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REGULAR ARTICLE

FARM DIVERSIFICATION IN THE CENTRAL HIGHLANDS OF ETHIOPIA: PATTERNS, DETERMINANTS AND ITS EFFECT ON HOUSEHOLD INCOME

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ABSTRACT

Crop-livestock production is the major farming system in the highlands of Ethiopia. This study aimed to describe crop-livestock diversification pattern, examine determinants of diversification patterns, and evaluate effects of diversification on household income. Principal component analysis (PCA), seemingly unrelated regression (SUR) and ordinary least square (OLS) regression models were employed. Five major crop-livestock diversification patterns: sheep and goat, staple crops, chicken, vegetables, and animal feed-based farming were identified. The SUR model revealed that sex, education, income, extension contact, land size, market and road distance, irrigated land, and household size were significant factors that influence crop-livestock diversification patterns. It is also found that sheep and goat, vegetable, and chicken-based farming were significant production patterns that had positive effects on household income. We suggest that adoptive and adaptive agricultural practices such as small-scale irrigation, chicken rearing and sheep-based production patterns are the most potential farming systems in the highlands of Ethiopia.

Keywords: Agriculture, competition; diversification pattern; mixed farming
JEL: C12, C38, D13, Q12

INTRODUCTION

Agriculture is the most common livelihood strategy and basis for Ethiopian economy (**Dinku, 2018**). The agriculture sector contributes for 39% of national GDP (**UNDP, 2018**), and 83% of the population is engaged in agriculture (**ILO, 2014**)**.** The majority (90%) of the rural population rely mainly on crop-livestock systems and natural resources for their livelihoods, and nearly 60% of the land coverage is under non-pastoral production systems (**Lebeda *et al*., 2010; Dinku, 2018**). Mixed crop-livestock production is a regular activity in the highlands of the country (**Asante *et al*., 2017**). Heterogeneous farming systems have economic, social, and ecological advantages and the sources of food, household income, foreign exchange earnings, and response for employment opportunities and raw materials for industries (**Nigussie and Alemayehu, 2013; Martin *et al*., 2016**). Moreover, most households use crops and livestock for risk reduction and coping strategies (**Berhe**, **2011; Kassie, Kim and Fellizar, 2017**). In uncertain environment and unstable marketing situations, diversified farms are less risky than monocultures (**Shahbaz *et al*., 2017**).

Many literatures argue for a range of farm activities as a means to minimize income insecurity and insurance against crop failures (**Alemayehu, Dorosh and Sinafikeh, 2011; Lin, 2011; Liniger *et al*., 2011; Herrero *et al*., 2012**). Mixed crop-livestock systems provide bio-diversity and ecosystem services (**Nkonya *et al*., 2011; IFAD, 2013**). The systems reduce vulnerability to food insecurity. On top of this, mixed farming provides recreational, cultural and spiritual significance (**IFAD, 2010; Liniger *et al*,. 2011; Moraine *et al*., 2014).** Agricultural intensification is also considered as another alternative strategy for smallholders (**Shideed and El Mourid, 2005; Manyong, Okikeb and Williams, 2006**; **Iiyama *et al*., 2007a**). Population pressure is the key driver for agricultural intensification and production dynamics in the farming systems (**Boserup, 1965, 1981; McIntire, Bourzat and Pingali, 1992**). However, intensification has been criticized for environmental pollution, soil deterioration, land degradation, and nutrient depletion (**IFAD 2013**). Many researchers have tried to mediate the contrasted debates between diversification and intensification in agriculture (for instance, **Daniel, 2010; Todaro and Smith, 2012**). The latter is more appropriated for large-scale, location specific and capital-intensive enterprises.

Even though the government of Ethiopia has made efforts to improve the livelihoods of the rural poor, persistent challenges have been continued on agriculture for centuries. Food insecurity and high population density have always been adversely affecting the landscape situations of the highlands (**Lin, 2011; Kuria *et al*., 2014**). Population pressure, land fragmentation, soil erosion, and poverty are the main confronts in the highlands agro-climates (**IFAD, 2013; Abate, 2014; Haregeweyn *et al*., 2015**). At country level, one-third of the rural households could not produce adequate food for the rising population and exhibited large rates of malnutrition (**Harerro *et al*., 2012**). The population living below poverty line and under nourishment is 29.6 and 35.0%, respectively (**FAO, 2014**). The ever-increasing human population and severe land fragmentation made the food situations worsened

(**Sisay, Degsew and Mekuria, 2018**). Despite apparent yield improvements have been reported, evidences on agricultural technologies particularly crop varieties and animal breeds are not overwhelming (**Mekuria and Mekonnen, 2017**).

