystem affects overall health and productivity of land. Agricultural land expansions lead to deforestation that not only makes blurred relation between these two land use practices but also affects overall productivity and health of ecosystem. In this context, agroforestry emerge new trend of farming system that involves both components into same piece of land simultaneously that are ecologically viable, socially acceptable and economically profitable. Nowadays, agroforestry systems are prevalent in most part of developing countries where it becomes a boon for farmers by producing various diversified timber and non-timber products that strengthen the farmer's socioeconomic status and improve livelihood security. The diversified components of agroforestry system intensify ecosystem services in both tangible and intangible ways. Resource conservation, soil health management, climate change mitigations, maintaining carbon footprints and farmers socioeconomic upliftments etc are key services delivered through sustainbale practices of agroforestry systems in various agro-ecological zones of the developing countries of the tropical world. Moreover, agroforestry system maintains carbon footprints due to its better carbon sequestration potential that makes carbon balance in the atmosphere and regulates carbon flow and flux in the ecosystem. Thus, practicing climate resilient agroforestry system in the developing countries controls GHGs emission and mitigates climate change problems. Carbon sequestration adds vegetational biomass and ensures soil carbon pools in the agroforestry system. Similarly, agroforestry and other horticulture based land use system provide various healthy and quality food and fruits that not only source of income but also maintain health status of the farmer's. Reclamation of degraded land, desertification and saline/alkaline soil are another potential of agroforestry systems in developing countries that not only make sustainable land practices but also intensify high yield and productivity to make food (grains, fruits, vegetables, spices, etc.) availability for burgeoning populations in developing countries. In view of the above, in-depth discussions were made in this paper that covers overall agroforestry scope and potential in food-soil-climate and farmer's livelihood security in developing countries.

Keywords

Agroforestry, Carbon sequestration, Climate change, Ecosystem services, Livelihoods, Environmental sustainability, Nutrient cycling

Introduction

Agroforestry is well known farming practices among farmers, researchers, scientists, policy makers, and other farming practitioner which is gaining wide importance in term of higher biodiversity (due to combination of tree, crop and livestock/pastures) that intensify ecosystem services (both tangible and intangible services) and maintains food-soil-climate security for ecological stability and environment sustainability [1-4]. However, this system are practicing from a time immemorial since farming system was clearly adopted in the tropics but now it covers various regions of developed and developing countries of the world. Peoples and poor farmers are very concern about this system due to its multifarious and uncountable benefits that helps in solving their issues related to social, economic, cultural dimensions along with protecting environment through better potential of carbon sequestration. Agroforestry is location specific and comprises various models that can be adopted in varying agro ecological zones due to changing biophysical measures, topography, availability of resources, soil types, species natures, tree-crop-livestock's interactions, water availability, irrigation facility and prevailing climatic situations [1]. However, successional changes and development are also observed in the every stages of agroforestry practice due to course of time [5].

Land use intensification including agricultural intensive practices destroys land quality, soil fertility which affects

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Accepted: December 29, 2020

Published online: December 31, 2020

Citation: Raj A, Jhariya MK, Khan N (2020) Agroforestry Systems: A Boon for Developing Country. Adv Environ Stud 4(2):368-375

overall food production and health of the ecosystem. High synthetic inputs and heavy mechanizations affect overall crop productivity and soil fertility. In this context, applying sustainbale and ecological oriented intensification in agroforestry systems will enhance biodiversity that intensify ecosystem services for better environment and ecosystem health. Thus, sustainbale agroforestry practices ensure various ecosystem services including higher system productions, better soil health, climate change mitigation through carbon sequestration and related biomass productions in varying agro ecological zone of developing countries in the world. Woody components in agroforestry system are a good sink of carbon that absorb atmospheric carbon through sequestration and fix into plant as biomass and soil as soil organic carbon (SOC) pools. It will help in making carbon balance in the atmosphere and maintains carbon flow and flux in the agroforestry ecosystem. As per one estimate, approximately 0.3-15.2 Mega carbon ha^{-1} yr^{-1} were reported under agroforestry systems that distributed throughout the world and this figure was observed in high rainfall areas having the humid climatic conditions [6]. Thus climate resilient agroforestry management play key role in GHGs emission control and ensure higher biomass, productivity, soil fertility and climate change mitigation.

