

Agroforestry based farming system, farm characteristics and climate change: A study of Dhanusha district, Nepal

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Abstract

This paper explores types of agroforestry based farming systems being practiced in Dhanusha district of Nepal and analyses farm characteristics of each system from climate change mitigation perspectives. Focus group discussion was carried out at two levels: expert level and farmers' level. The expert level discussion developed a scale to differentiate the farming systems in the study area considering all agroforestry components: agricultural crop, livestock, forest tree crop, fruit tree crop and vegetable crop. The farmers' level discussion was carried out to identify the farmers' preference of tree for timber and fodder. 200 households, randomly selected, were surveyed to assess the type of agroforestry based farming systems in the study area and farm characteristics that distinguish one system from another. The household survey revealed three types of agroforestry based farming systems in practice: less integrated agro-forestry based farming system (A), semi-integrated agroforestry based farming system (B) and highly integrated agroforestry based farming system (C). 32.5%, 32.5% and 22.5 % farmers are engaged with type A, type B and type C farming systems respectively. The diversity index of A, B and C were found to be 0.85, 1.2 and 1.6 respectively and significantly varied with each other. The tree density of type C farming system (241/ha) was higher and significantly varied with the rest two farming types (type A=156/ha and type B = 169/ha). Higher amount of chemical fertilizer was used by the farmers who have adopted the type C farming system. Farmers with larger land holdings (>2.0 ha) were found to be interested in tree plantation while farmers with smaller landholdings (<1.0) were interested in alley cropping. The survey revealed that the criteria set by the expert were quite useful for farmers to assess their farming systems and categorize them accordingly. Farmer preference for tree species varied with purpose. Further research is required to identify which farming system could be more viable and sustainable from both economic and environmental point of view, more specifically from climate change mitigation point of view.

Keywords: Agroforestry based farming, farm characteristics, tree preference, Nepal.

1. INTRODUCTION

Agroforestry is a kind of land use that has been practiced since long in many parts of the world [1]. However, the type and composition and extent vary from place to place because of varied topography, biophysical attributes and socio-economics. Agroforestry is commonly understood as integration of trees or deliberate retention of trees on agricultural land [2]. The primary objective of the retention is to fulfill basic needs of growing populations such as food, fodder, fuel-wood, timber etc. but it holds environmental importance as a co-benefit too that it addresses land management problems and ecological issues. Agroforestry has been adopted to enhance water quality, conserve soil from being eroded by water and wind and to conserve biodiversity ([3], [4], [5], [6]).

Until 90s, agroforestry research was more focused on livelihood aspects such as contribution of agroforestry in household economy ([7], [8], [9]), profitability of agroforestry over agriculture based farming system ([10], [11], [12], [13], [14]). In the recent past, a paradigm shift has occurred in agroforestry research and a more focus has been laid on the carbon sequestration and potential role of agroforestry in climate change mitigation.

In a developing country like Nepal where the per capita landholding is less than one hectare (0.96 ha) and which continue to further decrease because of land fragmentation followed by the population growth [15], agroforestry practice could be a viable option from both the livelihood and climate change mitigation point of view ([16], [17], [18], [19], [20]). But potential of climate change mitigation varies with agroforestry types, tree species composition, and tree management regime as the net carbon sequestration is influenced by these factors.

In Nepal there are some location specific agroforestry practices such as home garden, silvo-pasture and forest based agroforestry practice such as cardamom planting with alder *Alnus nepalensis* [21]. However, the general feature of the agroforestry practiced in Nepal involves the integration of three components in the system: livestock, agricultural crops and tree crops. But there is variation in these system components from one farm household to another in terms of diversity and preference. This variation holds significance because livestock and agro-crops are linked with greenhouse gas emissions while tree component is linked with sequestration. Livestock mainly releases methane and nitrous oxide into the atmosphere [22] while agro-crops mainly the rice cultivation and associated activities such as chemical fertilizer application, use of fossil fuels for irrigation and land management and use of insecticides/pesticides significantly contribute to increased concentration of greenhouse gases into the atmosphere ([23], [24],

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[25], [26]). Therefore, keeping all these factors in mind, a focused study is necessary to identify location specific agroforestry based farming systems and categorize them accordingly so that farmers can adopt more sustainable land use practice which can generate both the environment and economic benefits to them. To address this research objective, this study was carried out in *Dhanusha* district, part of Nepal's lowland (*terai*). More specifically this study covers identification of agro-forestry based farming systems in the study area and their distinguishing features and farmers' preference of trees for fodder and timber. The paper also highlights the implications of farm characteristics in relation to climate change.

