Synergy and trade-offs between economic efficiency and environmental effects of alternative land use practices using farm level static bio-economic modelling in Bale Eco-Region

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Received 27 February, 2017; Accepted 4 April, 2017

In Bale Eco-Region (EBR), production and productivity mainly suffers from fertility deterioration, skyrocketing prices of fertilizer, and unsustainable interactions among different land uses systems. This study was initiated to determine synergy and trade-offs between economic efficiency and environmental effects of alternative land use practices using farm level static bio-economic modelling EBR. Data were collected through household survey, group discussion, key informant interviews and field observation. The data collected was analyzed using both descriptive and econometric analysis. The result indicates economic return of crop-livestock mixed farming first falls but progressively increases as environmental quality increases, showing a more stable increasing rate at higher Environmental Performance Index (EPI) values in highland, in midland food crop production. However, trend of bio-economic optimality curve and coefficients of interaction between environmental and economic efficiency of land use both show large trade-offs and interaction between economic returns and environmental sustainability effects crop production in lowlands of BER is negative and large. Therefore, encourage integrated farming and discourage mono-cropping especially in mid and lowlands of eco-region through improving economic returns of integrated farming practices and creating awareness of rural households on environmental impacts of such farming practices.

Key words: Bio-economic, economic analysis, synergy.

INTRODUCTION

Making agricultural production sustainable in terms of food ability systems to meet current and future demand is crucial. Nevertheless, adoption of economically sustainable land management practices and technologies is constrained by shortage of land and capital resources. For instance, improved fallows are constrained by land

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shortages; use of high value seeds and fertilizers by capital and access to markets; intensive dairying and horticulture by high transport costs and poor market access; late maturity cash crops such as tea or coffee and soil erosion control measures by land tenure. While off-farm activities may provide much-needed income to augment farming activities, they may take away productive labour from farms. When farmers sell their labour, they do so at the expense of their own farm activities and in the process, they may delay in preparing their own land for planting, weeding and/or harvesting, resulting in sub-optimal yields (Place et al., 2003).

The interaction at economy-environment interface shows that conventional agricultural practices that tend to focus on profit maximization are no longer sustainable. Rather agriculture should be transformed to meet multiple goals of sustainable development such as economy, environment, and society (FAO, 2013). In front of climate change, transformation of agriculture to achieve sustainable development goals is indispensable. As it is not possible to increase the area under production in higher-potential areas, effective technologies and/or interventions are required that increase farm productivity and enhances sustainability and thereby improves human well-being. For agricultural systems to achieve climate-smart objectives, including improved food security and rural livelihoods as well as climate change adaptation and mitigation, they often need to be taking a landscape approach; they must become ‘climate-smart landscapes’. Climate-smart landscapes operate on principles of integrated landscape management, while explicitly incorporating adaptation and mitigation into their management (Scherr et al., 2012).

To achieve food security and agricultural development goals, adaptation to climate change and lower emission intensities per agricultural output will be necessary. Above all, this transformation must be accomplished without depletion of the natural resource base. Developing countries and smallholder farmers and pastoralists are being especially hard hit by degradation of natural environment. Many of these small-scale producers are already coping with a degraded natural resource base. Enhancing food security while contributing to mitigate climate change and preserving natural resource base and vital ecosystem services requires transition to agricultural production systems that are more productive, use inputs more efficiently, have less variability and greater stability in their outputs, and are more resilient to risks, shocks and long-term climate variability. More productive and more resilient agriculture requires a major shift in way land; water, soil nutrients and genetic resources are managed. Making this shift requires considerable changes in national and local governance, legislation, policies and financial mechanisms. This transformation will also involve improving producers' access to markets. By reducing greenhouse gas emissions per unit of land and/or agricultural product and increasing carbon sinks, these changes will contribute significantly to climate change mitigation (FAO, 2015).

The current challenges of agriculture and natural resources calls for incorporating improved farm planning for meeting multiple goals and then more than ever increased effort is required about proper farm planning and management practices objectives. In this regard, resource allocation in way that addresses the question of what or how to produce, and to whom produce is essential. This requires assignment of available resources to various competing uses based on social, economic, institutional and environmental criteria (Brian, 2009). In this regard, optimization, as a mathematical model based approach of decision making or resource allocation play significant role (Snyman, 2005; Eiselt and Sandblom, 2007; Griva et al., 2009). Schreinemachers and Berger (2006) pointed out that, land use decision using optimization is advantageous over heuristic decision modelling for three reasons: (a) Optimization techniques allow multiple input and output decisions, such as maximizing employment and profit (two outputs) from crop production from multiple inputs such as land, labour and financial capital, thus relatively easily capturing heterogeneity of agents. They also permit sensitivity analysis or economic trade-offs that can be easily evaluated to assist decision making; (b) Optimization models results imply clear policy recommendations identifying sources of economic inefficiencies and; (c) Optimization tools can make significant contributions to support sustainable environmental and natural resource management through enhancing agriculture efficiency (Bjorndal et al., 2012).