However, an intensified agroecosystem practice affects overall health and productivity of environment by deleting various natural resources. Loss of forest due to agricultural land expansion and intensive agroecosystem practices are major problems in the globe. These practices cause loss of top fertile soil in every year along with other resources depletions. This is key problems in the most part of developing countries. In this context, eco-designing in agroforestry works better i.e. applying sustainbale based agroforestry practices would be viable strategy that not only protect natural resources but also maintains soil-food-climate security in the world for long time. Further, soil enrichments by improving fertility and enhancing SOC pools that helps in promoting microbial populations, rhizosphere biology and nutrient use efficiency for enhancing yield and productivity to maintains soil-food-climate security for achieving the goal of sustainability. This can also helpful in enhancing socioeconomic status of poor farmers which is majority found in the most parts of developing countries.

Thus, in nutshell we can say, agroforestry is treated as carbon farming system that can solve the issue of carbon balance in the atmosphere, mitigate changing climate and global warming by reducing GHGs emissions, plays a key role in soil-food-climate security through better ecosystem services, enhance biodiversity which helps in providing multifarious tangible products as timber, fuelwood, NTFPs (e.g. gum) and maintains ecological stability. Proper resource utilizations and its conservations are also very important aspects in agroforestry that must be emphasized while studying the different models in varying climatic zones in developing countries.

In view of the above, this paper emphasized the scope, potential and importance of agroforestry system in developing countries along with its contributions in resource conservations, soil-food-climate management and generating farmer's livelihood through socioeconomic status of poor's peoples for achieving the goal of sustainable development and overall environment and ecological stability.

Scope and Potential

A large hectare land of farms and farm boundary along with degraded and unutilized lands are available in the developing countries which can extensively utilize for the agroforestry practices. Different models of agroforestry systems can be adopted in these unused and other farms land that make sustainable utilization of land along with reclamations of degraded land and provides various important ecosystem services along with improving soil fertility and delivery of uncountable benefits to peoples. For example, the practices of silvipasture model could have a greater potential to ameliorate the degraded and wasteland by improving soil fertility and quality along with providing some valuable and palatable pastures/fodder for integrating livestock's that maintains overall ecosystem structure and ecological integrity. Beside it, Agrosilvopastoral models having greater scope and potential in rejuvenating the degraded land along with provision of timbers, fuelwood, firewood's, NTFPs and other arable crops in lean seasons that helps in building economics of the poor farmers along with marinating food-nutrition-climate security for a long time. In developing countries, burgeoning population have exerted many other problems i.e. unavailability of quantity and quality foods and related other resources which have a greater impacts on people's health and their livelihood [7,8]. In this context, agroforestry is a boon for developing countries by solving these all problems and having potential to provide quality food and nutritive fruits that maintains both health and income of the poor farmers in the developing countries. Climate change mitigations are another important potential of agroforestry systems that can't be ignored and underestimated [9]. In addition, it helps in adding biomass and carbon into both vegetation and soils that would be highly supportive for maximizing soil fertility and crop productivity. Thus, agroforestry has uncountable potentials that need to explore and require synthesized studies for further better understanding of the models under prevailing varying climatic zones of developing regions [10].

Agroforestry for Natural Resource Conservations

Agroforestry system could efficiently utilize other natural resources which are quietly linked with success and development of different models that are practices in varying climatic zones in developing countries. The management and conservation of natural resources (tree, crops, animals, soil, water and essential nutrients, etc.) are prerequisite for the success of any agroforestry systems. The intimate combinations of these resources exert a shape and characteristics of varying agroforestry models such agrisilviculture, silvipastoral and Agrosilvopastoral systems. Also, a good management practices for agroforestry systems are also promotes resource conservation and its efficient utilizations. Integration of nitrogen fixing leguminous MPTs would be more viable for agroforestry & horticulture based land use system in which legume has potential to fix nitrogen into the soils that promotes other nutrients and microbial populations which make