2. STUDY AREA AND METHODS

2.1 Study area description

Located in the central development region of Nepal, *Dhanusha* district, one of the *terai* districts, that shares border with India in the south, is located 350 km south-east of capital city, Kathmandu. It covers an area of 119,000 ha. It is situated at 25.35⁰ -27.5⁰ N and 85.5⁰ – 86.2⁰ E. Out of 119,000 ha, agriculture land covers an area of 76,791.8 ha. The average annual rainfall is 2199.4mm. Temperature ranges from 27⁰ C in January to 39.6⁰ C in April [27]. The district is administratively divided into one municipality and 101 village development committees (VDCs). The project area of the Terai Private Forest Development Association (TPFDA) that covers nine VDCs of *Dhanusha* district was selected as a study site. The VDCs include *Bengadawar*, *Dhalkebar*, *Pushpalpur*, *Bharatpur*, *yagyabhumi*, *Hariharpur*, *Naktajhijh*, *Sakhuwa mahendranagar*, and *Laxminiwas*. The first five VDCs are located on the east-west highway and the rest are located, south of the highway, on the feeder road that meets with east-west highway at *Dhalkebar* intersection. This study was carried out in 2010 from May to August.

2.2 Study methods

Focus group discussion (FGD) at expert level

A group of ten experts from the relevant fields: forestry, agriculture, and livestock were consulted. Having at least master degree in relevant subject and involved with some development organizations-both governmental and non-governmental was considered expert. The purpose of this expert level discussion was to set criteria to define level of integration of system components to differentiate the agroforestry based farming systems that were in practice in the study area at the time of this research.

In the study area, agroforestry based farming system involves five major components: agriculture, livestock, forest tree crop, fruit tree crop and vegetable crops, which are integral parts of rural livelihood. However, the diversification and distribution of the system components vary from one farm household to another. For example, some farm households have raised tree crops as a plantation, as an alley cropping, around homestead and around fruit garden while some have practiced some of them or one of them only. Similarly, the livestock diversity and agriculture crop diversity also vary from one farm household to another. Considering all these variations that exist in the farming system, the expert group developed a scale (0.0 to 0.1) to identify the integration level of the system components in the farming systems that are in practice in the study area. The scale gives equal value to the system components: 0.2 for each system component. Each component was further divided into sub-components and score was assigned to each sub-component accordingly (Table 1). Score between 0.25 and 0.5 indicates less integrated agroforestry based farming system and the score above 0.75 indicates the highly integrated agroforestry based farming system.

Table 1: Criteria for differentiating the farming systems

Sc	System components													
	Agriculture crop diversity* (0.2)			Livestock diversity** (0.2)			Tree crop distribution (0.2)				Fruit crop raising (0.2)		Vegetable farming(0.2)	
	≤3	4-6	>6	≤2	3	>3	P	A	H	G	F	F+C	C	S
Sc	0.1	0.15	0.2	0.1	0.15	0.20	0.05	0.05	0.05	0.05	0.1	0.20	0.2	0.0

Note:

* Crop diversity: Number of crops per year. , ** Livestock diversity: Number of livestock species

Sc= Score, P = Plantation, A= Alley cropping, H= trees around homestead, G= trees around home garden, F= fruit trees, Fruits trees with cash crops, C= commercial level, S= Subsistence level

Focus group discussion at farmers' level

One focus group discussion (FGD) was carried out to mainly assess the farmers' preference for timber and fodder species. Forty five farmers above 45 of age –both male and female-with substantial experience on agriculture and agroforestry practices from nine VDCs (five participants from each VDC in an average) participated in the discussion.

The group also assessed farmers' preference for fodder and timber tree species. The group set the criteria of preference for both the fodder and timber trees separately (Tables 2 and 3). Score was given against each criterion. The score 1 represented the most preferred and 5 represented fifth most preferred. Based on the total score for each species, the species with the lowest total score was ranked the first (most) preferred.