**METHODOLOGY**

**Study area description**

**Location**

The study was conducted in Bale Eco-Region, South East Ethiopia. Bale Eco-Region (BER) lies at 400 km south east of Addis Ababa, the capital city of Federal Democratic Republic of Ethiopia. The Bale region is geographically found between 05°22’-08°08’N and 38°41-40°44’E (Figure 1) (Charlene, 2013).

**Topography, climate and vegetation**

The Afro-alpine plateau of central area of BER reaches more than 4000 m above sea level (masl). Containing Erica, Giant lobelia (Lobelia rinchopatelum) and Helichrysum, this is the largest remaining area of Afro alpine habitat on the African continent (BMNP, 2007). South of the plateau the altitude falls rapidly with moist tropical forest between 2600 and 1500 m.a.s.l. The moist forest is characterized by Hagenia abyssinica and wild coffee (Cofhea arabica).

The average annual temperature was 17.5°C (10 to 25°C range). Average annual rainfall was 875 mm with long rains experienced between June and October, and short rains between March and May (Yimer et al., 2006). The BER is rich in distinctive endemic flora and fauna because of its isolation from Ethiopian highland
bulk and its topography and climatic history (Hillman, 1986; Yalden and Largen, 1992).

North of plateau habitats, comprise of dry forest, woodlands, grasslands and wetlands, largely between 2500 and 3500 masl. The dry forests contain high-value commercial species such as Junipers procera and Podocarpus falcatus as well as Prunus africana, a threatened species. The lower altitude land of the south east of the BER, below 1500 masl, is dominated by acacia woodland (UNIQUE, 2008; Teshome et al., 2011).

Population

Demographically, BER falls within Oromia regional state, the most populous province in region with a population of 1,391,511 in 2007 (CSA, 2008). The population density of district is about 46 persons per square kilometre. Based on the census of 2007, the total population of BER projected for 2016 is 1,811,892 of which 906,689 are males and 905,203 females (CSA, 2013). Accordingly, Dinsho Woreda population is 49,574 with 24,312 males and 25,262 females; Harenna-Buluk woreda is 102,872 with 52,080 males and 50,792 females and Berbere woreda is 114,475 with 58,463 males and 56,012 females.

Land use and agriculture

BER known for mixed farming, that is, crop production, predominantly food crops: barley, wheat, horse bean, field peas, potatoes, flax, Niger seed, and livestock rearing. The highland is moderately productive; wheat, barley and pulses are dominant crops grown in this area income is earned from sales of crops, livestock, fodder, and eucalyptus trees. Mid-altitude is moderately populated; main crops practiced in this agro-ecological zone are maize, sorghum, teff, pulses, wheat and oil seeds (Niger, Sesame and Flax). Households also keep livestock (cattle and sheep). Lowland of BER was known dominated by Agro pastoralist livelihood strategies. Main crops practiced in this sub region are sorghum, teff and maize and livestock is composed of cattle and goats. For poorer households, significant part of their income is from farming, local labour and firewood collection/sales, which they use it for purchasing part of their staple food requirements during food shortage. They practice indigenous farming system.

Bale zone with the land area coverage of 43,690.56 km² is estimated to constitute 16.22% of Oromia region total area. From total area, cultivated land accounts for 10%, grazing land 24.6%, forest and bushes 41.8%, marginal wastelands 10.6% and others 13% (CSA, 2007).

Sampling techniques

For this study, data were collected from sampled households selected based on appropriate sampling techniques. Sampling is a technique, which helps to understand parameters or characteristics of population by examining only a small part of it. Therefore, it is
necessary that sampling technique should be reliable. Appropriate sample size depends on various factors relating to subject under investigation like time, cost, degree of accuracy desired, among others. But sample size and selection process procedure should assure population representativeness (Daniel, 2008).

