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# Economics of agroforestry land use system, Upper Blue Nile Basin, northwest Ethiopia

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**Abstract** In the northwest Ethiopian highlands, Fagita Lekoma district, farmers' are practicing different land use systems such as crop land use, fodder land use, tree based land use and a combination these land use systems. *Acacia decurrens* based small-scale agroforestry (SSA) land use system is commonly practiced. However, the economic advantage of the *A. decurrens* based SSA land use system is not yet investigated. Therefore, this study was conducted to investigate the productivity and economic benefit of the *A. decurrens* based SSA land use system. Within the district, five investigation sites were selected where *A. decurrens* based SSA land use system (LUS) widely applied. The study was designed in five treatments with five replications and the test crop was Teff (*Eragrostis teff*, *E. abyssinica*) and the test agroforestry tree was *A. decurrens*. The treatments were; (1) Sole crop (Teff) LUS, (2) Sole fodder LUS, (3) Crop—*A. decurrens* intercropped LUS, (4) Fodder—*A. decurrens* intercropped LUS, and (5) Sole *A.*

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*decurrens* LUS. The result shows that the Teff—*A. decurrens* intercropped, fodder—*A. decurrens* intercropped, and sole *A. decurrens* LUSs, respectively, were found to provide better income for small-holder farmers. The Teff—*A. decurrens* intercropped LUS provided 1.3 and 1.2 times more income than the sole Teff and sole Acacia LUSs, respectively. The fodder—*A. decurrens* intercropped LUS provided 11 times more income than the sole fodder LUS. These are the main reasons motivating farmers to change the sole Teff and sole fodder LUSs to mixed/intercropped LUS. In general, *A. decurrens* intercropped based SSA land use system was found to provide better income for small-holder farmers. Hence, the mixed land use system is recommended to be practiced by farmers and could be up-scaled to other areas having similar agro-ecological situations.

**Keywords** *Acacia decurrens* · Land use system · Cost–benefit-analysis · Small-scale-agroforestry

## Introduction

In Ethiopia, land is being used without taking into consideration of its economic suitability, although there were attempts made to prepare economical and productive land use systems (LUSs) at watershed levels in the last four decades (Temesgen et al. 2014; Zemen et al. 2017; Berihun et al. 2019; Nigussie et al. 2020). As a LUS, small-scale agroforestry (SSA) can be defined as the integration of trees and crops on farmlands to enhance productivity, profitability, ecosystem sustainability and climate change mitigation (Kalame et al. 2011; Viswanath et al. 2018). There are several SSA systems, based on people's needs and site-specific agro-ecological characteristics. For instance, in the northwest highlands of Ethiopia, smallholder farmers' are planting *A. decurrens* (Green wattle) (hereafter, *A. decurrens*) tree deliberately in a scattered form in crop fields together with native crops like Teff (*Eragrostis teff*, *E. abyssinica*) (Endalew et al. 2014; Wondie and Mekuria 2018). Smallholder farmers are also intercropping Maize (*Zea mays*) with *Eucalyptus globulus* in the northwest highlands of Ethiopia (Mekonnen and Abebaw 2020). In the central highlands of Kenya, farmers are intercropping *Grevillea robusta* and maize (Welker et al. 2016). Similarly, in central India, smallholder farmers' are intercropping *Acacia nilotica* and rice (*Oryza sativa*) as a SSA land use system (Rajeshwar Rao et al. 2018).

Soil fertility improvements, means of income, carbon stock and crop productivity enhancement are some of the advantages of SSA. According to Rajeshwar Rao et al. (2018), SSA provides a unique opportunity in enhancing crop productivity and improving the soil quality in degraded lands. Small-scale agroforestry LUSs are efficient ways of restoring soil organic matter (Viswanath et al. 2018), diversifying income ensuring benefits of short, medium and long term income to households (Min et al. 2017; Cerdà et al. 2018; Paudel et al. 2018) and reducing the risk of crop failure ensuring alternative income to smallholder farmers' (Sileshi et al. 2011). In terms of its potential to improve soil quality, SSA can offer significant economic and social benefit, especially for smallholder famers in developing countries and could improve the standard of living through increased agricultural productivity (Akinnifesi et al. 2010; Ospina 2017; Nigussie et al. 2020).

In the northwest highlands of Ethiopia, Fagita Lekoma district, farmers' planted different indigenous and exotic tree species as a SSA land use system to gain economic benefits, reduce soil erosion, amend soil fertility, and ameliorate microclimate. Among the exotic tree species *A. decurrens* is common and widely planted because it is a fast growing species, highly adapted to the area and provide the community wood and year round fodder for animals (Kassie 2015; Nigussie et al. 2017; Wondie and Mekuria 2018). As a result, farmers' are converting the sole cropping LUS to SSA land use system by planting *A. decurrens* together with different field crops (Wondie and Mekuria 2018; Mekonnen et al. 2017) and the spatial distribution of *A. decurrens* cover is increasing from time to time for the past three decades (Mekonnen et al. 2016; Wondie and Mekuria 2018; Worku et al. 2020).