Household survey (Selection of study households and data collection)

The households associated with the TPFDA were the population of this study. A total of 200 households were randomly selected. One of the purposes of the household survey was to identify the type of AF based farming systems based on the criteria set by the expert. More importantly the survey was carried out to identify the distinguishing features of different agroforestry based farming systems in the study area. The scale developed through the expert level discussion was adopted for the classification of the farming systems.

3. DATA ANALYSIS

SPSS (now PASW) was used to analyze the data. Descriptive statistics were used for data interpretation. One-way ANOVA at the significance level (0.05) followed by a Post hoc test was performed to see the difference between the farm attributes characterizing different agroforestry based farming systems.

4. RESULTS

Tree species preference

Preference varied with purpose. Result showed that if the purpose was timber production, farmers came up with a priority list of certain tree species which cannot be the same when the purpose was fuel-wood or fodder production because not a single species could serve all needs equally (Tables 2 & 3). This preference is very important from the land management point of view to design farmer-desired agroforestry based farming system because experience suggested that the expert designed or introduced farming technology had a very little adoption rate and in some cases even failed [28]. In the study area, there was no culture of tree retention with a purpose of fuel-wood production because the need of fuel wood was fulfilled when trees were harvested for timber and fodder. Natural death of trees and tree parts served this purpose too. Moreover, crop residues such as wheat straw and maize stover were used as source of energy for heating and cooking purposes. Further, cow dung burning was a common practice in the study area.

Table 2: Preference ranking for timber

Criterion	MSL	GMH	KDM	TK	NM
Fast growth	1	2	1	4	3
Marketability	1	2	1	2	3
Disease/termite resistant	2	1	2	1	1
Grow well in marginal land	1	3	3	3	3
Durability	3	1	3	1	2
Total score	8	9	10	11	12
Final ranking*	1	2	3	4	5

* 1 represents the most preferred and 5 fifth most preferred
MSL=Masala, GMH= Gamhari, KDM= Kadam, TK= Teak, NM=Neem

A total of 37 tree species were found in the study area, out of which fourteen species were primarily promoted for timber, 11 for fodder and 12 for fruit (Table 4). Farmers used mostly all species as source of fuel-wood except few species like *Khaksi*, *Ceiba pentandra*, *bombax ceiba*, and *Moringa oleifera*.

Table 3: Preference ranking for fodder

Criterion	I PL	BDHR	GZMA	KIM	DB
Fast growth	2	2	2	2	2
Tree vigour	3	1	3	2	2
Nutrient content	1	1	1	5	4
Easy harvest	1	3	2	2	2
Grow well in marginal land	2	3	4	3	4
Easy to establish	1	2	2	1	1
Total score	10	12	14	15	15
Final ranking*	1	2	3	4	5

* 1 represents the most preferred and 5 fifth most preferred
IPL= Ipil Ipil, BDHR = Badahar, GZMA= Gazuma, KM= Kimbu and DB= Dabdabe

Preference ranking of timber trees ranked *Eucalyptus camaldulensis (masala)* as first preferred, and *Azadirachta indica (neem)* as fifth preferred (Table 2). In fodder tree category, *Leucaena leucocephala (ipil ipil)* was ranked first and, *Garuga pinnata (dabdabe)* as fifth most preferred, *Artocarpus lakoocha (badahar)* as second and *Guazuma ulmifolia(gazuma)* as third most preferred (Table 3). The harvest age of timber tree species varied with species. For example, the mango tree that covers 85 percent of the total fruit trees survives 100 years. However, the general practice is that farmers replace old mango trees with new ones in a 30 year's cycle. This variation in harvest age of the trees along with types of tree species, tree management system, land uses and landscape affects the carbon sequestration potential of the agroforestry system ([29], [30]).