In this study, multistage sampling technique was employed to select respondents. In first stage, from BER, three districts/woredas (namely, Dinsho, Harena buluq and Berebere) were selected purposively. The main criteria used to select the three Woredas were representativeness agro-ecological variation highland, midland and lowland and by considering major land use practices/farm system. In second stage, two Kebeles were selected purposively. These selections were carried out by stratifying each Kebele into three land use system/practices (Mon cropping, Livestock rearing and Crop-livestock mixed farming). In third stage, from each stratum households were selected randomly. The required sample size was determined in proportion to population size of Kebeles. Simple random sampling is the simplest form of probability sampling therefore each population element of simple random sampling has a known and equal chance of selection.

Accordingly, in this study, sample size selection was based on the rule of thumb $N \geq 50 + 8 \, m$ developed by Green (1991). Where $N$ is sample size and ‘$m$’ is the number of explanatory variables ($X_i$) where $i=1, 2, ..., n$. Where a total of 14 key variables were assessed for this research hence the sample size is determined as:

$$N \geq 50 + 8 \times 14 \quad N = 174 \, HHs$$

Hence, based on rule of the aforementioned thumb, a total of 174 respondents from the selected PAs (Kebeles) of the district will be selected and interviewed.

Types and source of data

Both primary and secondary data regarding land use and production practices such as land size, cost and revenue of crop production, current farming practices, and research/farm field estimates of the productivity of crops per hectare were collected. And a review of secondary data such as reports of Ministry of Agriculture and FAOSTAT was made to estimate parameters of models for different scenario for household and aggregated models. Quantitative data collected from sample households and secondary sources were used to estimate costs and revenues of production per hectare of each land use system at farm level. Estimates of total land size, cost of production per hectare of land use type, estimated minimum production requirement for own consumption of each household and estimated productivity per hectare of land were obtained from primary data.

The secondary data were obtained from published and unpublished reports of agricultural bureaus at different levels (Region, Zone, Woreda, and Kebele), report of central statistical agency (CSA), different websites and different published articles. Besides, qualitative data regarding factors of cropland allocation, involvement, and awareness of environmental and natural resource constraints and level of involvement in natural and environmental resource management practices were collected using focus group discussions, household surveys, and key informant interviews.

Methods of data collection

For this study, a combination of household survey and Participatory Rural Appraisal (PRA) techniques were used to collect relevant data. PRA techniques used in this study include Focus Group Discussions (FGDs), Key Informant Interviews (KII), and field observations assisted by informal discussions with staff of NGO’s working in the area (e.g. Farm Africa, SOS shale).

Key informant interviews

Individuals who had lived in the district for long time and model farmers in managing their farm lands as well as those believed to have better knowledge about issues at both household and community levels in their localities were selected for key informant interviews. Accordingly, key informants were selected from each kebele administration and face-to-face interviews were conducted. Thus, key informants that were included in discussion were local community, government organization, and non-government organization. The questions raised during key informant interview were how land allocation decision at community level and household level is carried out, dynamics in land allocation decision, constraints to food production and natural resources and environmental degradation, and the possible solutions to the problems.

Focus group discussions

Focus group discussions were carried out with representatives of the community who had lived long in study area and had experience on how land allocation decision were made for alternative land uses in the area. The discussions were made with separate and independent groups of women, youth, and elders in selected Kebele and those with a total of two focus group discussions in each kebele were conducted. The reason for including woman, men and youth in discussion was to produce relevant information on certain topics like on different functions of different spaces of land, who makes decision, what actors are involved in decision making on both communal and private lands, and other related issues stated in research objectives. The discussions were facilitated by researcher together with enumerators group members were encouraged to share ideas freely on discussion topics.

Field observation

In addition to data collected through structured and semi-structured interviews, field observations accompanied by an informal survey were carried out. This would have enabled to have an insight on how land allocation decision is practically carried out, consequences of inappropriate land allocation, and whether there is differential allocation and outcome among households and among physical spaces.

Household survey

Survey of a total of 174 farm and agro/pastoral HH units (initially determined by the rule of thumb) was carried out to collect primary data in sixth kebeles study. To that effect, a semi-structured questionnaire was prepared for research topics separately (analysis of economic and environmental performance of alternative land use practice by using bio-economic modelling) and translated into Afan Oromo (local language). The questionnaire was first tested in all kebeles during reconnaissance survey, consequently amended and administered to sample respondents in each kebele via face-to-face interview conducted by trained enumerators and researchers (annex I-III for survey questionnaire templates for research topic).

