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Potential of Homestead Agroforestry for Socio Economic and Food Security: A Demonstration of Multi-story Agroforestry Practice in North Shewa Administrative Zone, Amhara Region

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Abstract

The homestead multistory agroforestry demonstration was conducted at Tarma ber district of North Shewa zone to demonstrate and evaluate model multistory agroforestry practice for its ecological and economic importance for the rural communities of the area. The demonstration in addition aimed to further enhance farmers' knowledge on this new cultivation method before any further adoption. The demonstration study was started in June 2013 as multistory agroforestry practices and established with special and temporal arrangements with three strata. The upper stratum comprised tree components, middle stratum was fruits and the lower stratum was different annual crops. The total area of a demonstration site was 0.045ha. *Persea americana, Rhamnus prinoides, Coffea arabica, Musa paradisiaca, Phaseolus lunatus, Hibisicus sabdariffa* and *Vigna unguiculata* were planted at different time of the lifetime of the study and yield data were collected. The results from this demonstration study showed that, on average 1507 kg of edible non-timber forest products harvested per hectare per year. Organic matter and available phosphorus were increased from 1.52 to 2.14%, and 4.26 to 15.98 ppm, respectively. In addition, this practice showed higher net present value (NPV) and benefit-cost ratio (B/C) than the two crop land 3537.36 US$ and 3.3 per ha from these different components. From this study it can be concluded that multistory agroforestry may be ecologically advantageous land use system for sustainable food, biomass production and economic return comparing with conventional agricultural practices. Therefore, future agricultural extension adoption should consider this homegarden agro-forestry practice for sustainable agricultural production and productivity especially in North Shewa areas where this practice is not well known.

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Keywords

Agroforestry, Home garden, Food insecurity and soil degradation

Introduction

One of the most severe challenges faced by decision-makers in developing countries is how to improve the well-being of the poor in rural areas while maintaining a healthy environment (El-Lakany, 2004). Food insecurity and poverty are undergoing processes that have been hampering livelihoods of the rural poor of many developing countries. Over the last four decades, agricultural production is increasing due to improved management and inputs. However, it is threatened by worsening climatic changes, land degradation, and low diversification. This resulted in the mismatch of demand and supply from agricultural production in the developing countries has seldom matched the needs of the people. Productivity has declined 16% on the African agricultural lands in the past 50 years. Of the degraded soils, 58% are in dry lands and 42% in humid areas (Teija, 2008).

Ethiopia is the second most populated country in Africa. Agriculture is the dominant land use sector contributing about half of the GDP and 90 % of national export earnings (MoFED, 2007). This sector is dominated by smallholders whose farming is considered as the basis for the national economic development (Djurfeldt *et al.*, 2011). Despite the efforts made to develop Ethiopian agriculture over the years, food insecurity and land degradation are the threat to the survival of the nation. Land degradation has thus become a social, economic, political and technical problem (Hellin, 2006). Soil degradation is the most common reason for declining productivity in developing country (Scherr, 1999).This soil degradation affects more the rural poor people, because they are more dependent on annual agricultural crops (Hellin, 2006). Malnutrition and poor diets are the two major factors for disability (Forouzanfar *et al.*, 2015). One area where diets are widely deficient is in the consumption of fruits and vegetables, which are associated with increased risk of micronutrient deficiencies, heart disease, cancer, and obesity (Forouzanfar *et al*., 2015). As a result, (WHO/FAO, 2003) recommended that using at least two servings fruits and three servings vegetables per day. However, most people in lower income countries do not meet these requirements (Del Gobbo *et al.*, 2015), largely because of affordability constraints. Ninety-four percent of the Ethiopian population relies on wood-based and biomass fuel for household energy. Scarcity of firewood has become acute in many parts of the country causing a continuous rise in prices, and thus increasing the economic burden on the household budget (Bishaw and Abdelkadir, 2003). Furthermore, deforestation, accelerated soil erosion, and land degradation are now serious problems in Ethiopia. As a result crop and livestock yields are generally very low. The land use system is associated with the decrease in the size of holdings of arable and grazing lands. The conversion of forest and marginal lands to other land uses resulted in environmental degradation and a serious threat for sustainable agriculture and forestry development (Bishaw and Abdelkadir, 2003).