In the study area, Wondie and Mekuria (2018), Mekonnen et al. (2017) and Worku et al. (2020) studied the land use/cover dynamics due to the introduction and fast expansion of *A. decurrens*. Kassie (2015) and Molla and Linger (2017) also studied the role of *A. decurrens* on soil fertility improvements. However, there was no thorough investigation on the impact of *A. decurrens* based SSA land use system on crop production/yield and farmers' income. According to Ospina (2017), technical knowledge and accurate information on the economic advantage of agroforestry systems should be carefully collected and compiled so that the practices can be sustained to maximize farmers' benefits. Therefore, the objectives of this study at Fagita Lekoma district as representative of the northwest highlands of Ethiopia were to (1) examine the productivity of *A. decurrens* based small-scale agroforestry land use system and (2) investigate the cost–benefit analysis of the different land use systems.

## Materials and methods

### Study area

The study was conducted in Fagita Lekoma district, in the northwest highlands of Ethiopia. Geographically, it is located between 10° 57′–11° 11′ N and 36° 40′–37° 05′ E (Fig. 1). The total area of the district was 67,950 ha with an elevation ranged from 1800 to 2900 m a.s.l. In addition to the native natural forest species, the exotic tree species like *Eucalyptus chamadulensis, Eucalyptus globulus,* and *Juniperus procera* planted scarcely. For the past three decades *A. decurrens* was the dominant plantation as a small-scale agroforestry system and expanding at a faster rate and covering large area of the district (Kassie 2015; Mekonnen et al. 2017; Wondie and Mekuria, (2018).

### *Climate and soils*

Vertisols, Nitosols, Cambisols and Acrisols are the major soil types in the Fagita Lekoma district (Gebre-Selassie 2002). About 80–90% of the rainfall falls during the main rainy season (locally called *Kiremt* in Ethiopia) from June to September as high intensity rainfall, and is preceded and followed by one month of irregular, low intensity rain. The average maximum and minimum temperatures of the area were ∼ 25 °C and 10 °C and the mean annual rainfall is 1328 mm (Fig. 2).

### *Farming system and population*

In the Fagita Lekoma District, rain-fed agriculture with a subsistence farming system was dominant by growing sole annual crops like Teff (*Eragrostis teff*, *E. abyssinica*), Wheat (*Triticum aestivum*), Barley (*Hordeum vulgare*), Maize (*Zea Mays*) and Potato


**Fig. 1** Location map of the study area, Fagita Lekoma district, in the northwest highlands of Ethiopia

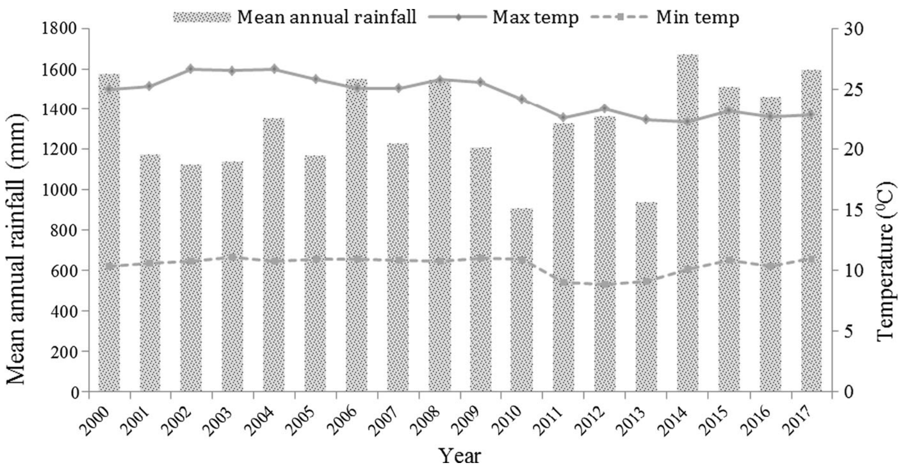


**Fig. 2** Maximum and minimum temperatures, and mean annual rainfall of Fagita Lekoma district, from 2000 to 2017 (NWEMA 2017)

(*Solanum tuberosum*). Agriculture, growing different crops and rearing of animals, is the mainstay of the community economy. Farmers' are using oxen to plough their farmlands. The common domestic animals in the study area include cattle, sheep, donkeys, horses, and chickens. The main sources of feed for livestock are communal/private grazing lands. Fodder from crop-*A. decurrens* intercropped land use system is also a source of feed.