Mekuria *et al.* (2018) have also found that competition among crop-livestock activities for land resources is increasing. Therefore, it is crucial to identify patterns for crop-livestock production and determine associated factors to alleviate such competitions. One of the strategies, often adopted to tackle livelihood confronts, is producing integrated diversified crop-livestock activities. Crop-livestock diversity in turn helps to improve dietary diversity (**Sibhatu, Krishina and Qaim, 2015**). Diversified agriculture has a potential to produce adequate food, provide sufficient incomes, and maintain agro-ecosystem services (**Rudel *et al.*, 2016**). Despite mixed farming contributes in managing production risks, previous studies on agricultural diversification are minimal as mainly focused on livelihoods and crop diversification (**Mesfin, Fufa and Haji, 2011; Rehima et al., 2013; Sibhatu, Krishina and Qaim, 2015**). Moreover, there is no study conducted in Ethiopia that addressed crop-livestock diversification patterns and determinants of diversification. Therefore, the objectives of the paper were (i) to examine crop-livestock diversification patterns, (ii) analyze determinants of diversification patterns and, (iii) evaluate effects of diversification on household income in the farming systems.

DATA AND METHODS

Description of the study area

The study watershed was located in *Gudo Beret Kebele*, *Basona Worana* district, North *Shewa* Zone, *Amhara* region, Ethiopia. The geographical coordinates are situated between 9° 76′ to 9° 81′ of northern latitudes and 39° 65′ to 39° 73′ eastern longitudes. The study watershed covered about 2425 ha of land. The altitude in the watershed ranges between 2828 and 3700 meter above sea level. The mean daytime temperature was between 2.4 °C and 19.2 °C. The climate of the watershed was wet and moist highland with a bimodal rainfall pattern. The mean annual rainfall in the watershed was 1651 mm. According to ***Kebele* census (2016)**, the total population size of the study watershed was 2070 and 447 households.

The research watershed was characterized by mixed farming systems. The dominant livelihood sources include mainly subsistence crop cultivation, livestock husbandry, and plantation of eucalyptus woodlots. There was no natural forest in the watershed but eucalyptus trees around homesteads, hillsides, and gully buffers covered about 15.2% of the total study area (**Tadesse and Tafere, 2017**). Barley, wheat, faba bean, field pea, and vegetables are the major crops grown in the watershed, while the major livestock types include cattle, sheep, and equines. In often times, livestock husbandry has been practiced in combination with crop production and eucalyptus plantation. The sources of animal feed include crop residue, industrial byproducts, and open grazing in communal and individual plots. Despite livestock were allowed to graze under the eucalyptus woodlots, the high density of woodlots inhibited pasture growth for animals.

Sampling techniques and data collection

A three-stage sampling procedure was employed. At first stage, the study district was selected purposively. Similarly, the study watershed was selected purposively for the reason that intensive mixed farming systems have been practiced. The watershed was also a part of the USAID; feed the future funded Africa RISING project in the highlands of the country. In this watershed, 211 household-heads were randomly selected. The study was based on cross-sectional data collected in the watershed between May and June of 2016. Questions in the interview schedule were prepared to capture the details of farm households. Training on methods of data collection was conducted for enumerators. Finally, the data were collected at household level that include demographic, socioeconomic, institutional, and biophysical variables such as crop varieties, livestock breeds, incomes, and others.

Methods of data analysis

Descriptive statistics such as percentage, frequency, standard deviation, mean, and specifically a multivariate analytical technique PCA was employed to determine crop-livestock diversification patterns. Econometric methods such as SUR and Linear regression models were also used to examine determinants of diversification and effects of diversification on household income.

