Octa Journal of Environmental Research *Jan.–Mar., 2017*
International Peer-Reviewed Journal ISSN 2321 3655
Oct. Jour. Env. Res. Vol. 5(1): 022-031
Available online http://www.sciencebeingjournal.com

Review Article

Octa Journal of Environmental Research
(Oct. Jour. Env. Res.) ISSN: 2321-3655
Journal Homepage: http://www.sciencebeingjournal.com

AGROFORESTRY SYSTEM: AN OPPORTUNITY FOR CARBON SEQUESTRATION AND CLIMATE CHANGE ADAPTATION IN THE MID-HILLS OF NEPAL

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Abstract: Agroforestry is a natural resource management system that integrates trees, crops and animals in a manner that produces two or more crops from a small unit of land sustainably. It is a sustainable land use system that is ecologically and economically sound and offers the added benefit of carbon sequestration. This paper reviews agroforestry practices in Nepal and its role in carbon sequestration and climate change adaptation. Agroforestry is being practiced in the mid-hills of Nepal for the requirement of daily needs like fodder, food and fuel as a substitute to forests. The fodder trees, fuelwood and fruit trees around the farm have an important role in diet supplement as well as in carbon storage. Various researchers have estimated carbon content in agroforestry range from between 12 and 228 MgC/ha with a median value of 95 Mg/ha in the terrestrial agro ecosystem. In Nepal, the mid-hills agroforestry is estimated to store about 48.60 ton C per hectare. Agro-ecosystems also contribute to the mitigation of the climate change and are being an adaptation strategy for the farmers.

Keywords: Adaptation;Agroforestry; Carbon sequestration.

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INTRODUCTION

Agroforestry is an interface between agriculture and forestry as a promising and sustainable land use practice in developing countries where trees on farmland form an integral part of the farming system. Agroforestry deliberately combines agriculture and forestry to create integrated and sustainable land-use systems including annual crops and trees. However, agroforestry has been defined in various ways. It has been called a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Leaky, 1996; ICRAF, 2006). Combination of trees on crops is an old practice defined by Nair (1993) as a land use system that integrates trees, crops, and animals in a way that is scientifically sound, ecologically desirable, practically feasible land socially acceptable to the farmers. In earlier times agroforestry was practiced by those farmers whose ultimate goal was food production and they retained tree as supportive for the agriculture crops. This is accepted as holistic applied science that has potential for addressing many of the ecological and livelihood services for the benefit of farmers and rural communities alike (Regmi, 2003).In other words agroforestry has been claimed, to have the possibility of improving agricultural land use systems and providing lasting benefits and alleviating adverse environmental effects at local and global levels (Alao *et al.,* 2011). The

practice of introducing trees in farming has played a significant role in enhancing land productivity and improving livelihoods in both developed and developing countries. In terrestrial ecosystems, forests are considered among the easiest means for enhancing carbon capture and sequestration (Dahal and Kafle, 2013), Although, this is land use system having tree and crops in a single unit of land with more than two benefits the recognition of role of forest trees in reducing emission of carbon is more (Montagini *et al*., 2004). Agroforestry and ecosystem conservation are key approaches in the integration of climate change adaptation and mitigation objectives, often generating significant co-benefits for local ecosystems and biodiversity (Matocha *et al.,* 2012). At the same time, FAO 2009 indicates land-based carbon mitigation schemes, such as avoided deforestation, reforestation, and agricultural and agroforestry practices that sequester carbon in vegetation and soil, can make a substantial contribution to global climate change mitigation with potential source of income to poor farmers. In developing countries agroforestry has been recognized as land use practice for the small farmers with improving agroforestry technique slowly and few studies has been done in related to agroforestry in relation with carbon and livelihood.Thus, the purpose of the paper is to review the different practice of agroforestry and their role in carbon sequestration and climate change adaptation focused particularly in midhills of Nepal.

AGROFORESTRY IN NEPAL

Geographically, diverse country with flat plains of the Terai in the south and the sloping terrain of the Mid-hills and snowy mountains in the north (HMG/N, 2002). It covers 147,181 sq.km. area where hills and high mountains cover about 86% of the total land area and the remaining 14% are the flatlands of the Terai (NPC, 2012). Agriculture is the principal source of food income and employment, which employs 73.9% of its economically active population (CBS, 2008) and contributes approximately 34% to GDP (NRB, 2014). In recent decades, Nepal's population has grown rapidly that's why more people have required increasing amounts of food and commodities from agriculture and natural resources. The land use of Nepal is changing day by day due to climatic effect and insurgency in country (Paudel *et al*., 2016) (Table 1). In midhills of Nepal there is intermixing of tree with agriculture land which indicates the peripheral effects on natural forest (Uddin *et al.,* 2015). That's why the recent assessment, done by government of Nepal represent other woodland as 4.38% where forest covers 40.36% and combined together form 44.74% of the total area of the country. The other wooded land represents the tree on farm land and fallow land with tree (DFRS, 2015).