Recently, farm diversification is neglected. The traditional diversification of farmlands for the sustenance of rural community in Ethiopia has largely been abandoned. Monocropping is encouraged to produce more food using high input and single crop farming.

Agroforestry is overlooked and not taken as a solution for food demands and environmental viability. Agroforestry is a dynamic land use system that integrates trees with crops and/or livestock for agricultural landscapes diversification to sustain social, economic, and environmental benefits (ICRAF, 2002). It has the potential to contribute to the improvement of rural livelihood through enhancing farm production and income, while protecting the agricultural environment (El-Lakany, 2004). These technologies were generally developed to solve the problem of soil fertility depletion, food security, shortage of fuelwood, fodder and land degradation (Kumar and Nair, 2004).

The growing food insecurity and deteriorating livelihood situations call to practice agroforestry, as a best and promising land use practices (Teija, 2008). Homegarden agroforestry is one of the agroforestry practices experienced by the farming community to produce diverse products and to improve land productivity. This is a common practice in South and southwestern Ethiopia (Okigbo, 1990). For centuries it has been known for its diversity, ecosystem balance, sustainability, household food security and rural development of the region (Abebe *et al.*, 2006). Several case studies conducted in the smallholder farmers in southwestern of Ethiopia showed that home garden agroforestry is practiced for ages and used by the community (Abebe *et al*., 2006; Tesemma, 2013). Even though this practice enable to ensure wood and food security in a parcel of land, it is uncommon to practice in central Ethiopia and not well demonstrated. Hence, the establishment and promotion of homegarden agroforestry can be one of the strategies to support the rural community to access food and improve the household income. This study aimed to demonstrate and evaluate the spatial and temporal arrangement of homegarden agroforestry components, diversification and products of homegarden agroforestry.

Materials and Methods

Description of the study area

The study was conducted at Armenia *kebele,* Tarma ber district, North Shewa zone which is located at 9º 51' 60N latitude and 39º 49’ 38” E longitude with an average elevation of 1981 m.a.s.l (Figure 1). The district is about 220 km north east of Addis Ababa. The mean annual rainfall ranges 1500 -2000 mm and the temperature ranges 11 – 25^{o}C.

The plot size of the home garden agroforestry was 0.045 ha. Seedlings of the species were raised at the nearby nurseries of the study site. Then species were planted for timber, fruits, and annual crop and/or root tubers in three strata (the upper, middle and lower).The upper stratum was encompassing tree component planted for timber, live fence and shade for the lower strata. The middle stratum was containing Mango (*Mangifera indica*), Banana (*Musa paradisiaca*), Rhamnus (*Rhamnus prinoides*) and Coffee (*Coffea arabica*). The lower stratum comprised of annual crops and root tubers including tea (Table 1). Since, the lower stratum components changed every year. Trees and crops were arranged and managed spatially and temporally to optimize products from the home garden.

Data collection

Yields of different component, tree growth parameter (DBH, Height), tree biomass and cost of all yields were collected. Soil samples taken from the stand and adjacent open land were collected during the end of the experiment. Farmers' opinions during field demonstration were incorporated in the analysis.

Estimation of biomass and wood yield

Tree density, basal area, above-ground biomass and carbon stock were estimated using a method of (Tolera *et al*., 2008) that was demonstrated for multistory agroforestry. The diameter at breast height (DBH) and height of each woody plant in the stand was measured using caliper and graduated stick.

Basal area (BA) is the cross-sectional area of a tree estimated at breast height (1.3 m), which is expressed in m^2. Basal area will be calculated using the formula of Philip (1994):

$$BA = \pi r^2$$

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrants is divided by the total number of quadrants studied.

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrants}}{\text{Total number of quadrants sutdied}}$$

Allometric equation developed by Chave *et al*., (2005) for wet tropical woody biomass and IPCC (2006) were used to estimate woody biomass and carbon stock. Values for wood specific density were taken from the global wood density database (Zanne *et al.*, 2009).

ABG = WD*exp (-1.239+1.980*ln ((D)+0.207*(ln (D))^2_0.0281*(ln (D))^3)_

Where; ABG = above ground biomass of tree^{-1} (kg), D = dbh (cm) and WD = species-specific wood density in g cm^{-3}

Yields of NTFPs (*Persea americana*, *Rhamnus prinoides*, *Coffea arabica*, *Musa paradisiaca*, *Phaseolus lunatus*, *Hibisicus sabdariffa* and *Vigna unguiculata*) and fuel wood extraction (from pollarding over shade tree) were recorded from the initial of the experiment 2013 to 2019 for seven consecutive years on unit area basis and extrapolated to hectare size (Figure 2 and Table 2).