Recently, farmers' are practicing small-scale agroforestry (SSA) farming system by intercropping field crops and trees. For example, Teff, the native and widely used staple crop in the area and in Ethiopia is being intercropped with *A. decurrens* tree. One of the main reasons for practicing intercropping is to diversify income. Population density, which demands more agricultural lands or better land use system to increase crop production or productivity, is another reason. According to DSA (2017), the total population of Fagita Lekoma district in 2000, 2010 and 2017 years was 97 446; 139 946 and 161 002, respectively, which shows an increasing trend. More than 90% of the population is living in the countryside practicing agriculture as the only means of living.

## Experimental design and sampling methods

The experiment was conducted in 2017/18 rainy season on farmers' fields under natural conditions. In the Fagita Lekoma district, five sampling sites where small-scale agroforestry (SSA) land use system was being practiced by farmers were selected, such as Ashewa, Amesha, Gula, Endewuha and Gafera. From each location five farmers' fields were selected purposely, which means farmers' fields with SSA practices were selected and the study was designed in five treatments with five replications. The treatments were; (1) Sole crop land use system (LUS); (2) Sole fodder LUS; (3) Crop—*A. decurrens* intercropped LUS; (4) Fodder—*A. decurrens* intercropped LUS and (5) Sole *A. decurrens* LUS. Table 1 shows the 5 years LUSs investigated.

(1) Sole crop (Teff) LUS (the farmers mostly grow Teff to harvest Teff grain yield & straw biomass, but there will be rotation with other crops during the 5 years). (2) Teff—acacia intercropped (during the 1st year, Teff & acacia intercropped to harvest Teff grain yield, & during the 2nd year fodder & acacia intercropped to harvest fodder, & from the 3rd to 5th yeas only acacia remains on the field, to harvest charcoal in the 5th year). (3) Sole fodder, to harvest fodder every year for the periods of 5 years. (4) Fodder—acacia intercropped (1st & 2nd years, fodder & acacia intercropped to harvest fodder; and from 3rd to 5th years acacia remains in the field to harvest charcoal in the 5th year). (5) Sole acacia (acacia covers the field throughout the 5 years, to harvest charcoal in the 5th year).

## Sampling procedures

(1) A farmer field with sole Teff crop grown was selected (Fig. 3a) in June 2018, and when the Teff crop gets matured in December 2018, grain

**Table 1** Chronology of the LUSs and treatments investigated, in the Fagita Lekoma district, northwest highlands of Ethiopia

| No | LUSs/treatments | Chronology of the LUSs | | | | |
|---|---|---|---|---|---|---|
| | | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
| 1 | Sole crop, Teff | Crop | Crop | Crop | Crop | Crop |
| 2 | Teff—Acacia, intercropped | Teff + Acacia | Fodder + Acacia | Acacia | Acacia | Acacia |
| 3 | Sole fodder | Fodder | Fodder | Fodder | Fodder | Fodder |
| 4 | Fodder—Acacia, intercropped | Fodder + Acacia | Fodder + Acacia | Acacia | Acacia | Acacia |
| 5 | Sole Acacia (SA) | Acacia | Acacia | Acacia | Acacia | Acacia |


**Fig. 3** Sole crop (Teff) LUS (**a**); sole fodder LUS (**b**); Teff and *A. decurrens* intercropped LUS (**c**; Wondie and Mekuria 2018); Fodder and *A. decurrens* intercropped LUS (**d**), and Sole *A. decurrens* LUS (**e**)

yield and straw biomass were collected. Five samples were taken from a single experimental field to make an average grain yield and straw biomass using a quadrant of 2 m * 2 m (4 $m^2$). The crop was harvested when it was ready for harvest and grain yield was separated from the straw by hand and weighed. The straw biomass was determined by taking the sun dry weight of Teff.

(2) A farmer grazing field (Fig. 3b) was selected in June 2018, and fodder biomass was collected when the fodder was at its maximum vegetative growth stage in October 2018 using a quadrant of 2 m * 2 m (4 $m^2$) at five locations to make an average fodder yield. The fodder biomass was determined by taking the sun dry weight of the grass.

(3) A farmer field in which Teff and *A. decurrens* intercropped (Fig. 3c) was selected in June 2018 and Teff grain yield and straw biomass were collected at the end of the growing season in December 2018 when Teff crop matured. Teff grain yield was separated from the straw by hand and weighed. The straw biomass was determined by taking the sun dry weight of Teff. To estimate charcoal yield from *A. decurrens* produce, a farmer field having 5 years old *A. decurrens* that was intercropped with Teff before 5 years was selected and the monetary value of the charcoal produce was estimated.