Model specification

PCA analysis: A multivariate statistical technique, PCA was employed to identify the dominant crop-livestock diversification patterns (**Lesschen and Verburg, 2005; Iiyama, Maitima and Kariuki, 2007b; Kebede *et al.*, 2016**). PCA is used to derive new sets of reduced and uncorrelated variables-diversification patterns (**Abdi and Williams, 2010; Keho, 2012**). PCA was derived from correlation matrix once different units of crop-livestock activities were standardized using z-score (**Gujarati 2003:173; Manyong, Okikeb and Williams, 2006**). Two criteria were employed to retain major components. High percentage of the total variation in the original variables is the first criterion (**Iiyama, Maitima and Kariuki, 2007b**) and as a rule of thumb Eigen values greater than 1.0 is the second criterion (**Manyong, Okikeb and Williams, 2006; Abdi and Williams, 2010**). The formula was adapted in **Keho (2012).**

$$Y_n = \alpha_{n1}(X_1) + \alpha_{n2}(X_2) + \cdots + \alpha_{np}(X_p) \qquad (1)$$

Where:

Y_n, the subject score on principal component indicates patterns and to what extent households engage in the production system; α_{n1} is the weight for variable X_1 in creating the component Y_n; $X_{1,}X_2, \dots X_p$ are variables or activities; α_{np} is regression coefficient for observed variable P; and X_p is subject score on observed variable p.

Model for determinants of diversification

Determinants for the major components of mixed farming systems were modelled using SUR assuming that error terms between components are expected to be correlated. SUR model is an efficient estimator of coefficients compared with OLS regression when the error terms between equations are correlated. The former provides a more robust parameter of estimates of coefficients, standard errors, and covariance compared to OLS regression (**Liew, 2017**). SUR model estimates more than two equations simultaneously. The parameters of each equation take information provided by the other equation into account (**Cadavez and Henningsen, 2012**).

$$Y_i = X_i\beta_i + \varepsilon_i \quad i = 1,2,\ldots,M \qquad (2)$$

Where:

Y_i is (T*1) vector with elements y_{ti}, X_i is (T*K_i) matrix whose columns represent T observation or an explanatory variable in the i^{th} equation, β_i is (K_i*1) vector with elements β_{ij}, M is parameters of equations and $\varepsilon_i = [\varepsilon'_{1,}\varepsilon'_2,\varepsilon'_3,\ldots\varepsilon'_M]$ is vector of disturbances.

The independent variables were selected based on previous empirical studies and the data gathered from household survey. The hypothesized variables were expected to influence diversification patterns differently; either positively or negatively (Table 1).

Model for the effect of diversification on household income

The impacts of crop-livestock diversification patterns on household income were modelled using OLS regression. The formula was adapted in **Greene (2002)** and computed as Eq. 3.

$$Y_i = X\beta + \varepsilon_i \qquad (3)$$

Where:

$Y$is t he proportion of annual income obtained in the i^{th} farmer, X is a vector of diversification patterns determining the amount of household income β is a vector of parameters to be estimated and ε_i is the error term.

RESULTS

Socio-economic attributes of households

In the study area, 29% of households were women-headed. The average household members were 4.5. Man equivalent and active labour force were accounted for 3.9 and 2.9 per household, respectively. The mean age of household heads was 44 years with a minimum and maximum of 23 and 82 years old. The age for the majority (90.5%) of household heads were between 23 and 65 years indicating that almost all household heads are in the range of active age. In terms of educational status, about 21% of household heads were illiterate while 43% household heads could read and write. The result also showed that, the mean land holding size was 1.3 hectare with a minimum of 0.1 and a maximum 4 hectares. Households have used inorganic and organic fertilizers for crop production. The majority of households (85%) used on average 100 kg compost while 58% of households applied on average 62 kg of inorganic fertilizer per household. Some households (30%) used on average 52 kg of improved seed (Table 2), mainly barley and wheat varieties.

Extension service is an advice that informs and influences rural households' decision while extension contact is the frequency of interaction of development agents with farmers for advisory services (**Anderson and Feder, 2003**) and technical supports. Extension service has immense roles for technology transfer. Nearly 23% of households had no contact with development agents throughout a year, while 39% and 28% of households had one and two contacts in monthly basis. Limited number of households (10%) could access three to five contacts per month. The local market, asphalt road, health clinic, elementary schools, electric power, potable water, and churches are key institutions and infrastructures found in the watershed.