Table 1. Land use change of Nepal from 1979-2015

Category	Percentage			
	1979 (LRMP)	1994 (NFI)	1999 (DFRS)	Uddin*et al.,* 2015
Cultivated	20.10	21.00	21.00	29.83
Non cultivated	6.70	7.00	7.00	10.65
Forest	38.10	29.00	29.00	39.10
Shrubland	4.70	10.60	10.60	3.40
Grassland	11.90	12.00	12.00	7.90
Water	N/A	2.60	2.60	0.60
other	18.50	17.80	N/A	N/A

Compiled from Uddin et al., 2015 and Paudel, 2016

Land use changes combines and interacts with social organization, religious beliefs, and access to land and markets to give rise to a wide variety of farming systems and great variances within them (Mahat, 1987; Thapa, 1994) which in turn has resulted in several agroforestry practices. The practice of integrating and managing crops, livestock and forestry for food security and livelihoods has a long history in Nepal's mid-hills (Gilmore and Fisher, 1991; Garforth *et al*., 1997). Agriculture, trees, and livestock are intertwined in the

Nepalese farming system which is practiced by farmers themselves on a regular basis; hence the sustainability of the farming system depends on the continuous existence of tree resources (Garforth *et al*., 1999). This system traditionally produces a wide variety of products from small unit of land, such as, timber, fuelwood, leaf litter, fruits; vegetables etc. to meet household needs with generating an income opportunity to small holder farmers (Regmi, 2003). Nepal's hills are characterized by steep slopes and limited cultivable land (Gilmour *et al.,* 2014). Most farmlands are located on steep slopes where farmers practice cereal-based land management, which requires intensive soil tillage, particularly frequent ploughing and hoeing. In that case, growing of trees, shrubs and herbs species on private lands to fulfill the basic household needs has been a long established tradition in the mountains of Nepal. Farmers maintain trees in the farmland adopting several forms of agroforestry, and collect fuel wood, leaf litter and fodder from these trees for their subsistence (Pandit *et al*., 2014). The practice of agroforestry followed in Nepal can be broadly categorized as: farm-based and forest-based. The former include home gardens, trees on or around agricultural fields, wood lots and commercial crops under shade trees, and intercropping of agricultural crops and commercial trees (Gilmour *et al.,* 2014).The forest-based practices involve specific agricultural practices associated with forests where farmers collect food, fruits and gums (Tejwani and Lai, 1992). Nowadays government of Nepal is practicing leasehold forestry or public land agroforestry, which also symbolizes forest based agroforestry practice (CBD, 2014). It has important implications, particularly through the division of the institutional landscape, including targeting communities, institutional involvement and long-term programs and strategic approaches (Gilmour *et al*., 2014). In other words we can say that the agroforestry played an important role in sustaining a variety of ecosystem services and practiced as adaptation tool (Jose, 2009). With regard to agroforestry, it is a prevalent traditional Nepalese farming practice that involves integrating trees within cropping systems on private land, as opposed to community forestry on public land. The midhills agroforestry system involves cultivation of crops and useful plants under the natural tree canopy, for example home gardens, tree on farmland, mostly for household consumption (Tewari, 2008).

Table 2. Different types of Agroforestry practices adopted by farmers in midhills of Nepal.

Agroforestry practices	Definition	Modified or adopted definition
Home garden	Spatial and temporal arrangement of diverse trees, shrubs, herbs, and other agricultural crops within a household boundary, and managed using family labor (Fernandes and Nair, 1986). Generally 0.1 ha in land.	Vertical and horizontal management of agricultural crops where household members are living permanently within the same unit of land irrespective of farm size (Modified from Nair 1986). It provides 60% of total fruit and vegetable consumption in a 5–6 member household in mid-hills of Nepal (Sthapit *et al*., 2010).
Tree on farm land (strip or scattered tree)	The number of trees or shrubs scattered or stripped among crops or pastures and along farm boundaries (FAO,1985).	Cultivation of multipurpose trees or fruit trees on boundary of the farmland where trees are on strip or scattered and agriculture crops (cereals, vegetables) are intercropped). For the purpose of soil conservation farmers are adopting this type of agroforestry practice in mid hills of Nepal.
Orchards (Block plantation)	The planting of trees or shrubs that are maintained for food production comprise of fruit, vegetable (FAO,1985).	Block plantation of fruits or multipurpose trees on farmland where agriculture crops (cereals, vegetables) are either intercropped or cultivated on adjoining land. For the protection of agriculture land from soil erosion, water spring drying up etc.(Neupane *et al.,* 2002).