Economic analysis

Semi-structured questioner interviewed of farmers was conducted to obtain the data needed for cost-benefit analysis of demonstrated agroforestry and the two crop lands. The two crop lands are potential crop land and marginal crop land. Qualitative analysis was carried out to investigate the economic potential of existing agroforestry systems. For cost benefit analysis, the net present value (NPV) and benefit-cost ratio (B/C) were calculated and compared following Stocking *et al*. (1990) method. The NPV determines the present value of net benefits by discounting the streams of benefits and costs back to the beginning of the base year (Disney *et al.*, 2013; Stocking *et al.*, 1990). The NPV is calculated by the following formula:

$$\text{NPV} = \sum_{t=0}^{T} \frac{Bt - Ct}{(1+r)^{\wedge}t}$$

Where; Bt is the benefits of production by a cultivation practice, Ct is the costs of production by a cultivation practice, t is the time, running until the end of the investment at T, r is the discount rate.

The B/C compares the discounted benefits with discounted costs. A B/C of greater than 1 means the cultivation is profitable; whilst a B/C of less than 1 means that it generates losses. The B/C is calculated as follows:

$$B/C = \frac{\sum_{t=0}^{n} \frac{B}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C}{(1+r)^t}}$$

Monetary inputs and outputs were calculated on the basis of the selling or buying price in the nearby villages and adjusted to net present value (NPV) at 10% discount rate.

Results and Discussions

Stand structure and productivity

Total stand biomass, tree density, basal areas are presented in table 2.Tree density and basal area of demonstrated multistory agroforestry were remarkably higher than the result reported by Mengistu and Asfaw (2016) in Dallo Mena District, South-East Ethiopia; Asfaw (2004) and Tessema (2013) in Southern Ethiopia. Number of tree in agroforestry could be vary according to total rainfall, altitudes of the farm, availability of moisture for plant without a negative effect on crop growth (Abebe *et al*., 2006).

Traditional management shade tree in Ethiopia is to reduce tree density and understory vegetation to improve the production of coffee while maximizing the use of selected tree species (Aerts *et al*., 2011), through various management techniques, including selection of tree species with desirable properties (Asfaw, 2004). For this reason, only few shade tree species with a greater economic or ecological value (shade) or both dominated the coffee-based agroforestry system (Table 4).The main outputs of the systems were analyzed in the form of fuel-wood, biomass and NTFPs extracted during the 2018/2019and values were pooled (Table.2).

The non-timber forest products (NTFPs) from homegarden agroforestry practice present a valuable source for household economies, as well as for supplementing the household diet. In average1507kg/ha/year from edible NTFPs (*Persea americana*, *Rhamnus prinoides*, *Coffea arabica*, *Musa paradisiaca*, *Phaseolus lunatus*, *Hibisicus sabdariffa* and *Vigna unguiculata*) were collected. The carbon stock potential of the demonstration site was 9.56 ton/ha. Agroforestry has been a part and parcel of tropical food production for millennia (Kumar and Nair, 2004). Homegarden agroforestry provide diversified products that can contribute for household food security, carbon sequestration, fuel-wood supply and environmental protection (Nair, 2010). The significance of diverse shade vegetation in providing products such as fruits, medicine, spices timber/building material, animals (protein), root crops, firewood and other materials, and thereby providing a diversified diet and income for small-holder farmers has been noted by a number of people (Peeters *et al*., 2003).The trend of NTFPs yield and level of diversification is indicated in figure 2.

Structure of multistory agroforestry

The structure of demonstrate agroforestry vegetation can be defined by two components: (i) the horizontal arrangement of species, i.e. the spatial distribution of individuals; and (ii) The vertical arrangement of species i.e. the stratification of vegetation (Figure 3).

Horizontal structure

On the basis of planting locations the homegarden species can be divided into 2 categories; species for border only and species for interior only. These include timber tree i.e. *Grevillea robusta* in border area. In interior part of agroforestry *Cordia Africana* (*Cordia*), *Musa paradisiaca* (*Banana), Mangifera indica* (*Mango*), *Persea Americana* (*Avocado*), *Coffea arabica* (Coffee), *Rhamnus prinoides* (*Rhamnus*) and annual crops i.e. *Phaseolus lunatus* (Harricot bean), *Hibisicus sabdariffa* (Hibisicus) and *Vigna unguiculata* (Cow pea) which are planted in different years .