Table 1: Independent variables in relation to crop-livestock diversification patterns

Acronyms	Variable explanations and measurements	Hypothesis
Dependent variables (Y_i)		
CLDP	Crop-Livestock Diversification Patterns	
Independent variables (X_i)		
SEX	Sex of household head (1=male; 0=otherwise)	+ (male)
AGE	Age of household head measured in years	+
EDUC	Educational level of household head in class years	-
LABOR	Household labor measured in man-equivalent	+
HHSIZE	Household size measured in number	-
LAND	Land holding size in ha	+
INCOME	Annual household income in $USD*	+
IRRIGAT	Irrigated land size in ha	+
CREDIT	Access to credit (1= access to credit; 0= otherwise)	+
EXTEN	Extension contact in number of days per year	+
DMKT	Distance between household's residence and the nearest local market measured in walking minutes	-
DROAD	Distance between household's residence and the nearest asphalt road measured in walking minutes	-

Note: *Official exchange rate1.00 US dollar =21.5 Ethiopian Birr (June, 2016)

The nearest local market is *Gudo Beret* located at the center of the watershed. The main asphalt road crosses the small town of *Gudo-Beret* from southwest to northeast direction. Accesses to tarmac road and the expansion of market opportunities have increased demands for market-oriented commodities such as eucalyptus poles, crop yields, and livestock products.

Table 2: Socio-economic attributes of sample households

Variable description	Mean	Std. Dev.	Min	Max
Age of household head	44.0	12.4	23.0	82.0
Land holding size	1.3	0.6	0.1	4.0
Household labour	2.9	1.3	1.0	7.0
Household size	4.5	1.8	1.0	10.0
Annual income	4.8	5.2	0.0	38.5
Extension contacts	1.3	1.1	0.0	5.0
Market distance	27.5	25.8	0.0	90.0
Road distance	18.4	20.1	1.0	90.0
Irrigated land size	0.1	0.1	0.0	0.3

Source: Survey data (2016)

Crop-livestock diversification patterns

Cereal crops were the most abundant varieties followed by pulses, and less land size was allocated for oil crops, oats, vegetables and potatoes. Almost every (99%) household has grown crops and 94% of households rear livestock. Of the total cultivated area, wheat and barley were accounted for 48%. Households also produced faba bean, field pea, lentil, vegetables, Irish potato, oats and linseed on small plots of land. Figure 1 shows the types and proportions of crop varieties and livestock breeds. According to **Magurran (2004),** diversities in crop species and animal breeds demonstrate the abundance while the extent to which one or more species or breeds dominate the watershed evenness. The percentage was calculated in terms of hectare for cultivated crops and TLU for number of livestock.

Cattle, equines, sheep, goat, and chicken were the major livestock types reared in the study watershed. Three-quarters (75%) of the cattle population were indigenous breeds while 25% were improved breeds. The highest cattle population was oxen while sheep and chicken were the highest livestock population in number. Sheep production was the most common practice mainly for the source of household incomes through selling. The majority (61%) of livestock population was livestock followed by sheep and goat (20%), equine (18%) and chicken (1%) in terms of TLU. In total, thirteen variables were included in PCA, in which five principal components with Eigen values greater than one were retained. Consequently, five major types of farming patterns were identified. The five principal components explained almost 71% of the total variability. These crop-livestock diversification patterns are presented in Table 3.

The first principal component explained 24.22% of the total variance and it is correlated substantially with sheep and goat, equines, and indigenous cattle production. This component represented a diversification pattern for animal production. Similarly, principal components II, III, IV, and V explained 20.13, 9.47, 8.56, and 8.50% of the total variance, respectively.

Determinants of crop-livestock diversification patterns

After determining diversification patterns, the next task of this study was identifying factors that cause crop-livestock diversification. To carry out it, the diversification patterns were regressed against socio-economic, demographic, and institutional variables that are expected to affect diversification pattern using seemingly unrelated regression procedure. This method was selected because the error terms between equations were assumed to be correlated. The estimated SUR model was tested for independence between the residual terms of diversification patterns using Breusch-Pagan test. The chi^2 value of the test is 28.83 and rejected at 1% significant level. The test result confirmed that the SUR model is appropriate to estimate the simultaneous equations of the diversification patterns.