Method of data analysis

In this study, two types of data analysis techniques were used, namely descriptive statistics and bio-economic modelling methods to analyse data collected at both community and household levels.
Descriptive statistics

Descriptive statistics were used to estimate parameters of variables addressed based on household survey data. Summary statistics such as mean, frequency, and percentage are estimated. Tables and graphs were used to organize and data present. Hypothesis testing of mean difference between performances among different major land use were made. The analysis was carried out using Microsoft Excel 2010 and SPSS 20.

Bio-economic modelling

Several quantitative and economic analysis methods and tools were used to empirically measure and comparatively analyse land use practices in terms of farm productivity and environmental sustainability in BER. To that end analysis of economic performance of farming; average/total cost and revenue of crop farming/ha, average/total cost and revenue of livestock rearing/TLU (total livestock unit), average crop yield/ha, average livestock income/TLU/year, total farm income/HH/year, and benefit-cost ratio of land use. In addition, smallholder farm HH level bio-economic modelling (Groot et al., 2012) was used to measure and determine interactions levels (synergies and trade-offs) between economic outputs and environmental effects (EPI values) of different farming/land use practices in BER. Subsequently, regression coefficients and farm level production function curves drawn from bio-economic modelling were used to analyse economic and environmental optimality and sustainability of different farming and land use practices of smallholder HHs in each agro-ecology.

With respect to the aforementioned, bio-economic optimality of major land use systems of rural HHs in BER was analysed with respect to their economic performances and environmental sustainability effects separately and simultaneously. Accordingly, a farm household level static bio-economic model (Groot et al., 2012) was used to quantify and empirically analyse the farm level production processes and interactions between the economic process (input-outputs) and environmental effects (soil quality, forest, biodiversity, etc) of major land uses and farming systems of rural HHs in BER.

Score ranking of environmental performances

To assess and determine environmental qualities and efficiency of different land use practices of smallholder farm/pastoral HH units, three important environmental quality indicators/parameters were assessed for most of HHs surveyed. The environmental quality indicators assessed were:

1. Soil quality (fertility, texture and moisture content, yield/ha).
2. Land management status/ level of degradation (erosion and gullies, terraces and bunds, etc).
3. Tree and vegetation cover and diversity (Number of trees/ha, Number of plants on farmland, Percentage of land covered by vegetation/grass, abundance of wildlife in the area), among others.

The assessment and rating of aforementioned indicators was carried out based on an environmental efficiency index (EEI) that was developed (Yale Centre for Environmental Law and Policy, 2008). Yale Centre for Environmental Law identified twenty-five environmental efficiency indicators for sustainability based on availability of information. Based on this evidence EEI indicators, soil quality and productivity, tree or vegetation cover and biodiversity management, and land management and sustainable use were used for this study.

In view of that, five different EEI classes were developed; from very low (EEI =0-1) to very high (EEI = 4-5). The qualitative characteristics and quantitative score value ranges of the environmental quality indicators used were defined in detail for each three indicators established (Annex V for sample EEI assessment indexes). Accordingly, both quantitative and qualitative measures of the environmental quality indicator parameters were carried out for each farm/pastoral HH units surveyed. The information obtained from these informants was later quantitatively interpreted based on EEI matrix established.

Finally, the results obtained from assessments made by three indicators assessed were averaged out to calculate mean score values of each indicator for each farm HH unit and consequently produce an aggregate EEI value of major farming/land use practices of rural HHs in BER region.

RESULTS AND DISCUSSION

This aspect of the study deals with the socioeconomic characteristics of respondents. The second presents decision-making behaviour of smallholder farmers for alternative land use practices and examines factors that influence it. The third is about return from major land use practices at farm level both in terms of physical yield and economic return. The fourth is about optimality and trade-offs between economic performances and environmental effects of alternative land use practices, using farm level static bio-economic modelling and environmental outcomes of alternative land uses.

Demographic and socio economic characteristics of respondents

Socioeconomic characteristics of respondents (dummy variables) were presented, followed by socioeconomic characteristics (continues variable). The result in Table 1 shows that 86.1% of sampled households were male-headed and only 13.9% were female-headed in Bale Eco-region. The result corresponds with Bezabih and Hadra (2015) findings who reported that most households are male headed where only two female households have participated from total of 141 respondents in their study.

Concerning marital status of respondents, 97.1% were married, 1.1% widowed and 1.1% were divorced (Table 1). The distribution generally shows that there are more married respondents than their widowed and divorced counterparts. Based on study results, regardless of their marital status people undertake land use practice activities in the district.