healthy rhizosphere biology and SOC pools along with higher nutrient use efficiency. Agroforestry system having close and efficient nutrient cycling in which the chances and loss of nutrient through leaching can be reduced and make the availability of nutrient to the plant through higher and extensive root systems of perennial tree species and in turn tree and crops produce good quality of nutritious food and fruits that maintains food-income-health security along with overall sustainable development [11]. Further, tree-crop combinations, types and nature along with efficient management practices can reduce the competition among different components for light, space, water and soil nutrients in agroforestry system and supports biodiversity and sustaining the life of poor farmers in developing countries. Among all these resources water is prerequisite for overall success of agroforestry systems. Every processes and mechanism in agroforestry practices such as soil solutions, nutrient movement, biogeochemical cycle etc are practically depends on water system. In this context one question has arises (a) "Is the water deserve a prime position among all resources in agroforestry systems and how it helps in maintaining agroforestry system?", (b) "Is better management of agroforestry system can enhance the water availability and its conservation?", (c) How agroforestry helps in resource conservation and management? Therefore, these questions need an extensive researches and studies that can explore the more ideas in depth. Thus, suitable species combinations and their management practices can enhance the water availability and their absorptive capacity with minimizing the competitions among the plants (tree, crops and grasses/pastures) [12]. Therefore, an appropriate combination of agroforestry elements can also solve the problems of resource depletion and enhance the resource use efficiency, its conservation, without affecting overall yield and productivity [13]. On this principles a large degraded and wasteland areas in developing countries lands are reclaim and utilized efficiently without disturbing ecosystem and biodiversity.

Agroforestry for Soil Management

Soil, as we know important natural resources which play an important role in managing other natural resources by enhancing biodiversity along with provision of ecosystem services. Soil stores a variety of micro-organism that helps in decaying and decomposition of leaf litter and other residues which in turn release essential nutrients that capture by tree-crops root systems and enhance yield and productivity [14]. A better management of soil can intensify the microbial populations and rhizosphere biology that promotes the soil health and quality. Soil carbon sequestration is another aspect of promoting SOC pools and other nutrients for maintenance of agroforestry system. In contrast to open type of nutrient cycling in sole cropping systems, agroforestry promotes close type of nutrient cycling that helps in conserving nutrients and make them available for plants for their proper growth and development [15]. In this context, a better soil management practices are very important for maintaining soil-food-climate security in developing countries where soil related problems are prominent such as desertification's, soil salinity, alkalinity and degraded land are extensively distributed which can be manage through a better practices of agroforestry systems that makes fertile land and maintain ecological sustainability. Climate smart farming practices such as agroforestry, conservation agriculture, multiple cropping practices, non-tillage practices, cover cropping system, and organic farming practices are important management aspects for healthy and quality soil that must be followed for better soil ecosystem which is linked with food and climate security [16].

Agroforestry for Farmers Livelihood

In developing countries, mostly poor, marginal and monsoon dependable farmers are prevalent and they sustain their life by selling some edible (food, fruits, milk, meat etc) and non-edible products. In this context, agroforestry play a key role in producing multiple products due to more in plant-animals diversification and provides important ecosystem services in both tangible (such as timber, fuelwood, fruits and NTFPs, etc.) and intangible ways i.e. food-soil-climate security. Farmers get multiple products from agroforestry systems (example home-gardens etc) which are important source of income that helps in maintaining socio-economic status and improve livelihood of poor farmers. Therefore, agroforestry system is promising and guaranteed income for farmers which can further enhance by addition of some MPTs (multipurpose tree species) that must be in leguminous in characteristics [17]. Incorporation of horticulture trees, vegetables, spices etc in agroforestry systems could potential source of quality fruits that maintain both health and incomes of poor people's [18].

Similarly, beside ecological stability the bund based agroforestry has potential to enhance socioeconomic status of the farmers [19] whereas addition of leguminous tree species either on boundary or as a scattered in the natural plantation would be ecologically sound and economically viable that helps in improving farmers livelihood in developing countries [20]. In this context, Acacia based natural plantation has a potential to revive the soil fertility by leguminous in nature and also provides important gum for farmer's livelihood basically in India and Africa [21]. Likewise, the practices of lac cultivation under agroforestry system become a boon for farmers in developing and poor countries. For example, farmers in the central India are engaged in lac cultivation in agroforestry system and earned around 700-800 INR by producing 1.5-2.5 kg of lac from one single host tree species *Butea monosperma* (Palas) [22]. Like this, there are many examples in developing countries where farmers have adopted some innovative and scientific practices which help in strengthening the income and livelihood security that build the sustainable development. Apiculture based agroforestry system is another good example of developing countries that extensively practices by farmers for gaining income security beside maintaining diversity and health of honey bees which is a good source of honey and performs as a natural pollinator. As we know, the degraded and wasteland are extensively distributed in India and other developing countries where practices of farming systems are narrowed. However, in that land areas farmers do some innovative farming practices as an agroforestry systems (basically silvopastoral system) and make unproductive land to productive and profitable land. If we have look on