(4) A farmer field in which fodder and *A. decurrens* intercropped (Fig. 3d) was selected in June 2018, and the fodder biomass was measured when the fodder was at its maximum vegetative growth stage in October 2018. Five samples

were taken using 2 m * 2 m (4 $m^2$) random quadrants to make an average fodder biomass. To estimate the charcoal yield from *A. decurrens*, a farmer field having 5 years old *A. decurrens* that was intercropped with fodder before 5 years was selected and the monetary value of charcoal produce was estimated.

(5) Concerning the sole *A. decurrens* land use system, a farmer field in which a 5 year old sole *A. decurrens* grown was selected (Fig. 3e). The charcoal and non-charcoal (chaffs/branches) produce were estimated harvesting the tree from a quadrant of 4 m * 4 m (16 $m^2$) area. All the data (1–5) were collected from the five locations that means replicated five times. Sensitive balance having two decimal digits precision was used to weigh grain yield, straw and fodder biomass. Teff yield and straw biomass obtained from the quadrant were converted to kilogram per hectare and to the US Dollar (USD) value using the current rate of exchange. Finally, the values were multiplied by five to get the 5 years cumulative economic benefits on hectare basis and compared with the 5 years sole *A. decurrens* based LUS. Five years data were used because *A. decurrens* requires a minimum of 5 years for maturity and harvesting. Figure 4 shows the general schematic methodological flow chart of the research.

Cost–benefit-analysis

Net benefit or cost–benefit-analysis (CBA) of the investigated land use systems (LUSs) was done by accounting the total required major input costs and produce costs of each LUS. The difference between the major costs invested for production and the produce costs incurred were considered. Major production costs for sole Teff LUS were seed cost, labour cost (from land preparation to harvesting and threshing) and fertilizer costs. Cost of the sole fodder LUS was mainly labour for harvesting and transporting the fodder. Similarly, the major costs of crop and *A. decurrens* intercropped LUS include cost of seedling, planting, managing the trees in the field, harvesting, making charcoal and non-charcoal produce, and the first year intercropped Teff production costs (seed, labour, land preparation, harvesting, threshing and fertilizer costs). The cost of fodder and *A. decurrens* intercropped LUS includes seedling, land preparation, planting, managing the trees in the field, harvesting, making charcoal and non-charcoal produce, and the first year costs of fodder harvesting and transportation.

## Results

Productivity of sole crop land use system (LUS)

Teff yield and straw biomass was evaluated as a sole crop LUS. Table 2 shows the mean annual Teff yield

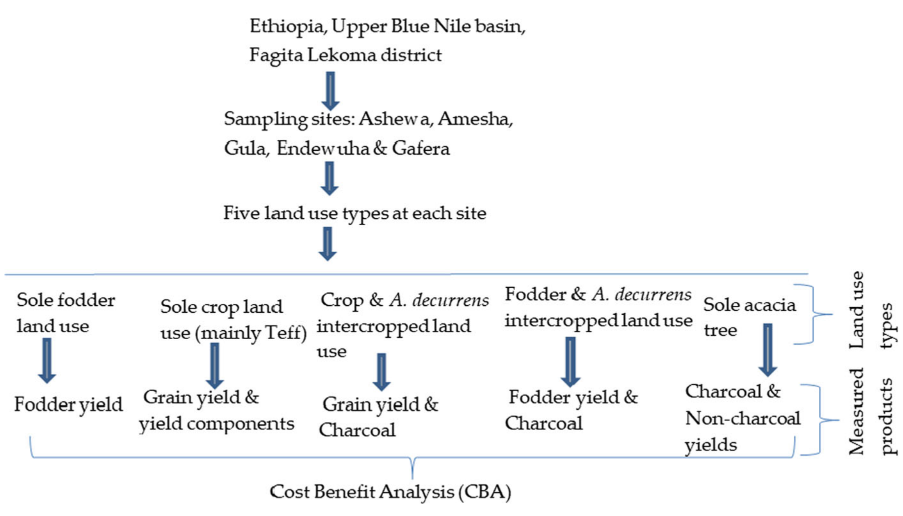


**Fig. 4** Methodological flow chart of the study in general

**Table 2** Productivity of the sole Teff LUS and its monetary value in USD

| Locations | Teff grain yield (kg $ha^{-1}$ $year^{-1}$) | Teff grain value after 5 years (USD $ha^{-1}$) | Teff straw biomass (kg $ha^{-1}$ $year^{-1}$) | Teff straw value after 5 years (USD $ha^{-1}$) | Total value after 5 years (USD $ha^{-1}$) |
|---|---|---|---|---|---|
| Ashewa | 1300 | 5590 | 3560 | 1071.6 | 6661.6 |
| Amesha | 1500 | 6450 | 3800 | 1143.8 | 7593.8 |
| Gafera | 1560 | 6708 | 3850 | 1158.9 | 7866.9 |
| Endwuha | 1360 | 5848 | 3160 | 951.2 | 6799.2 |
| Gula | 1420 | 6106 | 3120 | 939.1 | 7045.1 |
| Mean | 1428 | 6140 | 3498 | 1053 | 7193.0 |