The survey on household heads age, measured in years, provided a clue on working ages of households. In high land area, mean age of respondent was 42.2 ±8.4 (24-62 range) years old (Table 2). This result shows that mean age was within active labour age. Per Central Statistics Agency of Ethiopia Report (2007), age ranges from 15-64 are working age group. The result shows that household respondents were 39.5 ± 8.8 in low land (25-64 range). This is also the same as to Central Statistics Agency of Ethiopia (2007) age ranges from 15-64 who
Table 1. Demographic characteristics of respondents (Own Survey, 2016).

| Variable    | Description | Frequency | Percentage |
|-------------|-------------|-----------|------------|
| Sex         | Male        | 149       | 86.1       |
|             | Female      | 24        | 13.9       |
| Marital status | Single   | 1         | 0.6        |
|             | Married     | 169       | 97.1       |
|             | Widowed     | 2         | 1.1        |
|             | Divorced    | 2         | 1.1        |

Table 2. Socioeconomic characteristics of respondents (continuous variable) (Own Survey, 2016).

| Variable | High land | Mid land | Low land |
|----------|-----------|----------|----------|
|          | Min       | Max      | Mean     | SD        | Min     | Max     | Mean     | SD        | Min     | Max     | Mean     | SD        |
| Age      | 24        | 62       | 42.2     | 8.4       | 30      | 65      | 42.7     | 8.31      | 25      | 64      | 39.5     | 8.8       |
| Family size | 3        | 19       | 10.1     | 3.3       | 4       | 19      | 10.1     | 4.14      | 3       | 21      | 8.37     | 4.3       |
| Education | 0         | 10       | 3.55     | 3.14      | 0       | 8       | 2.26     | 2.3       | 0       | 8       | 1.82     | 2.3       |
| Experience | 16       | 62       | 39.3     | 10.2      | 15      | 65      | 36.1     | 11        | 11      | 64      | 31.6     | 15        |

are working age group.

Farming experience is one of the most important issues to sanction farmers with knowledge of farming system and using alternative land use practices in farm land. The result in Table 1 indicates that average framing experience in years, households is 31.6 in low land. However, this varies between 11 and 64 years. This means that some households have as small as 11 years of experiences. Per key informants minimum farming experience indicate most of farmer in study area are spontaneous and others are government sponsored. In high land of BER, the average framing experience the households is 39.3 years.

The result in Table 2 shows that respondents have a mean family size 8.37±4.3 peoples ranging from 3 to 21 in low land. Bigger family size has contributed to boost volume of practices in study areas to impact for better participation in alternative land use practices. This is well supported by David (1998) who stated that, demand side means more mouths to feed may promote expansion of cropland, while supply side means more hands to work land and more labour available for clearing land or for intensification of crop management practices.

Similarly, higher labour intensity of agriculture can take form of production on more marginal lands, less use of fallow, adoption of more labour, intensive methods of cultivation intensive investments in land improvement and/or adoption of more labour, and intensive commodities (Pender, 2001). This is likely to lead to higher yields and higher value of crop production per hectare, unless greater intensity is offset by land degradation (Ibid et al., 1988).

The result in Table 2 shows that educational level of respondents have mean of 2.26 ± 2.3 of grade ranging from 0 to 8. In midland agro-ecology that respondents have average of 1.82 ± 4.3(0-8) ranging educational level. This means that some households have no formal educational in the study.

**Major economic activities**

In the study area, greatest economic activity was agriculture. Subsistence agriculture is dominant. It is characterized with very low use agricultural inputs and in turn monitored by low outputs. About 32.82, 24 and 25% of highland, midland and low land respondents were engaged in mixed farming respectively in study area (Table 3). The result shows that crop livestock mixed farming system in highland is practiced more than mid land and low land areas.

Crop production and livestock rearing are the major components of farming system as a main basis of livelihoods. The households cultivate crops on distinct land plots. Per key informants and focus group discussion, most commonly they cultivate cereal crops including maize, barley, teff and sorghum. Per key informants they age also engaged in livestock rearing for use of animal products like meat, milk, manure, and for purpose of drought power, transport, income sources and skins. About 45.3% of respondents in highland, 43% in midland and 35.3% low land of total sampled households are involved in crop production, respectively (Table 2). Per key informants’ crop produced are used for both domestic consumption and income generation. This result compared with Hampwaye et al. (2007) and Hampwaye (2013) findings who stated that crop cultivators used crops for both domestic consumption and
income generation.