case studies of farmer success then we can see Aonla based agroforestry system are prevalent and distributed in marginal degraded land in rainfed condition where B:C ratio was 3.28 for 13 years of plantation that is enough for better livelihood of farmers. Similarly poplar (*Populus deltoides*) based bund agroforestry system is more profitable and having excellent economic return for poor farmers in Gangetic plains of Indian subcontinent than other sole cropping land use system [23]. Horticulture based farming systems also add more economical profits to farmers by producing diversified, healthy and nutritious fruits, food, vegetables, spices etc, that why we call biodiversity of developing countries like India is rich and can open a door for farmers to gain maximum economical benefits along with environmental development.

Agroforestry for Climate Change Mitigation & Carbon Footprint

Changing climate and global warming phenomenon are becoming usual talk among policy makers, stakeholders, academicians, scientists and farmers at national and international platforms. As per the report of UN EPA [24], different sectors such as agriculture, transportation, industry, electricity and commercial & residential activities contributed 26, 19, 17, 14 and 13 percent respectively that having harmful impacts on our environment causes global warming leads to climate change that disturbs our ecosystem structure and functions (Figure 1). These emissions affect our agriculture, agroforestry system, and horticulture production along with forestry health and productivity. In this context, agroforestry is a good strategy to cope out this climatic problem by efficient potential in removing atmospheric carbons and fix it into various components of tree-crop systems through better carbon sequestration potentials in addition to biomass addition and make carbon balance in the environment that's why we call agroforestry as a carbon farming system. However, tree-crop-animals associations, their types, nature and areas of different models practices are also determine the sequestration potentials of agroforestry systems in the most parts of developing countries in the tropical world. Thus, the nature of complexity and diversifying components in agroforestry system can help in enhancing sequestration potential which is directly and indirectly linked with higher SOC pools, higher biomass productions, diversifying yield and productivity, soil enrichments, and overall food-nutrition-health and climate security. Various woody perennial horticultural trees used in agroforestry and they are having goof sink of carbon that regulate atmospheric carbon balance and maintain carbon footprints. These are multipurpose and leguminous in nature that is integral components of agroforestry system. Shinde, et al. [25] have reported 115.4, 126.3, 78.8 and 54.3 Kg of carbon sink tree^{-1} in mango (*Mangifera indica*), Coconut (*Cocos nucifera*), Jamun (*Syzygium cumini*) and Guava (*Psidium guajava*), respectively. Similarly, approx 285.0 metric tonnes of carbon are absorbed by mango (*Mangifera indica*) based tree orchards of Indian subcontinent [26]. Thus, these carbons sink values in different tree species in agroforestry system not only helps in climate change mitigations but also maintains carbon footprint and environmental sustainability in the developing countries. A table has been synthesized which describe a comparative study on carbon sink value of different agroforestry systems in developed and developing countries of the world (Table 1) [27-48].

Agroforestry for Food Security

Food and nutritional security are other very important services of agroforestry system. Apart from the global populations, developing countries like India and China having continuously, unstoppable and remarkable populations that affects the food and nutrition system. Burgeoning populations makes unavailability of quality food, fruits and fodder (for livestock's) that make a very tense situations among farmer's and poor peoples. In this context, agroforestry system