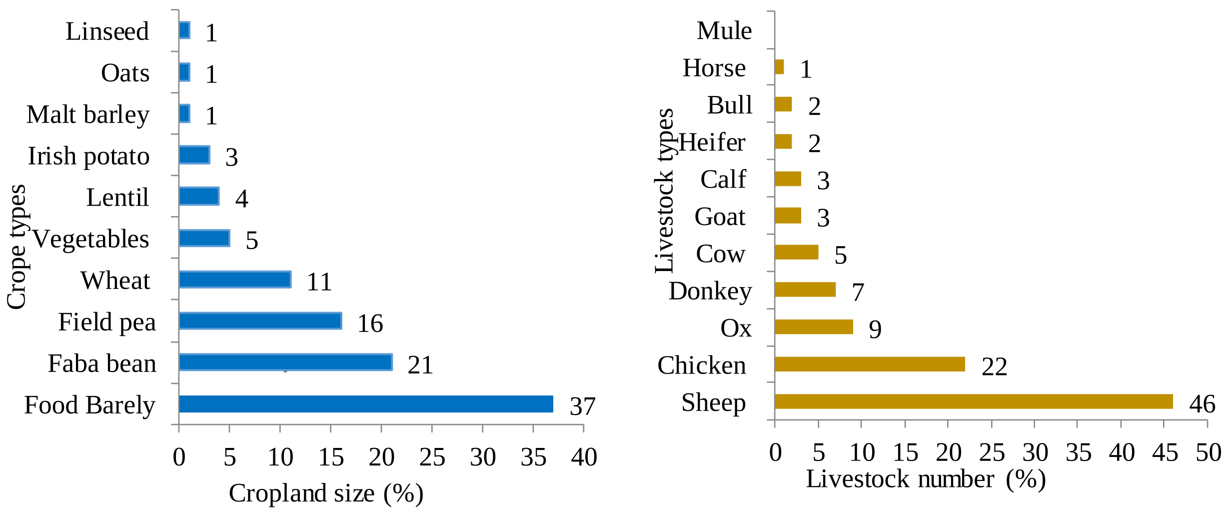

Figure 1: Crop and livestock diversity

Table 3: The major crop-livestock diversification patterns (PCA result)

Major crop-livestock activities	Major components				
	CLD I Sheep and goats	CLD II Staple crops	CLD III Chicken	CLD IV Vegetables	CLD V Animal feed
Improved cattle (%)	0.56	-0.29	0.31	0.09	-0.17
Indigenous cattle (%)	0.72	0.39	-0.14	-0.02	0.17
Equines (%)	0.76	0.23	0.03	-0.08	0.05
Sheep and goat (%)	0.78	0.10	0.15	0.07	0.09
Chicken (%)	0.14	0.15	0.79	-0.18	-0.15
All animals (TLU)	0.97	0.18	0.10	0.02	0.06
Cereal (%)	0.28	0.66	0.01	0.23	-0.03
Pulse (%)	0.12	0.79	-0.03	-0.04	0.06
Oil crops (%)	-0.03	0.58	0.21	-0.35	0.00
Vegetables (%)	-0.01	0.13	-0.02	0.86	-0.05
Oats (%)	0.12	0.08	-0.05	-0.09	0.88
Total crop land (ha)	0.22	0.92	0.00	0.24	0.07
Bee colonies (No)	0.10	-0.09	0.64	0.28	0.48
Eigen values	3.15	2.62	1.23	1.11	1.11
% variance	24.22	20.13	9.47	8.56	8.50
Com. explained variance	24.22	44.35	53.82	62.38	70.88

Note: Coefficients are factors loadings; extraction methods are principal component analysis. A rotation method is varimax with Kaiser Normalization.

Table 4: Results of SUR model (N=211)