[NB]Average price of 1 kg Teff was 0.86 USD and 1 kg Teff straw was 0.0602 USD

(kg $ha^{-1}$) and Teff straw biomass (kg $ha^{-1}$) and its monetary value in USD. On average, farmers' are producing 1428 kg $ha^{-1}$ $year^{-1}$ Teff grain yield for human consumption and 3498 kg $ha^{-1}$ $year^{-1}$ Teff straw biomass for animal feed. In terms of money, farmers are gaining 7193 USD every 5 year only from the Teff grain yield and the straw biomass.

## Productivity of sole fodder and intercropped fodder land use system

Productivity of the sole fodder, and fodder and *A. decurrens* intercropped LUS were analysed. Table 3 shows the mean fodder biomass (kg $ha^{-1}$) of the sole fodder LUS, and fodder and *A. decurrens* intercropped LUS, as well as the corresponding monetary values. On average farmers produce 3450 kg $ha^{-1}$ $year^{-1}$ of fodder for their livestock feed with the lowest and highest biomass of 3250 kg $ha^{-1}$ and 3700 kg $ha^{-1}$, respectively. In 5 years, farmers' produces 17,250 kg $ha^{-1}$ fodder from the sole fodder LUS, which was estimated as 751.8 USD. Farmers' intercropped *A. decurrens* and fodder to get grass for their livestock, charcoal for sale and non-charcoal products like tree branches (chaffs) for firewood. From the fodder and *A. decurrens* intercropped LUS, during the 1st year farmers produce 3124 kg $ha^{-1}$ $year^{-1}$ of fodder with an average monetary value of 134 USD $ha^{-1}$ $year^{-1}$, and during the 2nd year farmers produce 1474 kg $ha^{-1}$ $year^{-1}$ of fodder with an average monetary value of 64 USD $ha^{-1}$ $year^{-1}$. Every 5 year farmers can get 8461 USD $ha^{-1}$ from *A. decurrens*. In general farmers' income from fodder and *A. decurrens* intercropped LUS during the 5 years was 8658.5 USD.

**Table 3** Productivity of sole fodder LUS, *A. decurrens* and fodder intercropped LUS and the monetary value in USD

| Research sites | Sole fodder LUS | | Fodder and *A. decurrens* intercropped LUS | | | | *A. decurrens* value after 5 yrs (USD $ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| | Fodder biomass (kg $ha^{-1}$ $year^{-1}$) | Fodder value after 5 years (USD $ha^{-1}$) | 1st year fodder biomass (kg $ha^{-1}$ $year^{-1}$) | 1st year fodder value (USD $ha^{-1}$) | 2nd year fodder biomass (kg $ha^{-1}$ $year^{-1}$) | 2nd year fodder value (USD $ha^{-1}$) | |
| Ashewa | 3310 | 711.7 | 3110 | 133.7 | 1510.0 | 64.9 | 8470.7 |
| Amesha | 3250 | 698.8 | 3190 | 137.2 | 1571.2 | 67.6 | 8430.4 |
| Gafera | 3700 | 759.5 | 2990 | 128.6 | 1490.1 | 64.1 | 8490.6 |
| Endewuha | 3300 | 795.5 | 3350 | 144.1 | 1562.0 | 67.2 | 8412.2 |
| Gula | 3690 | 793.4 | 2980 | 128.2 | 1238.0 | 53.2 | 8500.2 |
| Mean | 3450 | 751.8 | 3124 | 134.3 | 1474.1 | 63.4 | 8460.8 |

[NB]The current average price of 1 kg fodder was 0.043 USD; *A. decurrens* value (USD $ha^{-1}$) was calculated after 5 years. 3rd and 4th years were the *A. decurrens* growing/maturity years without fodder

### Productivity of crop and *A. decurrens* intercropped land use system

Table 4 shows the total productivity of Teff and *A. decurrens* intercropped small-scale agroforestry LUS. On average farmers collect 1836 kg ha$^{-1}$ Teff grain yield and 4374 kg ha$^{-1}$ straw from the Teff and *A. decurrens* intercropped LUS during the first year. From Teff and *A. decurrens* intercropped LUS, during the 1st year farmers produce 1836 kg ha$^{-1}$ year$^{-1}$ of teff grain with an average monetary value of 1579 USD ha$^{-1}$ year$^{-1}$, 4374 kg ha$^{-1}$ straw with an average monetary value of 63 USD ha$^{-1}$ year$^{-1}$. During the 2nd year farmers produce 1328 kg ha$^{-1}$ year$^{-1}$ of fodder with an average monetary value of 57 USD ha$^{-1}$ year$^{-1}$. Farmers also can gain 7096 USD ha$^{-1}$ every 5 year only from Teff and *A. decurrens* intercropped LUS. In general the farmers' income was 8995USD (288,000 Ethiopia Birr) from Teff and *A. decurrens* intercropped LUS, every 5 year.