Vertical structure

The upper layer of agroforestry consists of different fruit and timber trees such as *Cordia africana*, *Musa paradisiaca* and *Grevillea robusta* from 6 - 10 m height. *Mangifera indica, Persea americana, Rhamnus prinoides* and *Coffea arabica* occupy middle layer from 1.3 - 5m height. Lower layer consists of different annual crops i.e. Hibiscus, Haricot bean, Cow pea which are planted in different years.

Soil nutrient availability

Result of soil analysis for demonstrated agroforestry stand and adjacent crop land as control are summarized in Table 3. Slightly changes in soil characteristics were observed after the establishment of agroforestry practices. Organic matter increased 1.52 to 2.14% due to addition of biomass in the soil. Trees can have a potential to increase organic matter and nutrient status under the canopy as compared to other land uses (Young, 1997). Higher organic carbon recorded under the canopy of *Cordia africana* and *Millettia ferruginea* than that of open area (Asfaw, 2004). Available soil phosphorus was influenced by the practice. Available phosphorus highly increased 4.26 to 15.98 ppm. Higher soil phosphorus level found under the agroforestry practices might be due to high litter accumulation from above and belowground tree biomass. This also increased the soil organic carbon (SOC). As SOC increased, correspondingly the organic phosphorus increased (Wolle *et al*., 2017). This practice added substantial amount of available phosphorus due to trees and this result agreed with the other studies (Tedla and Asfaw, 2018; Wolle *et al*., 2017). Similar trends were also reported under *Faidherbia albida* and *Cordia africana* on farm lands in Ethiopia (Yadessa *et al.*, 2009). Overall, soil pH became slightly neutral (6.39 to 6.47), exchangeable Potassium decreased from 1.04 to 0.59 me/100g soil (Table 3). Soil fertility is said to be maintained in multistory agroforestry in the long-term (Kumar and Nair, 2004). The integration of crops, trees, and livestock is a multifunctional production system critical for sustaining farm land in marginal landscapes.

Cost benefit analysis

The economic analysis was carried out for the demonstrated agroforestry, potential and marginal cropland considering the rotation period and the actual number of farmers who have harvested the produce in the past seven years. The result of financial analysis of the three land use systems are presented in table 4. It was revealed that demonstrated multistory agroforestry was more profitable than the two systems because of low cost and high benefit. Profitability measured by net present value (NPV) for agroforestry three and ten times higher than potential and marginal cropland respectively. This is driven by the high output prices of the *Cordia africana* and *Grevillea robusta* timber production from this system. Even though agroforestry practices requires some additional costs for rotation.

The major drawback for this model agroforestry practices is reduce the production potential of annual crops where trees compete for use of arable land. And relatively long production period of tree return. Costs and returns of investment emerged critical in determining decisions to plant trees along with tenure security (Duguma, 2013).Improved agroforestry systems can provide a landowner the opportunity to develop short and long term investments that allow for some spreading of financial risk through diversification (Hoekstra, 1987). Other benefits are higher income throughout the year and better food security. According to (Murniaty *et al.*, 2001), who claimed that agroforestry systems were superior land use systems for buffer zones of conservation areas providing income, products, and even environmental services (Table 4). Cost benefits analysis of model multistory agroforestry practice and selected cultivation systems in Armania kebele USD per hectare.

Table.1 Components of the homegarden agroforestry

Species Name	Spacing between plant (m)	No. of plant/ stand	Uses
Grevillea robusta	1	6	Timber, live fence
Coffea arabica	2	25	Stimulus, Cash
Cordia africana		10	Shade, Timber and Fuel wood
Mangifera indica	4	3	Fruit and Cash
Persea americana	4	4	Fruit and Cash
Rhamnus prinoides	1.5	2	Cash, Flavor drink and Medicine
Musa paradisiaca	3	11	Fruit, Cash, Fodder
Annual crops: Cow pea (*Vigna unguiculata*), Harricot bean (*Phaseolus vulgaris*),Hibiscus (*Hibiscus sabdariffa L.*)			Food and fodder