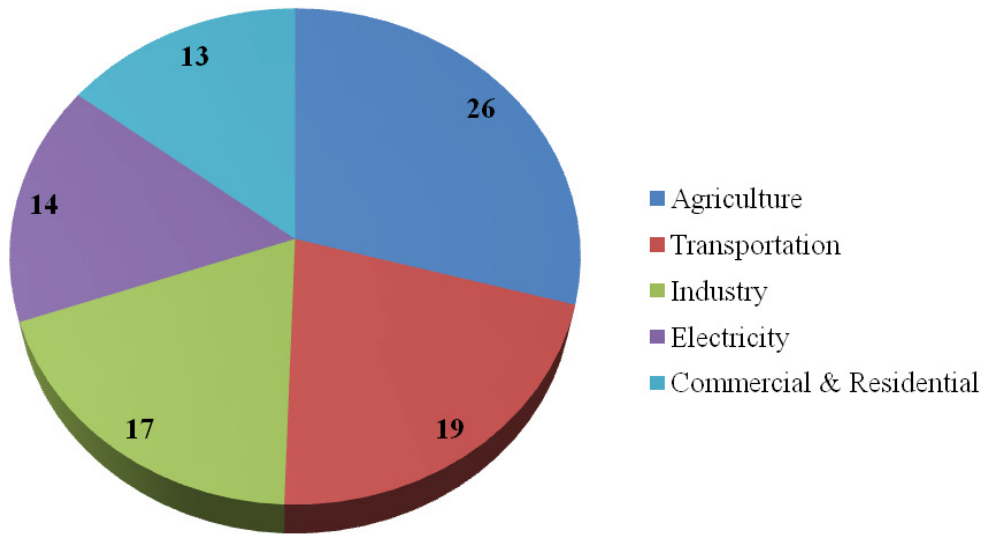

Figure 1: Emission percentage of GHGs from different sectors by US EPA [24].

Table 1: Comparative studies on carbon sink value of different agroforestry systems in developed and developing countries of the world.

Agroforestry models in developing countries	Soil carbon sink value (US ton/ha)	Reported authors
Central Indian sub-continent comprised *Gmelina* tree based Agri-silviculture models	30.20	Swamy and Puri [27]
Homegarden based agroforestry system in the Panama city, U.S.A.	49.60 to2.50	Kirby and Potvin [28]
Homegarden based agroforestry system in the African continent	220.5	Nair [29]
Silvopastoral model in African continent	1.65-3.85	
Poplar (*Populus deltoides*) and Soybean + maize + wheat based hedgerow intercropping system in Canada	1.38	Oelbermann, et al. [30]
Silvopastoral model having combination of *Pinus elliottii* and *Paspalum notatum* (common grass species) in the region of U.S.A.	7.60 to 26.7	Haile, et al. [31]
Mixed tree stands of *Eucalyptus* + *Casuarina equisetifolia* in the region of Puerto Rico situated in U.S.A.	68.23	Parrotta [32]
Mixed tree stands of *Leucaena leucocephala* (Subabul) + *Casuarina equisetifolia* in the region of Puerto Rico situated in U.S.A.	62.39	
Mixed tree stands of *Leucaena leucocephala* (Subabul) + *Eucalyptus* in the region of Puerto Rico situated in U.S.A.	68.01	
Cork oak (*Quercus suber*) based Silvopastoral model in the region of Spain	29.21 to 55.3	Howlett [33]
Betula pendula based Silvopastoral model in the region of Spain	146.6 to 165.3	Howlett, et al. [34]
Eucalyptus + *Brachiaria* (grass species) based Silvopastoral model in Brazil	389.1	Tonucci, et al. [35]
Varying Silvopastoral models in the region of U.S.A	564.4	Haile, et al. [36]
Populus deltoids (Poplar tree) based Alley-cropping system distributed in the Canada	62.83	Bambrick, et al. [37]
Populus deltoids based Agri-silviculture model in the region of Punjab, India	10.4	Chauhan, et al.[38]
Leucaena leucocephala (Subabul) based Agri-silviculture model in the region of Andhra Pradseh, India	3.05	Rao, et al. [39]
Acacia nilotica (babul) based Silvopastoral model in the region of Haryana of Indian sub-continent.	3.09	Kaur, et al. [40]
Homegardens of Kerala in India	1.76	Saha, et al.[41]
Casuarina equisetifolia based Agri-silviculture model in Tamilnadu of Indian subcontinent	1.73	Viswanath, et al. [42]
Brachiaria brizantha + *Guazuma ulmifolia* + *Cordia alliodora* based Silvopastoral model in the region of Costa Rica	145.5	Amezquita, et al. [43]
Acacia mangium + *Arachis pintoi* (fodder species) based Silvopastoral model in Costa Rica	190.7	
Populus deltoids (poplar tree) + *Hordeum vulgare* (barley) based Agri-silviculture model in the region of Canada	86.5	Peichl, et al. [44]
Douglas fir (*Pseudotsuga menziesii*) + *Trifolium subterraneum* based Agri-silviculture model in the region of USA	105.8	Sharrow and Ismail [45]
Leucaena leucocephala (N_2 fixing leguminous tree) based Alley-cropping system in the African continent	14.9	Lal [46]
The practices of fodder/protein bank system comprising the combination of *Pterocarpus marsupium* + *Gliricidia sepium* species in the region Mali	36.81	Takimoto, et al. [47]
Gliricidia trees + *Zea mays* based Agri-silviculture model in Malawi	135.6	Makumba, et al. [48]