The result in Table 3 shows that 21.88% sample respondents were engaged in livestock rearing in highland, 33% in midland and 40% in low land was livestock rearing for their economic activity in BER. The result shows that in low land of BER most household were engaged in livestock rearing than in mid altitude and in high land.

Bio-economic optimality and trade-off between of major land-use/farming systems in BER

Based on economic and environmental efficiency indicators findings (Appendix 1 and 2), combined bio-economic optimality function of each farming systems was constructed by modelling average farm income/ha/year (Y) against aggregate EEI values of farmland (X).

The resultant bio-economic optimality function curve was drawn and compared to optimal LU curve in each agro-ecology based on farm HH design model adopted. Consequently, coefficients of interactions between dependent variable (farm income) and explanatory variables (Environmental qualities) were produced.

Based on bio-economic optimality curves drawn for two farming systems in highland agro-ecology of BER (Figure 2), crop-livestock mixed farming system has a maximum EPI index value, 2.0 (X-axis) while cereal food cropping has a maximum EEI value of 1.5. And crop-livestock mixed farmers highest average farm income/ha (25,000 Birr per) was obtained when farmland is managed at better environmental quality (at X = 2.0). The average highest farm income per ha for cereal food cropping HHs (19,000 Birr) was obtained at low environmental quality index values (at X= 0.5).

In Figure 2, bio-economic optimality of two farming systems in highland Eco-region reveals that, as environmental quality of farm increases, economic efficiency of cereal (mono) crop production sharply decreases resulting in large gap (loss of income) shown by long disparity line with optimal land use curve (at x= 1.5).

In contrast, economic return of crop-livestock mixed farming first falls but progressively increases as environmental quality increases, showing a more stable increasing rate at higher EEI values in Figure 2. The gap between ideal optimal LU curve and mixed farming optimality curve also widens as environmental quality improves.

The coefficients of interaction between environmental quality (X) and farm income (Y) in optimality equations of two farming systems were ideal optimality. Evidently, primary coefficient of interaction between environmental quality (X) and farm income (Y) in crop-livestock mixed farming curve was a=0.538 indicating positive interaction and synergy between environmental management and economic return (Figure 2). Conversely, big negative coefficient of interaction between environmental quality (X) and farm income/ha (Y) in optimality function of cereal mono crop farming (a= -2.857) indicates large trade-offs between economic efficiency and environmental sustainability of farming practice. The magnitude of non-optimality of land use and trade-offs between two objectives is significantly higher from cereal food cropping compared to mixed farming in same agro-ecology.

In mid-altitude of BER, bio-economic optimality modeling of three farming systems has shown remarkable variations both in economic optimality and environmental sustainability of land uses. As shown in Figure 3, tree-crop agro-forestry (involving some level of income generation from NTFPs, cash cropping and few livestock) has shown the highest EEI (X = 3.5) both in mid-altitude and entire BER. Next to agro-forestry, traditional crop-livestock mixed farming (agro-pastoralism) has shown a maximum environmental efficiency of 2.0, while maximum EEI for food cropping in same agro-ecology was 1.5. In Figure 3, in terms of farm income per ha, the highest income (15,500) for agro-forestry farm units was obtained at moderate environmental quality (X=2.0) but lower than its maximum EEI (X= 3.5). Similarly, maximum income/ha (5,500) for agro-pastoral HHs was obtained at low (1.25) environmental quality index, lower than its maximum environmental quality index (2.0). And for midland food cropping, maximum farm income per ha (14,000) was made at lowest environmental sustainability index (0.5).

The bio-economic optimality curves together with coefficients of interactions between environmental quality (X) and farm income/ha (Y) reveal that the midland agro-forestry (also considered as conservation agriculture practice), income/ha from farming is positively influenced by increased environmental sustainability (a = 0.178).

| Variable        | High land N=64 Frequency | High land N=64 Percent | Mid land N=50 Frequency | Mid land N=50 Percent | Low land N=60 Frequency | Low land N=60 Percent |
|-----------------|--------------------------|------------------------|-------------------------|-----------------------|-------------------------|------------------------|
| Crop Production | 29                       | 45.3                   | 22                      | 43                    | 20                      | 35.3                   |
| Livestock Rearing | 14                      | 21.88                  | 18                      | 33                    | 24                      | 40                     |
| Mixed Farming   | 20                       | 32.82                  | 12                      | 24                    | 16                      | 25                     |
Figure 2. Bio-economic optimality curve of farming systems in the highlands of BER (Own Survey, 2016).