Independent Variables	Dependent Variables				
	Sheep and goat	Staple crops	Chicken	Vegetables	Animal feed
AGE	0.005 (0.005)	-0.007 (0.005)	0.005 (0.006)	-0.009 (0.006)	-0.008 (0.006)
EDUC	0.015 (0.048)	-0.217*** (0.050)	0.098 (0.063)	0.087 (0.062)	0.017 (0.062)
SEX	0.350*** (0.122)	-0.054 (0.128)	-0.421*** (0.160)	0.151 (0.157)	0.133 (0.158)
LAND	0.173* (0.104)	1.079*** (0.110)	-0.168* (0.136)	0.454*** (0.134)	-0.056 (0.135)
FLAB	-0.022 (0.060)	0.013 (0.064)	-0.128 (0.079)	0.054 (0.078)	0.030 (0.078)
INCOME	0.047* (0.025)	-0.012 (0.026)	0.051 (0.032)	0.038 (0.032)	-0.011 (0.032)
CREDIT	-0.057 (0.108)	-0.136 (0.114)	-0.103 (0.142)	0.263 (0.140)*	-0.045 (0.140)
EXTEN	0.070 (0.052)	0.077 (0.055)	0.135** (0.068)	0.026 (0.067)	-0.002* (0.067)
DMKT	0.007* (0.004)	0.001 (0.004)	0.005 (0.005)	-0.011** (0.005)	0.004 (0.005)
DROAD	0.011** (0.005)	-0.006 (0.005)	-0.002 (0.006)	0.010 * (0.006)	0.008 (0.006)
IRRIGAT	-0.073 (0.758)	2.155*** (0.797)	0.643 (0.993)	-0.470 (0.977)	-1.308 (0.981)
HHSIZE	0.156*** (0.048)	-0.080 (0.051)	0.093 (0.063)	-0.071 (0.062)	0.012 (0.063)
Cons	-2.185*** (0.340)	-0.172 (0.358)	-0.611 (0.445)	-0.277 (0.405)	0.027 (0.440)
R^2	0.464	0.406	0.080	0.109	0.100
Chi²	182.42***	144.38***	18.43**	25.91***	23.67***

Note: The parenthesis are standard errors; *, **, and *** are significance at 10, 5, and 1%.

The results of SUR model showed that different factors could influence crop-livestock diversification patterns. The hypothesized and tested independent variables were included in the model as shown in Table 4. The major determinants that influenced crop livestock diversification patterns were educational level of household heads, sex of household head, total land size, frequency of extension contact, distance to the nearest market place, distance to the nearest asphalt road, household size and land used for irrigation. The mixed farming systems had five diversification patterns in the study area. However, there was no a common factor that influenced all diversification patterns at the same time; due to the fact that diversification patterns have different attributes that were not influenced by common factors. Indeed, land size could affect the four diversification patterns at different significant levels with positive and negative coefficients. It implies crop and livestock-based diversification patterns had different socio-economic and bio-physical attributes.

EDUC: Educational level negatively affected the staple crop-based diversification patterns at 1% significant level. As a household head level of education increases by one year of schooling, the household decreases staple-based crop diversification by 21.7%. Similarly, some other studies also found that education has negative effects on livestock husbandry, vegetable production, and crop-livestock diversification (**Mesfin, Fufa and Haji, 2011; Matsane and Oyekale 2014; Ojo *et al*., 2014; Kassie, Kim and Fellizar, 2017**). There are possible explanations for negative relationships between education and farm diversification. As a farm household acquires skills and knowledge, either she /he may prefer specialized farm activities or search for non-farm employment opportunities. On the contrary, some previous studies revealed that a farmer with better level of education is more likely to adopt crop and livestock diversification compared to an illiterate farmer (**Manyong, Okikeb and Williamsc, 2006; Iiyama, Maitima and Kariuki, 2007b**). Thus, education can have mixed effects on farm activities depending on other factors.

SEX: Gender difference has mixed effects on farm diversification. Male-headed households affected sheep/goat-based production positively at 1% significant level. As a household head being male, the production pattern for sheep and goat increases by 35%. On the contrary, a household head being male had negative correlation with chicken-based diversification and it was significant at 1%. As a household leads by male, chicken-based production declines by 42.1%. In the traditional farming systems, shepherd is for males while reproductive roles including poultry and child care is for females. Findings of other studies also revealed that male-headed households found to have positive correlation with cereal, vegetable and oat production while it is negative with livestock and chicken production (**Ochieng, Owuor and Bebe, 2012**; **Xaba and Masuku, 2013; Asante *et al.*, 2017**).

LAND: Land is the most important variable on which different farm activities were carried out. Land size had positive effects on sheep/goat, staple and vegetable based production at 10%, 1% and 1% significant levels, respectively. As land size increases by 1.0 ha, the sheep/goat, staple, and vegetable-based production patterns increases by 17.3, 107.9, and 45.4%, respectively. A farmer with more lands, can access pasture for livestock, eucalyptus trees, and vegetable crops. **Rehima *et al.* (2013)** and **Asante *et al.* (2017)** have found that land size has negative effects on farm diversification while **Ojo *et al.* (2014**) and **Matsane and Oyekale (2014)** found that land size is positive on oats, vegetables, and sheep and goat-based diversifications.

