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Agricultural productivity, land use and draught animal power formula derived from mixed crop-livestock systems in Southwestern Ethiopia

Asrat Guja Amejo[1,2*], Yoseph Mekasha Gebere[3], Habtemariam Kassa[4] and Tamado Tana[5]

[1]Department of Animal Science, College of Agricultural Science, Arba Minch University, P. O. Box 21; Arba Minch, Ethiopia.
[2]School of Animal and Range Sciences, College of Agricultural and Environment Sciences, Haramaya University, P. O. Box 138; Dire Dawa, Ethiopia.
[3]Ethiopian Agricultural Transformation Agency, P. O. Box 708; Addis Ababa, Ethiopia.
[4]Center for International Forestry Research, CIFOR Addis Ababa Office, 5689, Ethiopia.
[5]School of Plant Science, College of Agriculture and Environment Sciences, Haramaya University, P. O. Box 138; Dire Dawa, Ethiopia.

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The interaction of agricultural land cover area between land use systems and level of household income was identified. The annual cropland area was significantly higher than the natural pastureland and perennial cropland. The difference in household income earned was not significant between the annual crop and livestock. Such a difference however is not surprising because smallholder land system is a dual asset, and farm components are interrelated to and interdependent upon each other. In one season directly and simultaneously, the diversified forms of agricultural land provide food and feed that reduce the direct allocation of land for grazing. Nonetheless, decisions made in the household on the land use allocation for farm enterprise is neither random nor optional but are through behavioural adaptation of the system in changing condition, emerging opportunity and its ability to maximize choice and utility in the household. The study set up was initiated from the characterization of smallholder mixed crop-livestock systems divided into different agro-ecological zones for land use in South-western Ethiopia. Agricultural productivity in a smallholder system is chiefly an aggregate effect of interaction between elements and component, specialization and diversity in a farming system mainly found in food production biomass base. Several challenges, however, limit various positive significant balance reflected in the food and non-food production biomass base, as well as non-farm activities.

Key words: Agricultural productivity performance, agro-ecology, crop-livestock, draught animal power, soil distribution, system interaction.

INTRODUCTION

In collective farming, crop-livestock systems coexist and are managed together in many different production systems in similar environment, as this combination can provide a useful scheme for the description and analysis

*Corresponding author. E-mail: gujasrat@gmail.com. Tel: +251911071200.

of development opportunities and constraints in crop and livestock production (Otte and Chilonda, 2002; Ryschawy et al., 2012; Lipper et al., 2014). It could be agreeable ideal to model different future scenarios for these systems. Afterwards, decisions can be made to the smallholder and their natural environment (Notenbaert et al., 2009), for investments in agriculture to have a sustainable impact on food security and poverty reduction.

A rural smallholder agricultural production is mainly traditionally organized in a dual system. The land is the only productive asset base that transfers from family, owned privately by an individual as well as exists in the collective term. The land market is not common and restructuring as too, so as smallholder peasant cannot easily acquire additional land to increase production. The smallholder farm plot provides not only subsistence but income for family, obtained from the land organized in a dual system. Smallholder farmer is, therefore a result of the precarious nature of peasant agricultural production and is modelled by forces, which constrain and strengthen their position within the family. They attempt to increase food production and improve farm efficiency by selecting farm enterprises, flexible in the land use efficiency over seasons and relative turnover in ecology, marketing condition, competence, price, and labour requirement. A means of system interaction, output delivery, and mechanization as well as joint production socially for land, labour, seed, and oxen between the wealth groups have enhanced their ability and capability.

Gliessman (2007) reported that an integrated farm is one in which livestock are incorporated into farm operations to achieve synergies among farm units and not just as a marketable commodity. There are recent evidences on smallholder farms in terms of the world's agricultural land and potential food production. According to FAO (2015) report, smallholders farm representing the vast majority of the world's farms are small and medium-sized; about 85% of them are below 2 hectares and almost 95% are below 5 hectares in contrast to the large farms of more than 100 hectares occupying more than 50% of the world's farmlands. Small and medium-sized farms below 2 hectares are only around 12% and farms below 5 hectares are less than 20% of global share. These smallholder farms support food production systems, livelihoods of rural and urban households, and local and regional economies; however, they have some important similarities and significant variation in the regional and global context (Lowder et al., 2016; Graeub et al., 2016).