Agroforestry practices	Definition	Modified or adopted definition
Silvi- pasture	The trees and shrubs may be used primarily to produce fodder for livestock or they may be grown for timber, fuelwood, fruit or to improve the soil (Nair,1999).	Fallow land with at-least one tree species were livestock are either grazed seasonally or permanently throughout the year.
Commercial crop under tree shade	Growing of shade bearer cash crop under tree shade is practice of agroforestry system. Such as coffee, Cocoa, tea, etc. are grown with tree species.	In this system, agricultural cash crops such as tea and coffee are grown along with tree crops. This is used for the commercialization of the product. (Amatya, 1999).This is also known as improved agroforestry in Nepal.

The traditional farming system in Nepal has not been adequate to sustain agricultural production and present level of food requirements (Neupane, 2002). Agroforestry practice in Nepal seems like recent practices followed in developed countries but they are not scientifically managed. The challenge towards the traditional agroforestry practice in mid-hills is to manage scientifically for the betterment of the livelihoods, sustainable production and improvement of socio-economic condition of the people.

CARBON SEQUESTRATION THROUGH AGROFORESTRY

Trees in agroforestry systems are an important resource providing products and services to the society. It has unique role in stabilizing the atmospheric carbon dioxide concentration and reducing the carbon emissions or on increasing the carbon sink in different land use system (Murthy *et al.,* 2013). Carbon emission is higher from deforestation and forest degradation which can be managed through the sustainable management of land and forests, and enhancement of forest C stocks through agroforestry can be considered as one of the main options for reducing greenhouse gases in atmosphere (Nair *et. al.,* 2012). Agroforestry systems have indirect effects on carbon sequestration because they reduce harvesting pressure on natural forests as because trees are the largest source of sinks for terrestrial carbon. Nowadays, there is a growing attention in the role of different types of land Carbon sequestration in the long term storage of carbon in oceans, soils, vegetation (especially forests), and geologic formations and carbon storage in different agroforestry system (ESA, 2001). Carbon sequestration rate of soil depends upon the input of dead organic matter provided by plants, soil properties such as soil structures and their aggregations, and climate (Lal, 2004). Whereas, Tree-based agroforestry systems are a preferred method for aboveground biomass C sequestration as compared to treeless pastures, there is evidence that C storage in deep soil horizons is greater (Takimoto *et al.,* 2009). The available estimates of C stored in agroforestry range from 0.29 to 15.21 Mg C/ha/year above ground, and 30–300 Mg C/ha up to 1 m depth in the soil (Nair *et al*., 2010). Different agroforestry system have different rate of carbon sequestration in different region shown in Table 3.

Table 3. Examples of various agroforestry practices with carbon stock

S.No.	Region	AF practices	Carbon stock	Reference
1.	West Africa	Fodder bank AF	0.29 MgC/ha/yr	Nair, 2009
2.	Puerto Rico	Mixed species	15.29 MgC/ha/yr	Nair, 2009
3.	Costa Rica	Silvopastoral	173 Mg C/ha/yr	Nair, 2009
4.	Ecuador	Silvopastoral in above ground	7- 41 MgC/ha	McGroody *et al*., 2015
5.	Philippines	Mixed multi story system	161.52 MgC/ha	Mildrade *et al.,* 2012
6.	Indonesia	Homegarden system	107 C ton/ha	Roshetko *et al.,* 1999
7.	Indonesia	Agroforestry system	287.9 C/t/ha	Eutis, 2003
8.	Srilanka	Homegarden	10-145Mg/ha/yr	Mattson *et al*., 2013
9.	India	Poplar based AF system	3.8- 4.82 t/ha/yr	Chauhan *et al*., 2015
10.	India	Home garden	16-36 Mg/ha/yr	Singh and Panday, 2011
11.	Nepal	Midhills agroforestry	48.6 t/ha/yr	Pandit*et al.,* 2012