Table 4: Tree species found in the study area

Sn	Species	Scientific name
A	Timber	
1	<i>Masala</i>	<i>Eucalyptus camaldulensis</i> Dehnh.
2	<i>Gamhari</i>	<i>Gmelina arborea</i> Roxb.
3	<i>Kadam</i>	<i>Anthocephalus chinensis</i> Lam.
4	<i>Sisau</i>	<i>Dalbergia sissoo</i> Roxb.
5	<i>Teak</i>	<i>Tectona grandis</i> Linn.
6	<i>Siris</i>	<i>Albizia sps.</i>
7	<i>Nim</i>	<i>Azadirachta indica</i> L.
8	<i>Jamun</i>	<i>Syzigium cuminii</i> (L.) Skeels
9	<i>Mahuwa</i>	<i>Madhuca indica</i> J. F. Gmel.
10	<i>Kapok</i>	<i>Ceiba pentandra</i> L.
11	<i>Khayar</i>	<i>Acacia catechu</i> (L. f.) Willd.
12	<i>Simal</i>	<i>Bombax ceiba</i> L.
13	<i>Karma</i>	<i>Adina cordifolia</i> Roxb.
14	<i>Bakaino</i>	<i>Melia azedarach</i> L.
B	Fodder	

15	<i>Dabdabe</i>	<i>Garuga pinnata</i> Roxb.
16	<i>Ginderi</i>	<i>Premna latifolia</i> Roxb.
17	<i>Khanayo</i>	<i>Ficus semicordata</i> Buch.-Ham. ex Sm.
18	<i>Ipil Ipil</i>	<i>Leucaena leucocephala</i> Lam.
19	<i>KHAKSI</i>	NA
20	<i>Tanki</i>	<i>Bauhinia purpurea</i> L.
21	<i>Koiralo</i>	<i>Bauhinia variegata</i> L.
22	<i>Badahar</i>	<i>Artocarpus lakoocha</i> Roxb.
23	<i>Khasreto</i>	<i>Ficus roxburghii</i> Wall
24	<i>Kimbu</i>	<i>Morus alba</i> L.
25	<i>Gazuma</i>	<i>Guazuma ulmifolia</i> L.
C	Fruit	
26	<i>Amala</i>	<i>Phyllanthus emblica</i> L.
27	<i>Harro</i>	<i>Terminalia chebula</i> Tetz.
28	<i>Barro</i>	<i>Terminalia belerica</i> L.
29	<i>Aanp</i>	<i>Mangifera indica</i> L.
30	<i>Rukh kathar</i>	<i>Artocarpus heterophyllus</i> Lam.
31	<i>Kagati</i>	<i>Citrus</i> sp.
32	<i>Bhogate</i>	<i>Citrus</i> sp.
33	<i>Sitafal</i>	<i>Annona squamosa</i> L.
34	<i>Sarifa</i>	<i>Annona reticulata</i> L.
35	<i>Lychee</i>	<i>Litchi chinensis</i> Sonn.
36	<i>Sajna</i>	<i>Moringa oleifera</i> Lam.
37	<i>Amba</i>	<i>Psidium guajava</i> L.

Farm characteristics of agroforestry based farming system in the study area

Following the criteria set by the expert group, four types of farming systems were identified: simple agriculture based farming, less integrated agroforestry based farming, medium integrated agroforestry based farming and highly integrated agroforestry based farming. 12.5 percent farmers are engaged with simple farming system while 32.5 percent have practiced less integrated agroforestry based farming (Type A). Another 32.5 percent farmers are engaged in medium integrated agroforestry based farming (Type B) and the 22.5 percent have adopted highly integrated agroforestry based farming (Type C). In the following section we will discuss about the distinguishing features of these three agroforestry based farming systems only since the simple agriculture based farming is beyond the scope of this study. Summary of farm characteristics is presented in table 5.

Tree species diversity

Diversity index (DI) (see [31] for details) was used to assess species diversity variation in these systems. A total of thirty seven tree species were identified in the study area (Table 4) out of which all tree species were present in type C agroforestry while 21 and 26 were present in type A and type B agroforestry respectively. The tree species was more diversified (DI= 1.6) and more evenly distributed (EI= 0.47) in the type C agroforestry as compared to the rest two types (type A, DI= 0.85, EI= 0.28 and type B, DI = 1.2, EI=0.37). The diversity of plant

species varied widely between agroforestry based farming systems. This indicates that the type C agroforestry harbours higher species diversity than that of type A and type B. This implies that increase in integration level increases the species diversity.