### Productivity of sole *A. decurrens* land use system

Table 5 shows the productivity of the sole *A. decurrens* LUS. Farmers' harvest 119,030 kg ha$^{-1}$ charcoal and 43.8 carts of non-charcoal produce on average, which was estimated as 11,260 USD ha$^{-1}$, 566 USD ha$^{-1}$, respectively. Farmers also produce 11,826 USD (379,566 Ethiopian Birr) ha$^{-1}$ in 5 years considering the current conversion rate of USD and Ethiopian Birr. The sole *A. decurrens* LUS is different from the Teff and *A. decurrens* LUS and fodder and *A. decurrens* intercropping LUS in plantation spacing. In the sole *A. decurrens* LUS, *A. decurrens* is planted at close spacing compared with the spacing in fodder—*A. Decurrens*, and Teff—*A. Decurrens* LUS.

### Cost–benefit analysis (CBA)

In cost–benefit analysis the total cost invested, the total produce and the net income obtained by farmers for the five land use systems (LUSs) such as sole crop (Teff) LUS; sole fodder LUS; crop and *A. decurrens* intercropped LUS; fodder and *A. decurrens* intercropped LUS and sole *A. decurrens* LUS were investigated. Since the sole *A. decurrens* LUS took a minimum of 5 years for harvesting, comparison was made based on the 5 year cost invested, produce and income obtained.

In 5 years' time farmers could get a gross income of 7193 USD from sole crop (Teff) LUS; 751 USD from sole fodder LUS; 8995 USD from the crop (Teff) and A. *decurrens* intercropped LUS; 8659 USD from the fodder and *A. decurrens* intercropped LUS; and 11,826 USD from the sole *A. decurrens* LUS (Fig. 5). The smallholder farmers obtained the greatest gross income from the sole *A. decurrens* LUS followed by the crop (Teff) and *A. decurrens* LUS, and the fodder and *A. decurrens* intercropped LUS, respectively. The smallest gross income was from the sole fodder LUS. However, the net income (USD ha$^{-1}$) is 8184 (Teff-acacia intercropped), 7672 (fodder-acacia intercropped), 6850 (sole acacia), 4920 (sole Teff), and 278 (sole fodder). The highest income is from Teff-Acacia intercropped followed by fodder-Acacia intercropped and sole Acacia, respectively. The smallest net income was from the sole fodder LUS.

## Discussion

Linking agroforestry based produces with farmers' income is vital for sustainable production and maximized benefits. In this study farmer's income and the different small-scale agroforestry (SSA) land use system (LUS) were analysed, which LUS could generate better income for smallholder farmers was examined. The cost incurred for production and the financial value of the produce were calculated and the net income of the produce were used to evaluate the different LUS in relation to farmers' livelihood improvements.

In the Fagita Lekoma district, farmers' are practicing different LUS based on SSA land use system: (1) Some farmers intercropped Teff and *A. decurrens* to harvest Teff grain yield for human consumption and straw for livestock feed in the first year; fodder for livestock feed in the second year (fodder and Acacia intercropped LUS); and charcoal and non-charcoal products for financial income after 5 years from Acacia produce. (2) Some farmers intercrop *A. decurrens* and fodder to harvest fodder in the 1st and 2nd years for livestock feed, and charcoal and non-charcoal products for financial income after 5 years. From the 3rd to 5th years, only *A. decurrens* remain in the field to mature and will be harvested in the 5th year. (3) Some farmers' plant only *A. decurrens* in