Another study done by Albrecht *et al*. (2003) showed that the carbon sequestration potential of agroforestry systems is estimated to be between 12 and 228 Mg C/ha with a median value of 95 Mg C/ha. Adoption of agroforestry practices has greater potential to increase C sequestration of predominantly agriculture dominated landscapes than monocrop agriculture (Nair *et al.,* 2009). Beside that agroforestry has been recognized to bea distinct position as a carbon sequestration strategy because of its applicability in agricultural lands as well as in reforestation programs (Cairns and Meganck 1994). Agroforestry systems show significant carbon accumulation in living biomass, as well as soil carbon, demonstrating the potential to offer the environmental service of carbon sequestration. Soil C stocks have been demonstrated to generally be larger in agroforestry systems compared to conventional cropping systems (Kumar and Nair, 2011).In Nepal, Pandit *et al*., (2012) estimated that a total of 48.60 ton C per hectare whereas Bajracharya *et al.*, (2015) found that leasehold agroforestry in cool agro-ecological has more carbon stock than conventional agriculture practice. Forestry is considered to encompass more broadly the larger landscape beyond individual farms, where private farmland, common access forest and grazing land, farm animals, water resources as well as household members, all interact. KC (2011) estimated that CO_2 emissions from AF systems in Nepal were 0.15 % of the total global carbon sequestered through AF, which is considered to be a huge amount relative to the country's size. In the country, high carbon stocks and sequestration potential of forest land have been well documented by numerous researchers as well as research and survey department (Dahal and Kafle 2013). However, AF practices improve food and nutritional needs and mitigate environmental degradation by combining trees and crops (Nair, 2007).

Contribution of Agroforestry to Climate change Adaption and Mitigation

Climate change due to addition of GHGs has been one of the biggest issues for the human welfare in the world (IPCC, 2001). Developing countries are going to accept the effect of climate change and are suffering from its negative impacts with consequences the vulnerability in the area.The outward fluctuation of Carbon dioxide, Nitrous oxide and Methane can be reduced through better management of agroforestry system which will contribute significantly in reducing GHG emissions and mitigation that's why agroforestry system has been identified as a long term sink (Verocht *et al*., 2007). In developing countries adaptation is concern and critical because the vulnerability is high and ability to adapt is low. In that way, climate change is expected to affect food and water resources that are critical for livelihoods (Hassan 2008). Adaptation is necessary to deal with adverse climatic stresses and hazards and to take the opportunities such as new innovations, which can be both to current, actual or projected conditions (Smith *et al.,*1999). Adaptation to climate change is not something that must start from scratch. It is an incremental process that can build upon a long history of previous adaption. The new thing is the need to adapt much more rapidly because of the impact of human activities on climate (Burton 2000). Besides adaptation mitigation is also important in the climate change aspect. It means, mitigation is needed to reduce the impacts and allow for adaptation to takes place, for ecosystems these boundaries are generally narrower for human systems. Because mitigation measures will not be able to immediately avoid global warming (Parry *et al*., 2007) adaptive measurements will be needed to avoid the negative consequences of climate change. On the longer term mitigation measures will be able to avoid further warming or even reduce the effect. In developing countries climate change is significantly affecting the agricultural sector,leading to serious consequences related to food production and food security, with bigger impacts on small-holder farmers and the poor (IPCC, 2007).

Agroforestry knowledge is being adapted in rural and urban area to address the challenge of climate change. Agroforestry is suitable

practice to assist in creating productive and healthy farm and ranch operations,it has the potential to contribute to both climate change mitigation and adaptation by sequestering carbon, reducing GHG emissions, enhancing resiliency, and reducing threats while facilitating migration to more favorable conditions in the highly fragmented agricultural landscapes (Schoeneberger *et al*., 2012). The option for land use practices should be according to the condition of the area so that increase the adaptive capacity of subsistence farmers' and hence less vulnerability to climate change impacts are necessary (Ford *et al*., 2011). Thus and agro-ecosystem can be designed to support adaptation of communities and households to local and global change (Van Ardenne *et al*., 2003). However, traditional resource management adaptations, such as agroforestry systems, may potentially provide options for improving farmer adapting to climate change through simultaneous production of food, fodder and firewood as well as mitigation of the impact of climate change (Adger*et.al*, 2010). Tree-based systems are more profitable and less risky than other agricultural options because of the variety of products and have less infected by pest (Kebebew *et al.,* 2011). The twin objective of climate change adaptation and mitigation can be addressed by agroforestry (Murthy *et. al.,* 2013) which has unique opportunity to accomplish those prospects. These agroforestry practices are based on a variety of management approaches and have potential positive implications for climate change mitigation (Albrecht *et al.,* 2003). Agroforestry systems can meaningfully reduce the pressure on natural forests for essential energy. Expansion and use of agroforestry for sustainable fuel wood can contribute to energy substitution and becomes an important carbon offset option (Unruh *et.al.,* 1993).It is reported that Agroforestry systems that combine trees and shrubs with crops and livestock enhances organic carbon accumulation in soils by providing continuous supply of organic matter, and it also increases soil microorganisms by which the nutrient cycle is preserved (Araujo *et al*., 2011). Reducing the presence of GHGs specially CO_2 in atmosphere for the decreasing the process of global warming include the way of removing carbon from atmosphere and depositing it in reservoir or transforming Carbon to secure in other long-lived pools (UNFCCC, 2007). The best reservoir for the sequestration of carbon is tree and soil in Tree-based farmland tree play significant role to carbon sequestration both in above and below ground as well as reduces emission of greenhouse gases from agricultural practices (Branca *et al*., 2013).