Tree species abundance and density

Four types of land-uses were visible in the farm: Alley cropping, plantation, marginal land and homestead area. Distribution of trees by land-use types and agroforestry types varied. Plantation was more prominent in type C agroforestry while alley cropping held the highest percentage of trees in type 'A' agroforestry. Even though plantation covered 57% of the total trees in type B agroforestry, it is very much less than the type C agroforestry plantation (fig 1a, 2a and 3a). The reason behind this variation in tree density in plantation across three agroforestry types might be the per capita land holdings. The per capita landholdings of C, B and A are 2.6 ha, 1.5 ha and 0.77 ha respectively. This indicates that farmers are more inclined to adopting alley cropping with decrease in farm size rather than plantation. The overall tree density is also different across these three systems: 241/ha for type C, 169/ha for type B and 156/ha for type A agroforestry practice.

Figure 1: Type C Agroforestry

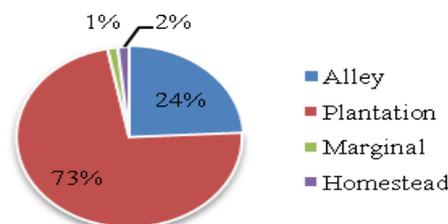


Fig 1a: Distribution of trees in different land uses within the farm

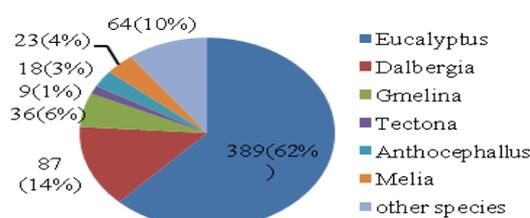


Fig 1b: Specieswise tree distribution in the farm

Figure 2: Type B agroforestry system

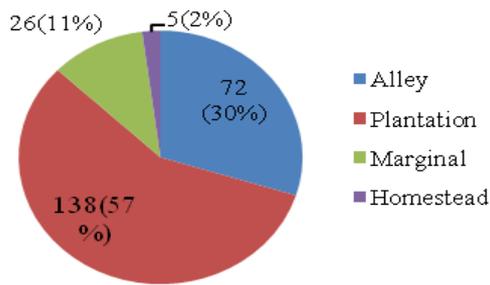


Fig 2a: Tree distribution in different landuses within the farm

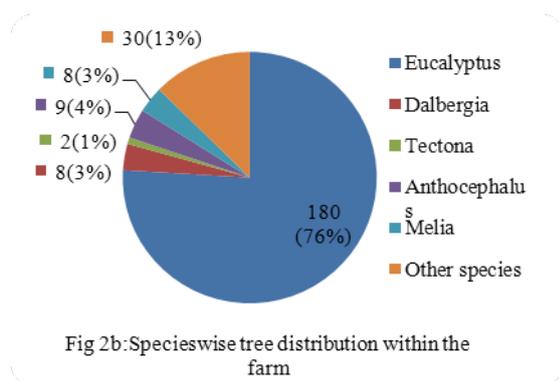


Fig 2b: Specieswise tree distribution within the farm

Figure 3: Type A agroforestry system

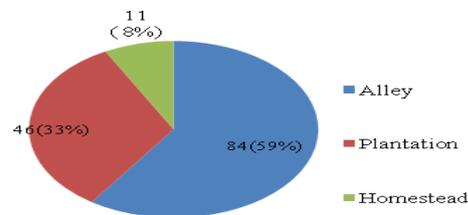


Fig 3a: Tree distribution in different landuses within the farm

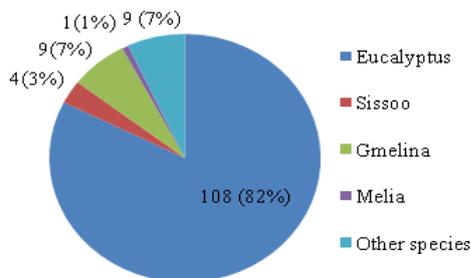


Fig 3b: Specieswise tree distribution in the farm

Farm size

The average farm size of the three farming types A, B and C is 0.77ha, 1.5 ha and 2.6 ha respectively. The farm size varied significantly across the groups. The farm size of the type C is significantly different from the rest two agro-forestry types. Likewise, Type B is significantly different from type A in terms of per capita land holdings. The average area of the irrigated paddy field varied significantly across the three types. The average area of irrigated paddy field between these three (A, B and C) is 0.31 *Katha*, 3.82 *Katha* and 10.89 *Katha* respectively. The irrigated paddy field size of the type C is significantly different from the rest two AF types but type B and C are not significantly different. In terms of rain-fed paddy field, the average area is 3.58 *Katha*, 5.89 *Katha* and 7.67 *Katha* for the type A, B and C agroforestry respectively and the mean was found to be varied significantly across the groups.