Table.2 Stand characteristics of agroforestry practice

Parameters	Values
Tree density (tree/ha)	355.6
Basal area (m^2/ha)	11.1
Fuel wood extraction (kg/ha)	588.9
Tree biomass (ton/ha)	19.9
Biomass carbon stock (ton/ha)	9.56
NTFPs collection (kg/ha/year)	1507.0

Table.3 Stand soil characteristics and nutrient availability

	pH(1:2.5)	E.C(dS/m)	EX.K (me/100g)	%OC	%OM	AV.P(ppm)	T.N (%)
Agroforestry	6.47	0.11	0.59	1.25	2.14	15.98	0.13
Control (adjacent crop land)	6.39	0.08	1.04	0.88	1.52	4.26	0.11

Table.4 Cost benefits analysis of model multistory agroforestry practice and selected cultivation systems in Armania kebele USD per hectare

Particulars	Agroforestry	Potential crop land	Marginal crop land
Input cost for crops and trees:- Labor, seed, fertilizer, pesticide cost,	679.80	866.64	690.03
Return from crops, fruits	1396.98	1507.48	819.97
Return from selling timber	3153.72		
Total returns	4550.70	1507.48	819.97
NPV (r = 10 %)	3537.36	1077.60	323.12
B/C	3.3	1.7	1.2

Table.5 Determinants for adoption of multistory agroforestry

Determinants	Percentage
Additional income	88
Fodder	28
Source of money in emergency	40
Supply fruit for the homestead	72
Fuel wood	32
Timber	24
Soil fertility	48
Provide better Environment	32