**Table 4** Productivity of Teff and *A. decurrens* intercropped LUS and the monetary value in USD

| Study sites | Intercropped Teff grain yield (1st year) | | Intercropped Teff straw (1st year) | | Fodder (2nd year) | | Intercropped *A. decurrens* value after 5 years (USD $ha^{-1}$) | Total income after 5 years (USD $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | kg $ha^{-1}$ $year^{-1}$ | USD $ha^{-1}$ $year^{-1}$ | kg $ha^{-1}$ $year^{-1}$ | USD $ha^{-1}$ $year^{-1}$ | kg $ha^{-1}$ $year^{-1}$ | USD $ha^{-1}$ $year^{-1}$ | | |
| Ashewa | 2020 | 1737.2 | 4680 | 281.3 | 1324.1 | 56.9 | 7045.6 | 9121.0 |
| Amesha | 1760 | 1513.6 | 4480 | 269.7 | 1477.0 | 63.5 | 7101.1 | 8947.9 |
| Gafera | 1900 | 1634 | 3900 | 234.9 | 1369.2 | 58.9 | 7060.2 | 8988.0 |
| Endewuha | 1780 | 1530.8 | 4220 | 254.0 | 1420.1 | 61.1 | 7070.4 | 8916.3 |
| Gula | 1720 | 1479.2 | 4590 | 276.3 | 1052.0 | 45.2 | 7200.7 | 9001.4 |
| Mean | 1836 | 1578.9 | 4374 | 263.3 | 1328.0 | 57.1 | 7095.6 | 8994.9 |

NB, current average price of 1 kg Teff was 0.86 USD; 1 kg Teff straw was 0.0602 USD, 1 USD is ~ 32 Ethiopian Birr

During the 1st year, farmers' harvest Teff grain and straw, and during the 2nd year farmers' harvest fodder

**Table 5** Productivity of the sole *A. decurrens* LUS and the monetary value in USD

| Study sites | Charcoal | | Non-charcoal | | Total value (USD ha$^{-1}$) |
|---|---|---|---|---|---|
| | Yield after 5 years (kg ha$^{-1}$) | Value after 5 years (USD ha$^{-1}$) | Yield after 5 years (cart ha$^{-1}$) | Value after 5 years (USD ha$^{-1}$) | |
| Ashewa | 112,000 | 10,595.2 | 43.2 | 557.8 | 11,153.0 |
| Amesha | 122,800 | 11,616.9 | 45.2 | 583.7 | 12,200.6 |
| Gefera | 122,800 | 11,616.9 | 44.4 | 573.3 | 12,190.2 |
| Endewuha | 113,850 | 10,770.2 | 44.8 | 578.5 | 11,348.7 |
| Gula | 123,700 | 11,702.0 | 41.4 | 534.6 | 12,236.6 |
| Mean | 119,030 | 11,260.3 | 43.8 | 565.6 | 11,825.8 |

NB, 1 kg charcoal was 0.0946 USD; 1cart chaff was 12.9 USD (cart is an open vehicle with two wheels pulled by a horse or mule used for carrying loads) and 1 USD is ~ 32 Ethiopian Birr

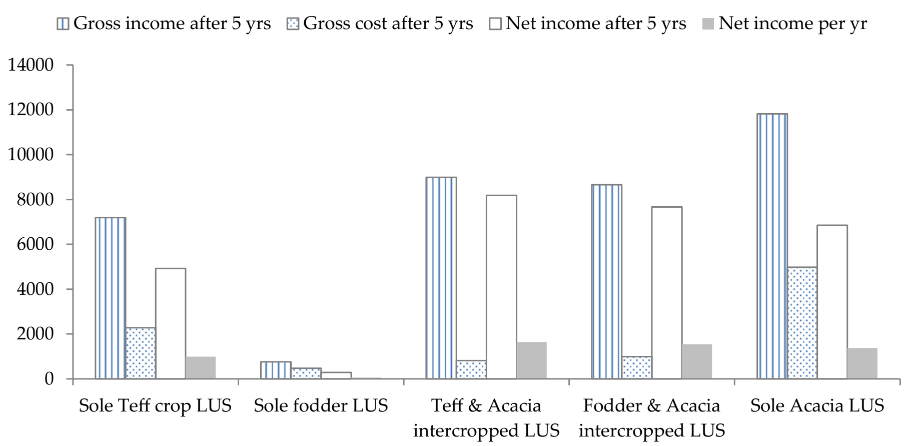


**Fig. 5** The cost applied and the income incurred (in USD) by farmers' from different LUSs

their field from the 1st to the 5th year, to harvest *A. decurrens* and produce charcoal and other non-charcoal produce, and (4) some farmers' grow only Teff to harvest Teff grain yield for human consumption and straw for livestock feed.

The gross cost incurred is the highest in the sole Acacia LUS (4976 USD) followed by sole Teff (2275 USD) and the least cost incurred is from the sole fodder LUS (474 USD). Although the gross income is the highest in the sole acacia LUS, the net income is highest in Teff-acacia intercropped LUS, followed by the fodder-acacia intercropped LUS. The reason is difference in cost incurred during the production processes.