Figure 3. Bio-economic optimality curve of major farming systems in the midlands of BER EPI.
increasing positive synergy between two slowly weakens as the environmental quality significantly increases as shown in Figure 3.

For midland food crop production, however, trend of bio-economic optimality curve and coefficients of interaction between environmental and economic efficiency of land use both show large trade-offs. Evidently, an increase in a unit of cropping income is matched with a large decline in environmental quality (a = -3.14). More pronounced than trade-offs in highland mono-cropping, income/ha from mid-altitude food cropping sharply falls below 5,000 Birr/ha/year when farm production is carried out at better land/ecosystem conditions (Figure 3).

In lowlands of BER (Figure 4), bio-economic optimality modelling of three major farm and land use systems (food crop production, tree-crop-livestock mixed farming and traditional pastoralism) has shown significant variations both in terms of synergies and trade-offs for optimal and sustainable land use. As shown in Figure 4, EEI for tree-crop-livestock mixed farming system (agro-silvo-pastoralism) has shown the highest index value (X = 2.5) in lowlands, and second highest EEI value in Eco-region. Following agro-silvo-pastoralism, traditional pastoralism (with some periodic food cropping) has shown EEI value of 1.75 while environmental quality index of lowland crop production was 1.25. The latter is the lowest EEI among all farm/HH level land uses in entire BER.

In Figure 4 shown in terms of farm income, the highest average farm income/ha (25,500) for tree-crop-livestock mixed farmers is made at the highest EEI value (X=2.5), only farming system in BER where both economic and environmental efficiency of land use simultaneously increase with very strong positive interaction and relatively little fluctuation.

However, for traditional pastoral, HHs maximum income/ha (9,500) is obtained at low environmental quality (X = 1.25), lower than maximum observed EEI value by system (X=1.75). In contrast, the highest average income/ha under food cropping system (5,000) was made at the lowest environmental quality (0.5); a trend almost identical to crop production in mid-altitude agro-ecology but with much more reduced income per ha of a crop land (Figure 4).

The coefficients of interactions between environment efficiency (X) and farm incomes (Y) from optimality functions show that bio-economic optimality curve of agro-silvo-pastoral integrated farming system is closest to ideal optimal land use curve not only in lowland but also among all land use systems in BER. Particularly, large positive coefficient of interaction between economic returns and environmental sustainability index (a = 2.687) in agro-silvo-pastoral system clearly shows strong synergies between economic outputs and ecological sustainability effects of production system. Evidently, higher bio-economic optimality of land use in tree-crop-
livestock mixed farming is not only the highest among exiting HH level land uses systems in lowland agro-ecology but also among all HH level land use systems in BER (Figure 4).

In Figure 4, traditional pastoralism in BER lowlands has shown some degree of complementarities between environmental quality and income from farming system as environmental sustainability moves from X= 0.5 to X= 1.25. However, complementarities gradually weaken and trade-offs begin to outweigh synergies as environmental sustainability of farming system increases as shown by significant negative coefficients of interactions (a = - 0.635).

Trade-off/synergy between economic and environmental efficiency of land use that is sharply gap with the optimal land use curve as shown in Fig 3. The coefficients of interaction between economic returns and environmental sustainability effects crop production in BER lowlands is negative and large (a = - 1.8).

Conclusions

In support of stimulating growth, economic development, food security and alleviating poverty, sustainability of environment plays an important role in an ongoing or future small scale farmers farming use/system. This study was conducted at high land of Dinsho, mid land of Harena Bullq and low land of Berebre district analyze economic and environmental performance of alternative land use practices of smallholder farmers for building optimal and sustainable land use systems.

The findings from this study have shown the need to improve economic and environmental efficiency of alternative land use practices of smallholder farmers for building optimal and sustainable land use systems in BER. Five major farming systems/land use practices are currently being used by rural HHs of BER.