Climate change mitigation through enhancing carbon sequestration and strengthening the system's ability to cope with adverse impacts of changing climatic condition can be done by the different practice of agroforestry system. In a meantime, agroforestry set best example for the copping of adverse impact of changing climatic condition (Verocht *et al.,* 2007). In addition, improved farming practices, including the use of organic fertilizers, conservation farming practices, etc., can increase crop yields, reduce GHGs emissions, and enhance soil organic carbon (SOC) storage (Branca *et al.*, 2013). Agroforestry is a viable alternative to prevent and mitigate climate change. IPCC recognized agroforestry as having high potential for sequestering carbon under the climate change mitigations strategies (Watson *et al*., 2000). Because trees are the largest component of aboveground biomass in terrestrial ecosystems, a number of studies have paid attention to the role of forests in mitigating climate change, carbon sequestration and biodiversity conservation (IPCC, 2007). In addition that, agroforestry has been proposed as a strategy not only for adapting to climate change, but also for mitigating and addressing issues of food security and environmental degradation in agricultural systems. Agroforestry is gaining popularity as an adaptation strategy, in part because traditional agricultural systems often include agroforestry practices (Liang *et al*., 2009). In such a way, the implementation of agroforestry is less costly and more effective than other approaches (ICIMOD, 2013). The adoption of the practice of agroforestry increases crop production, income, savings, improves food security, and provides firewood

and fodder (Akinnifesi *et al*., 2008). Tree-based agroforestry practices could bring opportunities for rural development through promoting agro-industries and improving local economies by reducing unemployment (Kumar *et al*., 2012). In Nepal, Climate-related changes have been observed in precipitation patterns, temperature, high intensity floods, landslides, erosion and increased sedimentation (IPCC, 2007). These changes in climatic factors have substantial impacts at the local level as they change the agro-ecosystem, resulting in loss of land, livestock and household assets (Pant, 2011).

As far as possible, raising trees on the farm is a traditional practice in Nepal, particularly in the mid-hills with a purpose of producing fodder for livestock and fuel-wood for heating and cooking (Amatya and Newman, 1993). Various forms of agroforestry were adopted by farmers over time such as homestead agroforestry, alley cropping, buffer strips, fruit garden, woodlot, and boundary plantation, improved agroforestry like coffee plantation in midhills and terai (Dhakal *et al*., 2012). That's why; the practice of agroforestry is a contributing factor in reducing human impact on the natural forest and maintaining agro-biodiversity as well as reducing greenhouse gas emission (Acharya, 2006). Agroforestry practices have been approved as a strategy for soil C sequestration under afforestation and reforestation programs and also under the Clean Development Mechanisms of the Kyoto Protocol (IPCC, 2007). Agroforestry has received widespread attention in tropical and temperate regions of the world for providing ecosystem services such as carbon sequestration, biodiversity conservation, soil quality, and preserving air and water quality (Thevathasan and Gordon 2004; Jose, 2009).

CONCLUSION

This paper reviewed agroforestry is an important strategy to sequester C from both developed and developing nations. Forest and farm based agroforestry both have equally important roles in reducing carbon emissions and providing food security to the people of rural areas. Agroforestry and sustainable agricultural methods help to mitigate climate change by sequestering and storing carbon in the trees and in the soil. There is need of management strategy of agroforestry in developing countries for the climate change adaptation. Traditional agroforestry mostly seen in the midhills of Nepal should be changed towards thecommercialization so that produce green employment and conserve tree as source of sink.

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Sources of Financial Support: None.
Conflict of interest: None. Declared.