EXTEN: Agricultural extension service has positive effects on chicken-based diversification at 5% significant level. As extension contact frequency increases by one day per month, chicken-based diversification pattern increases by 13.5%. Extension contact is one of the major sources of information for agricultural practices and improved technologies such as animal breed, and other agricultural inputs. Extension is found to have positive correlation with crop diversification and chicken production in many studies (**Ochieng, Owuor and Bebe, 2012; Rehima *et al.*, 2013; Ojo *et al.*, 2014**). There are cases where extension contacts could adversely affect the crop-livestock systems (**Manyong, Okikeb and Williams, 2006; Mesfin, Fufa and Haji, 2011**).

DMKT: The relationship between market distance and vegetable-based diversification market was negative at 5% significant level. As walking distance increases by one minute, vegetable-based diversification declines by 1.0%. The possible reason may be households who reside near to the local market diversify their farm activities mainly vegetables for home consumption and market demands. **Asante *et al.* (2017**) reported that market distance has mixed effects on crop-livestock diversification. They found that market distance is negative towards the probability of adoption on crop production and the extent of decision on livestock production. Many studies reported that distance to the local market have negative correlations with crop diversification, vegetable production and chicken rearing (**Mesfin, Fufa and Haji, 2011; Ochieng, Owuor and Bebe, 2012**). In the study of **Rehima *et al.* (2013),** market distance is positive with crop diversification. Similarly, in this study market distance has positive correlation with sheep and goat-based production at 10% significant level. As market distance increases by one minute, sheep and goat-based production increases slightly by 0.7%.

IRRIGAT: Irrigation land impacted the staple crop-based diversification pattern positively at 1% significant level. As irrigation land increases by 1 ha, the staple crop-based diversification pattern increases by 215.5%. Hoffman and **Livezey (1987)** also reported similar findings. In the study of **Rehima *et al.* (2013**), irrigation is positively correlated with oats production and negatively associated with crop diversification.

DROAD: Road distance has positive correlation with both sheep and goat and vegetable based-diversification at 5% and 10% significant level, respectively. As road distance increases by one minute, the sheep and goat and vegetable-based diversification increases by 1%. Sheep and goat-based farming is positive for market and road distance. It implies households who reside far from the center of the *Kebele* and the main asphalt road have better access to grazing fields for small ruminants.

HHSIZE: Household size has positive and significant correlation with sheep and goat-based diversification at 1% significant level. As household size increases by one member, the diversification for sheep and goat increases by 15.6%. It implies that this pattern is labor intensive activity in the farming systems.

Effects of crop-livestock diversification on household income

In the study area, the three major sources of income include 68% farm, 25.3% non-farm, and 6.7% off-farm activities. This section is devoted to evaluate the effect of identified patterns on annual household income in the study area. Demographic, economic, social, institutional and bio-physical variables are potential factors that can affect the total household income. Nevertheless, from the previous studies, the missing link is crop-livestock diversification patterns and its impact on household income that obtained from various income sources. From the total farm incomes, sale of crop yields, animals and their products and agro-forestry products accounted for 55.4, 26.4, and 18.2%, respectively. Payment for retirement, remittance, masonry, carpentry, petty trading, and related activities were the major source of non-farm income. In *Gudo Beret* watershed, the main source of off-farm income was labour wage. The annual average total income was 4837 birr per household, which is equivalent to 225 dollars. However, there is a large variation among households on farm income levels as they pursue different crop-livestock diversification patterns.

To determine the effect of crop-livestock diversification on household income, the major components or crop-livestock diversification patterns are considered as explanatory variables. The total annual income level of households then regressed against the major components using OLS regression procedures. The result is presented in Table 5.