RECOMMENDATION

To improve productivity and economic competitiveness of smart land, there is need for it to be used for conservation agriculture, tree-crop mixed agro-forestry, tree-crop-livestock integrated farming, and agro/ pastoralism particularly in areas under NRM through provision and facilitation of more integrated farm production technologies/systems and provision of improved crop varieties and production inputs

Improve productivity of environmentally better optimal land use and farming systems such as crop-livestock mixed farming, tree-crop mixed farming, tree-crop-livestock integrated farming and agro/pastoralism through improved farm production technologies, improved crop varieties, improved water storage and use systems, among others.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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### Appendix 1. Summary of farm level production inputs (costs), outputs (income) and economic efficiency of major farming systems in BER.

| Agro-ecology | Farming system/land use type | *Crop yield in quintal/ha/Year | Food and cash crop production cost in Birr/ha/Year | Livestock production cost/ in Birr/TLU/Year | Total farm production cost in Birr/ha/Year | Net income from food and cash cropping in Birr/ha/Year | Net income from livestock in Birr/ha/Year | Income from forest & other sources in Birr/ha/Year | *Total net farm income in Birr/ha/Year | Total net income in Birr/HH/Year | Economic Benefit–Cost ratio (B/C) of the farming |
|---------------|-------------------------------|--------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Highland      | Cereal mono-cropping          | 23.83                          | 2,806                           | 536                             | 2,933                           | 8,054                           | 2,454                           | 153                             | 9,427                           | 34,090                          | 3.21                            |
|               | Crop-livestock mixed farming  | 21.62                          | 2,483                           | 452                             | 2,610                           | 9,411                           | 2,483                           | 10.43                           | 11,466                          | 49,876                          | 4.39                            |
|               | Food Crop production          | 15.06                          | 1,360                           | 580.30                          | 4109                            | 3641                            | 1286                           | 73.40                           | 5275                            | 8,800                           | 2.91                            |
| Midland       | Tree-crop- agroforestry       | 13.20                          | 1,404                           | 470.46                          | 3880                            | 2436                            | 1550                           | 1,284                           | 8811                            | 11,870                          | 4.02                            |
|               | Agro-pastoralism              | 8.81                           | 925                             | 695                             | 3814                            | 4303                            | 805                            | 834                             | 4898                            | 11,026                          | 3.37                            |
|               | Food crop production          | 10.50                          | 892                             | 628                             | 1,136                           | 2,691                           | 1,797                           | 285                             | 3518                            | 10,171                          | 3.09                            |
| Lowland       | Tree-crop- livestock farming  | 11.23                          | 780                             | 565                             | 2,108                           | 1,623                           | 1,326                           | 1,231                           | 7194                            | 11,854                          | 3.41                            |
|               | (Agro-silvo-pastoralism)      |                                |                                 |                                 |                                 |                                 |                                 |                                 |                                 |                                 |                                 |
|               | Pastoralism                   | 8.62                           | 483                             | 613                             | 3,405                           | 1,304                           | 2,357                           | 769                             | 16381                           | 28,272                          | 4.25                            |

*Crop yield quantified in the highland were wheat and barley; in the mid-lands and lowlands barley, sorghum and maize per ha.

### Appendix 2. Average and aggregate EPI values of studied farming systems in BER (0 = low and 5 = high).

| Agro-ecology | Farming system/land use practice | Soil quality index | Land manage index | Tree and biodiversity index | Aggregate EPlindexvalu e | Economic efficiency (B/C) | Bio-economic optimality ratio (0 < r < 1 ) |
|--------------|----------------------------------|-------------------|------------------|-----------------------------|-------------------------|--------------------------|------------------------------------------|
| Highland     | Cereal mono-cropping             | 1.45              | 1.44             | 1.00                        | 1.297                   | 3.21                     | 0.404                                    |
|              | Crop-livestock mixed farming     | 1.93              | 1.79             | 1.86                        | 1.860                   | 4.39                     | 0.424                                    |
|              | Crop production                  | 0.95              | 1.35             | 1.06                        | 1.120                   | 2.91                     | 0.385                                    |
| Midland      | Tree-crop agroforestry           | 2.95              | 3.09             | 3.55                        | 3.197                   | 4.02                     | 0.795                                    |
|              | Agro-pastoralism                 | 1.46              | 1.53             | 2.18                        | 1.723                   | 3.37                     | 0.511                                    |
|              | Crop production                  | 0.52              | 0.95             | 1.11                        | 0.860                   | 3.09                     | 0.278                                    |
| Lowland      | Tree-crop-livestock mixed farming| 1.81              | 2.08             | 2.64                        | 2.177                   | 2.90                     | 0.751                                    |
|              | Pastoralism                      | 1.23              | 1.52             | 2.5                         | 1.750                   | 4.25                     | 0.412                                    |