becomes a boon for farmers and poor peoples in developing countries. Agroforestry is a potential source of food and nutrition's by providing multifarious and uncountable edible products that not only maintain the health status of farmers but also make sustainable environment and ecological stability. Horticulture based land use systems could potentially provide various important fruits (*Emblica officinalis, Carica papaya*, *Mangifera indica*, *Citrus* species, etc), vegetables, spices and other important medicinal and aromatic plants are a good source of essential nutrition (protein, vitamins and minerals etc) that can fulfill minimum balance diet requirements per capita per day as 220 and 85 gram for vegetable and fruit crops which make farmers health and maintain income security [49]. Thus, both agroforestry and horticulture

based land use systems have greatest potential in quality and ample food productions along with guaranteed socioeconomic upliftments and employment generations [50].

Farmer's Attitude towards Agroforestry System and Constraints

In-depth discussion were made on agroforestry potentials in resource conservation and soil-climate-food security due to significant role and potential of these sustainable land use based farming systems but there are various constraints behind success of agroforestry systems in various tropical zones of developing countries. Anthropogenic factors, climate change, intensive agriculture practices, lack of farmer's awareness, etc are the major constraints which made narrowing down the agroforestry practices in the developing countries. As we know, developing countries like India having monsoon depended farmers which is uncertain about farming practices and they have a hope for better and favourable environment for extensive agroforestry practices for quality and quantity productions that maintains health and wealth of poor's. The unawareness of farmers about potential and significant performance of agroforestry systems are another constraint that can be solve by visualizing the better agroforestry models performance and its contribution in their overall livelihood development and income security through better management and practices of agroforestry systems in varying agro-climatic zones of the tropical countries [7,51].

Research Development and Policy

A proper research and development are needed to explore tree-crop interactions and their associations which make a better understanding of the varying agroforestry models in different climatic zones in developing countries. A research is needed to explore the agroforestry performance in rejuvenating and reclaiming the degraded and wasteland such as saline, alkaline and desertified land in most parts of developing countries that leads to unhealthy and unproductive land which can be reclaim by better management practices of agroforestry systems. A good governance and policy can be reviving the agroforestry practices in developing countries. Policy must be reform and revised as per biophysical attributes, topography, tree-crops interactions, species associations, soil types, climatic conditions and extent of land degradation that can be helpful for better performance of agroforestry systems and its ecosystems services. A policy for attracting farmers in agroforestry are needed that helps in building farmers positive attitude and their views regarding significant scope and potential of agroforestry system in developing countries.

Conclusion

The practices of agroforestry system is more prevalent in developing countries due to farmers dependency for higher income, better livelihood, food availability and other tangible benefits as timber, fuelwood, fodder and NTFPs etc. Agroforestry system become a hero among farmers, policymakers, stakeholders, scientist and academicians due to its uncountable benefits and ecosystem services either in tangible products and intangible benefits such as maintaining ecosystem structure, ecological integrity, resource conservations, farmers socioeconomic development through diversified products, soil enrichment, provision of closed and efficient nutrient cycling, maintain food-nutritional-health (through adoption of horticultural crops) security along with overall climate security (through carbon sequestration) and environment sustainability. These all multifarious benefits through agroforestry system can rich the farmer's livelihood, environment sustainability and ecological stability which is a pillar for achieving overall sustainable development. Carbon credit and trading are new concept in agroforestry system which affects overall developmental goal of developing countries. Research development and a good policy are needed for better utilization of agroforestry systems in resource conservations and food-soil-climate security for betterment of environment in developing countries in the tropical world.

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DOI: 10.36959/742/233