Table 5: Effects of crop-livestock diversification patterns on household income

Diversification patterns	Coefficients	Std. Err.	t-value
Sheep and goat	59.86***	22.72	2.63
Staple crops	5.74	24.27	0.24
Chicken	38.31**	15.95	2.40
Vegetables	45.84*	23.61	1.94
Animal feed	2.65	19.89	0.13
Constant	224.99 ***	15.66	14.36
R-square			0.12
F-value			3.43***

Note: ***, **, * significant at 1%, 5%, and 10%

The results in Table 5 revealed that sheep and goat, chicken, and vegetable-based diversification were positively correlated with household income and significant at 1%, 5% and 10%, respectively. As diversification for sheep and goat, chicken, and vegetable-based farming increases by each of one standardized unit, household income increases by 59.86, 38.31, and 45.84 dollars, respectively. It implies that small body size animals (chicken, sheep, and goat) and vegetables such as onion, tomato, and potatoes grown with supplementary irrigation were the major sources of farm income for rural households. Intensive production of small ruminants in the private, communal and open access grazing lands bring high economic returns that served mainly for home consumption and cash incomes.

DISCUSSION

The focus of this study is to identify crop-livestock diversification pattern, determinants of diversification and its effect on household income. Sheep and goat, staple crops, vegetables, chicken, and animal feed (Oats)-based diversifications are identified patterns. Most of crop-livestock activities are integrated within and among different patterns in the farming systems. Diversified farming has incentives not only to enhance household income but also lessons competition among crop-livestock activities. Patterns of production for sheep and goat, vegetables, and chicken are positively associated with household incomes.

The most significant and predominant diversification pattern is sheep and goat, which is associated with equine, cattle and cereal production. In this pattern, the highest factor loading is for sheep and goat production. The average holding size of sheep is seven per household whereas goat is very limited in size between zero and one animal per household. In our study, like many previous studies did, for instance, **Iiyama *et al.* (2007a),** sheep and goat are under one category. In the study area, the proportion of households that own sheep and goat is 82% and 18%, respectively. It implies that sheep is the most potential livestock breed in this highland agro-climate. **Edea *et al.* (2012)** also pointed out that sheep is the most diversified breeds and the main source of livelihood in many parts of Ethiopia. It is also a source of meat, skin, manure and coarse wool or long hairy fleece (**Mengesha and Tsega, 2012).** In this study, it is found the most influential source of household annual income.

Chicken-based diversification pattern is the third component in the mixed crop-livestock systems. Chicken production is the leading activity after sheep rearing. The average holding size of chicken is 4.5 per household. Beekeeping, improved cattle, and oil crops are integrated with this pattern. In contrast, indigenous cattle, equine, chicken, pulse crops, vegetables, and oats are correlated negatively with the pattern. Chicken production is one of the identified opportunities for smallholder where small landholding size is prevalent. The study area has suitable agro-climate for chicken production.

Some activities (beekeeping and cereal crops) are integrated with vegetable-based diversification pattern whereas activities such as pulses, oil crops and the majority of livestock species are competed with this pattern. Depending on availability of land and agro-climate suitability, vegetables can be grown either as sole crop or intercropped with other vegetables or cereals through rain-fed or supplementary irrigation systems. Ethiopia is potentially profitable and comparative advantage in production of vegetables because its favourable climate, cheap labour, market proximity to Europe, and rivers for irrigation (**Ashebre, 2015**).

CONCLUSIONS

Mixed crop-livestock production is one of the major livelihood strategies in rural highlands of Ethiopia. Diversified farming is the major source of food, cash income, and agro-ecological services. Nevertheless, crop production has competed with the livestock sub-systems for land resources. Hence, households have prioritized major farming patterns in the crop-livestock systems to minimize competitions among farm activities and reduce pressures on land resources. Male-headed households are potential producers of sheep-based diversification pattern, while chicken-based diversification pattern or small-scale poultry production is appropriated for landless and rural women.

Households that have access to adequate farmlands are found to adopt crop production in general, and, grain and vegetable-based farming systems in particular. In the same way, access to irrigation lands enabled to adopt irrigation-based farming, whereas households led by educated farmers had adverse effects on crop-based farming systems because they shift their decision mainly from crop production to off-farm and non-farm activities. Overall, diversified farms are the source of income for the majority of households, which can improve the livelihoods of farm households. Among the identified farming typologies, sheep and vegetable-based farming were the major source of income followed by chicken-based farming systems. Women friendly agricultural technologies and agro-climate adaptive practices such as small-scale vegetable production, chicken rearing and sheep-based farming patterns should be encouraged to improve the livelihood of smallholder farmers in the study area.

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