Cropping intensity

Cropping intensity (CI) refers the ratio of gross cropped area under different crops to net available farmland [32]. The average CI of the three agroforestry types A, B and C is 1.3, 1.6 and 1.9 respectively. The cropping intensity was found to be significantly different between them indicating that the type C agroforestry was more intensively cropped than the other two types. Type B is also significantly different from the type A agroforestry. Increased CI is associated with increased level of integration. Similar results were obtained by [33].

Use of agricultural inputs

The major inputs that farmers in the study area applied in farmland were farmyard manure, chemical fertilisers, irrigation and use of farm machineries such as tractor for land preparation. The per hectare fertilizer application, the per hectare irrigation hours and the per hectare disking hours were used as variables to see whether or not the three types of agroforestry varied in terms of use of agricultural inputs. The one way ANOVA followed by Post hoc test suggested that the rate of the agricultural inputs varied significantly.

The annual amount of chemical fertilizer application in these three agroforestry systems was found to be 261 kg, 486 kg and 546 kg respectively in a hectare basis. Farmers who have adopted highly integrated agroforestry based farming have applied significantly higher amount of chemical fertilizer. Result shows that increased level of integration requires higher amount of fertilizer. Likewise, the average annual hours of irrigation per hectare of these agroforestry systems (A, B and C) were found

to be 126, 165 and 201 respectively and significantly different between groups. Type C was found to be significantly different from the rest two types and type B also varied significantly with type A.

The average annual hours of use of farm machinery (tractor, thresher etc.) for land preparation (per hectare) of the three farming groups were 28.5, 37.8 and 54.3 respectively and found to be significantly different between groups. Type C was found to be significantly different from the rest two and type B also varied significantly with type A. This indicates that increased level of integration demands more soil preparation and more harvesting and hence more hours of use of farm machineries. These farm machineries are operated by fossil fuels and these fossil fuels are the source of CO₂ emissions.

Location of farm household

The mean distance of farm households from the national forest adopting highly integrated agroforestry was 12.5 kilometres while those adopting type A and type B were 5.6 and 7.4 km respectively. The mean distance varied significantly between groups. Similarly the mean distance of farm households adopting type A, type B and type C farming system were 4.7km, 4.0 km and 3.5 km respectively and they did not vary significantly. This finding holds significance because the farm households far away from the forest tend to plant more trees in their farm to reduce forest product collection time so that the saved time could be utilised in some other productive works. Similar results were obtained by [34].

Table 5: Farm characteristics of agroforestry systems

Farm characteristics	Mean value			Statistics and significance*
	A	B	C	
Diversity	0.85	1.2	1.6	df=2, sig.=.000
Species evenness	0.28	0.37	0.47	df=2, sig.=.000
Tree density	156	169	241	df=2, sig.=.000
Farm size (ha)	0.77	1.5	2.6	df=2, sig.=.000
Plantation (katha)	1.1	1.3	6.9	df=2, sig.=.000
Cropping intensity	1.3	1.6	1.9	df=2, sig.=.000
Use of fertilizer (kg/year)	261	486	546	df=2, sig.=.000
Irrigation (hours)	126	165	201	df=2, sig.=.000
Use of farm machineries (hours)	28.5	37.8	54.3	df=2, sig.=.000
Home-forest distance (km)	5.7	7.4	12.6	df=2, sig.=.000
Home-highway distance (km)	4.7	4.0	3.5	df=2, sig.=.085
Agriculture labour force (no./househol	3	4	5	df=2, sig.=.000

d)				
Livestock size	4	5	5	df=2, sig.=.052
Input expenditure (rupees)	987.1	1511.5	2056.9	df=2, sig.=.000

5. DISCUSSION AND CONCLUSIONS

The analysis of farm characteristics clearly indicate that these farming systems in the study area are different and those differences hold significance while evaluating farming systems from climate change mitigation point of view. About 88% of the households has adopted this tree based a farming system in the study area even though the scale of retention and density of tree components varies from household to households as the finding of this study suggests that plant species diversity and tree density has increased with increased level of integration from the less integrated agroforestry based farming system to highly integrated agroforestry based farming system.