Figure.1 Map of the study site

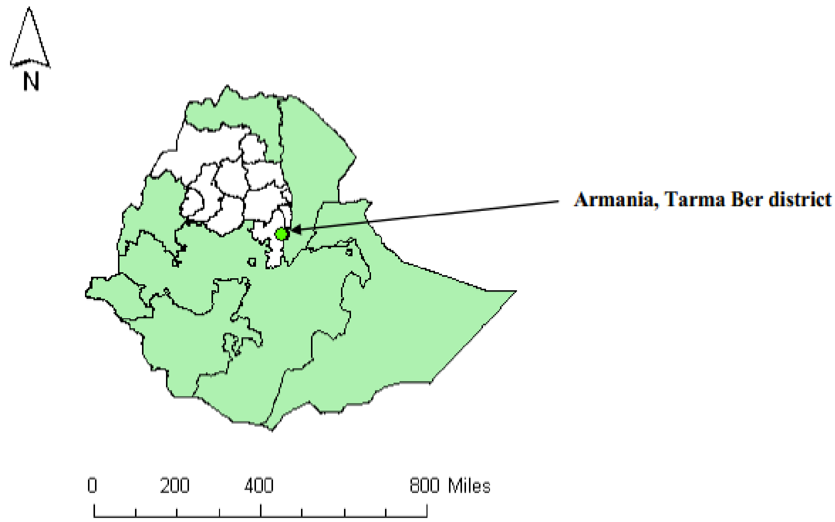


Figure.2 Trend of different products over time after establishment

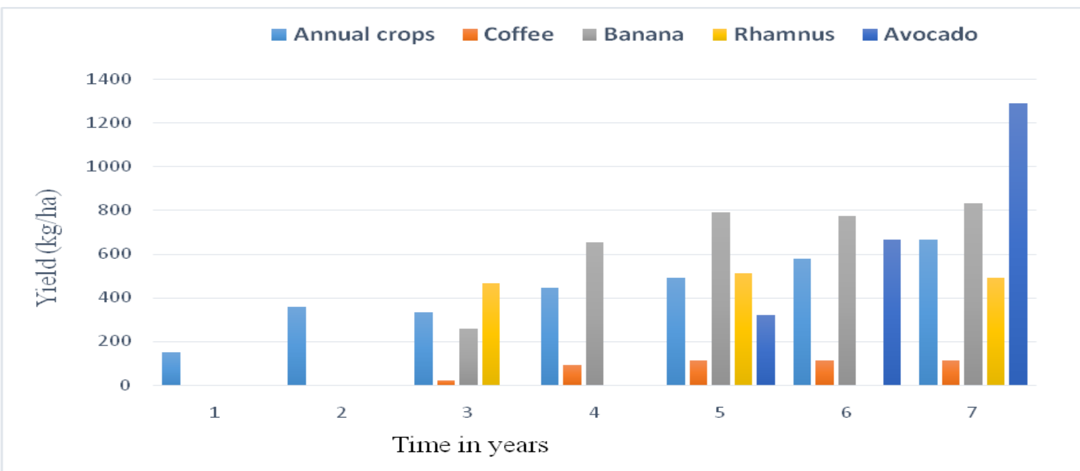
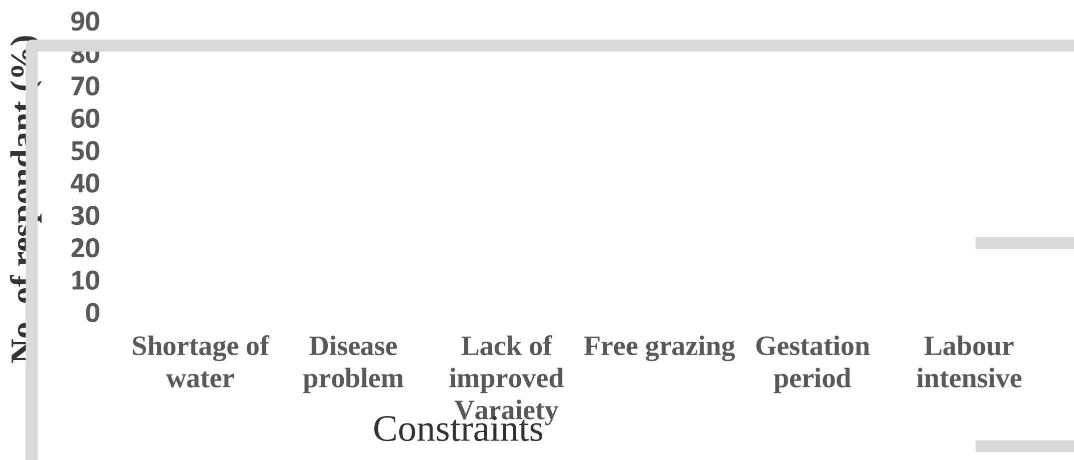


Figure.3 Model multi-strata agroforestry demonstration at Armania kebele

Figure.4 Constraints for adoption of agroforestry practice (n = 25)



Farmers' attitudes towards multistory agroforestry

The farmers' positive perception is indicated as an important step in adoption process (Franzel *et al*., 2002). The semi structured questionnaire interviews with 25 key informants in Armania kebele farmers revealed some of the factors for adoption multistory agroforestry (Table 5). For majority of the farmers (88%) multistory agroforestry was a prime source of household income. The other major reason for adoption of agroforestry was food from fruit tree (72%). Very few farmers contribute to timber for making farm implement and household furniture. Near to half percentage of respondents also mentioned positive attitude towards soil fertility (48%) (Table 5).

Despite agroforestry systems being more profitable, most farmers in the study area still persist with the less profitable marginal crop land cultivation. The semi structured questionnaire interviews with 25 key informant Armania kebele farmers revealed some of the factors for adoption multistory agroforestry (Figure 4).

The major constraint for the adoption of multistory agroforestry is shortage of water (80%) and a long period of time for harvesting (40 %). This is particular true for study area farmer as their cultivation are largely depend on rain fed and subsistence oriented and yield insufficient to invest on agroforestry.

Conclusion and recommendation are as follows:

Practicing homegarden agroforestry can enhances the livelihood of the farmer by providing socio-economic and rehabilitating the degraded lands. Tree species, play a vital role to improve soil fertility and farmer livelihood. Demonstrated multistory agroforestry have a potential to contribute 20% of annual average income of Armania farmers. After five years establishment the multistory agroforestry rapidly increased its production but it need intensive management.

Farmers in the study village were willing to adopt the multistory agroforestry practices but they were concerned about shortage of water and give more need for fast growing species. Generally, a well-managed multistory agroforestry can provide food, fodder and fuel wood for the rural people. The following suggestions are recommended to increase the livelihood of the people.

Unused homestead and marginal land is available around most of the households; this land can be converted to multistory agroforestry to meet the demand for timber, fuel wood, fruit, fodder and raw materials.

Increasing the number of fast growing and improved species is important in order to provide early cash return to the farmers.

In order to promote sustainable agroforestry to the region, the extension networks with water harvesting techniques at the local level should be strengthened.

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