Based on; (1) annual grain yield produce for human consumption, (2) annual straw biomass/fodder produce for animals consumption, and (3) better net income after 5 years from acacia; the Teff-acacia intercropped LUS is recommended to be practiced by farmers. Fodder-acacia intercropped LUS is the second recommendation/advise to be practiced by farmers due to its fodder produce during the 1st and 2nd years, and the net income it provides to farmers next to Teff-acacia intercropped LUS. The third recommendation is the sole acacia LUS because it is the 3rd in net come. Therefore, the Teff- acacia intercropped, fodder-acacia intercropped and the sole acacia LUSs have to be up-scaled at wider spatial scale in order to maximize the farmers' income and improve their livelihood.

Moreover the SSA land use system has additional benefits confirmed by different studies, although not studied in the study area, Fagita Lekoma district. For instance, acacia based SSA land use system is crucial to improve the fertility of the soil (Rajeshwar Rao et al. 2018; Keesstra et al. 2018), mitigate climate change (Viswanath et al. 2018) and reduces the risk of crop failure and ensures alternate income to smallholder farmers' (Sileshi et al. 2011).

## Intercropping and small-scale agroforestry

Intercropping as a small-scale agroforestry (SSA) system is very positive from an environmental point of view, to mitigate climate change sequestering the greenhouse gases (Brooker et al. 2015; Himanen et al. 2016), to reduce the soil losses as vegetative cover (Tanveer et al. 2017) and as source of income since the economic benefit is the key issue for farmers when they need to take a decision about land management (Min et al. 2017; Vlachostergios et al. 2018; Cerdà et al. 2018; Rosa-Schleich et al. 2019). Small-scale agroforestry as intercropping can also improve the domestic economy (Chapagain et al. 2018) and achieve proper biophysical land resource management and societal development (Xhuang et al. 2019). In the Ethiopian highlands where the population density is high, like Fagita Lekoma, the need for more productive and sustainable use of the land becomes more urgent to meet the demand for food production. Small-scale agroforestry LUS is part of the solution since agroforestry is the intentional integration of trees into crop and animal farming systems for better production as well as for environmental, economic, and social benefits (Min et al. 2017) and achieve international development goals (Keesstra et al. 2016).

Land degradation because of inappropriate LUS is severely affecting the highlands of Ethiopia, which account $\sim$ 45% of the nation's total land area, in which $\sim$ 90% of the population is settled and 90% of the productive cropland found (Hurni et al. 2010). To reduce land degradation, for the past four decades the government had tried to bring a change in the LUS using laws or regulations. For instance, the government had tried to change the crop based LUS on steep slopes to plantation LUS because using steep slope lands (> 40% slope gradient) for crop production is causing land degradation. However, farmers didn't accept the law and changed the LUS as required (Worku et al. 2020).

On the other hand, in the Fagita Lekoma district, farmers are changing the crop LUS to plantation LUS without any enforcing laws'. Here the enforcing factor is income obtained as a result of the land use change, not the law or regulation. This confirms that the SSA land use system being practiced by farmers in the Fagita Lekoma district will be one solution to change the existing exploitative LUS, especially in the degraded highlands, to productive LUS. Therefore, the Ethiopian government, the national and regional concerned ministries/offices should consider this finding as a policy input to bring a land use change.

## Limitations of the study

(1) In the study district farmers' are using crop rotation, however, Teff grain yield and straw biomass were calculated for 5 years without considering such rotation, which will influence the produce; (2) Fodder biomass was calculated for 5 years from a year collected data, which might be different in different years; (3) During this study plant spacing during acacia plantation was not considered. Plantation spacing in sole acacia and Teff-acacia intercropped LUS is different. The spacing is far in Teff-acacia intercropped LUS than in sole acacia. This will have a great influence on the volume of wood produce. (4) This study doesn't take into account farmers preferences, market demand, soil stabilization, firewood for direct household consumption, etc. A social science survey is required to collect such data. (5) In this study only the economical aspect of Acacia based SSA system is studied, its ecological and environmental importance is not studied yet. Therefore, further studies, which will consider all these limitations is recommended.

## Conclusions

The economic benefit of different land use systems (LUS) practiced by smallholder farmers was investigated at Fagita Lekoma district in the northwest highlands of Ethiopia. The Teff-acacia intercropped, fodder-acacia intercropped, and sole acacia land use systems (LUS) were found to provide better net income for farmers, respectively. The Teff—*A. decurrens* intercropped LUS provided 1.3 and 1.2 times more income than the sole Teff and sole Acacia LUSs, respectively. The fodder-acacia LUS provided 11 times more income for farmers compared with the sole fodder LUS. These are the main reasons motivating farmers to change the sole Teff and sole fodder LUSs to mixed/intercropped LUS. In general, *A. decurrens* intercropped based SSA land use system was found to provide better income for smallholder farmers. Hence, the mixed LUS is recommended to be practiced by farmers and could be up-scaled to other areas having similar agro-ecological situations. The acacia based SSA land use system, not only help in increasing farmers' income but also in changing the exploitative land use to productive land use.

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