There are some other farm characteristics which were found to be associated with highly integrated agroforestry. Farm households who have adopted highly integrated system have got bigger landholdings and therefore have allocated comparatively larger area for tree crop plantation. Tree planting in farm land is not risk -free because there are some legal formalities that farmers have to meet before harvesting the tree crop which stops smallholder farmers from raising trees extensively. Another reason, why the smallholder farmers who have adopted less and medium integrated agroforestry tends to have a small area of plantation, is that increased tree planting will decrease the land available for agricultural production and hence put them at risk of food insecurity. Another farm characteristic that differs significantly between farming systems was use of agricultural inputs to maintain farm productivity. The major farm inputs that are applied by study area farmers include water supply, chemical fertilizer, and use of farm machineries such as tractor and thresher. Use of these farm inputs has increased with increase in integration level. Because of larger area under tree planting in case of big farmers adopting type C farming system, they are forced to increase the farm inputs to maintain the productivity to meet food demand and increase in crop diversification has increased the use of farm input significantly.

Agroforestry is considered as a sink of carbon as the tree component of the system stores carbon in both above ground and below ground biomass and also enhances the organic carbon stocks in the soil through litter fall, root exudation and turn over and soil erosion control [31]. By increasing tree density in the farm can achieve this environmental benefit but increased density may require more farmland

area and hence reduce the land available for agriculture production and decreasing land is faced with higher farm inputs that result into land degradation in the long run. Not only the density but the type of tree species planted and tree management regime (rotation age) largely influences the sequestration potential of the agroforestry systems ([29], [30]). In the study area, farmers preferred most *Eucalyptus camaldulensis* as a timber species and *Leucaena leucocephala* as fodder species. From the point of economic return on investment, farmers' choice of *E. camaldulensis* as the most preferred seems rationale because it is a fast growing species and farmers have got a secured market for Eucalyptus pole. But from environmental point of view, this *E. camaldulensis* is considered to responsible in drying up of groundwater resources. Similarly, farmers' selection of *L. Leucocephala* as the most preferred fodder species is also rationale because it supports in maintaining fertility by capturing nitrogen from the atmosphere into the soil and it has got a low shadow effects on the main crops. However, promoting legume tree species such as *L. Leucocephala* is now questionable because legume tree crop is responsible to releasing nitrous oxide into the atmosphere [35]. Therefore, while designing an agroforestry based farming system, the species choice should be taken into consideration.

Agroforestry involves agriculture as well as livestock keeping. Both the agriculture and livestock are contributing to global climate change through emissions of methane, carbon dioxide and nitrous oxide. Use of chemical fertilizer as an agricultural input to increase farm production has been the source of greenhouse gases emissions. It releases significant amount of methane, nitrous oxide and carbon dioxide from production to application in the agricultural land ([25], [26], [36],[37],[38], [39]). Use of fossil fuels to operate farm machineries to perform agricultural activities such as land preparation, and crop harvest and post harvest also releases a considerable amount of greenhouse gases into the atmosphere [40]. As the highly integrated agroforestry based farming system has utilized higher amount of farm inputs as compared to other two farming systems, it is obvious that highly integrated system is responsible to higher amount of green house gases emission into the atmosphere in the long run.

Rice cultivation is an integral part of agroforestry based farming system in the study area. Upland rice cultivation is not responsible to methane emission but lowland (irrigated) rice field releases methane into the atmosphere ([22], [24], [41]). Since the area under rice cultivation is higher in highly integrated agroforestry, emission from rice cultivation is obviously higher in this farming system than in

other two farming systems. If we analyze the farm characteristics of other two farming systems, we find lower level of farm inputs and hence lower emissions and lower tree density and hence lower carbon sequestration. Now there is a question which farming system is more sustainable: one which causes less emission and sequesters less carbons or one which causes higher emissions and sequesters higher carbon. Any farming practices should not be only high yielding but sustainable to meet the need of future generation without deteriorating the land productivity. Therefore further research is necessary to see the tradeoffs between carbon sequestration, greenhouse gases emissions and farm productivity to achieve the goal of climate change mitigation and sustainable land use.

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