The overwhelming story of more small farms, shrinking farm sizes and increased income diversification (Hazell's, 2013) have occurred in agriculture during the last fifty years in most of the world's small farms located in Africa and Asia regions (Cervantes-Godoy, 2015). The fundamental properties of complex dynamic systems and their relation with the mechanisms that govern resilience and transformability in African smallholder agriculture emerge from the aggregation of diverse livelihood strategies in response to changes in the agro-ecosystem context, and are characterised by non-linearity, irreversibility, convergence/divergence and hysteresis (Tittonell, 2014).

In low-income countries, farms less than 2 hectares occupy about 40% and less than 5 hectares occupy about 70% of farmland. In Ethiopia, smallholders below 0.5 hectares are around 29% and below 1 hectare is around 55% (CACC, 2003). In 2015/16 production year, smallholder producers' national share accounted for more than 95% of grain production and more than 98% of livestock production (CSA, 2016). More than 90% of rural households in Ethiopia rely on livestock, crop production or a combination of the two as the main occupation of their household head (Ethiopia et al., 2014).

Instead of smallholders' resource base, therefore, Cervantes-Godoy (2015) suggests to focus on the degree, which makes resource use, most productive. The degree of integration between system units and intensifying use efficiency is vital significant in economic return both individual household, group of farm society and the country at large. More often smallholder farming systems are dynamic entity, developed by adopting patterns in farming practices based on the conditions of specific location and aims of the farmers. To devise proper measures in agricultural policy, it is necessary to understand the schemes the rural smallholders farming systems are managed.

Tittonell (2014) summarized that desirable shifts in farming systems can only be stimulated by working on both ends simultaneously to deal with the Matryoshka effect or with interactions that are presumably panarchical; the knowledge base for the ecological intensification of smallholder landscapes, policy and market developments can be approached through agroecology stratification; whereas thresholds in specific variables that may point to the existence of possible tipping points are rather elusive and largely site specific in East African agroecosystems.The objectives of this study are therefore:

(1) To estimate land use land cover of smallholder enterprise at farm level as well as the level of communal biomass share in the household.
(2) To identify major soils and soil property from metadata source at farm level in the household.
(3) To asses productivity performance of smallholder farm enterprise in terms of landholdings in the households and
(4) To assess the role of system interaction in food production biomass base or from communal base, if available in the households.

Moreover, the study aimed to provide fairly a holistic view on a socio-economic and environmental analysis of how different types of production systems contribute to the sustainability of smallholder livelihood in mixed crop-livestock system in southwestern Ethiopia.

MATERIALS AND METHODS

Description of study area

The study was conducted in smallholder mixed crop-livestock systems in South Nations, Nationalities and Peoples' (SNNP) regional state in Dawuro and Gamo Gofa zones in southwestern Ethiopia. The study area consisted of virtually a complex raged landscape within the altitudinal range of 1214 meter above sea level (m.a.s.l) in dry lowlands to 2723 m.a.s.l in wet highlands. Station data show that the mean annual rainfall of 1240 mm was measured at 2800 m.a.s.l and 850 mm at 1300 m.a.s.l. Rainfall occurs bi-modally, mainly in late dry (March to May) season, and in summer (July to November) as the main rainy season. However, often community subdivides a year into four different seasons locally: September-November as 'adile'; December-February as 'boneya'; March-May as 'assura' and June-August as 'balegua' with respect to differences in rain and sunny condition, environment and access to and availability for livelihood options in a period of season.

The livelihood system of the community is organized based on the environment and landholdings, the scale of food and feed products available from the plots and socio-cultural means to sustain life across seasons in the year. In tropics, according to Ruthenberg (1971), farm operation and labor productivity are further hindered by the acute seasonality of many climates, in which wide differences exist between the wet and dry seasons and without irrigation water.

The production of cereals, pulses, potato, and garlic in terms of crop and mare, sheep with cross-breed dairy in livestock has characterized highland agriculture farming. Enset (*Ensete ventricosum*), a perennial drought-resistance crop produced from highland to lowland, is a staple food in form of *kochoo* (carbohydrate-based diet) and the mainstay of food security. Crops such as maize, teff, sorghum, root crops and banana and goats with cattle dominate the lowland system. The midland agricultural system incorporates both lowland and the highland with relative reflectance gradient. Toward the lowland gradient, the area is an abundance of rangelands, shrubs, browses, and grasslands with pasture. Dawuro and Gamo Gofa zones are about 2286 counts of surface water bodies with 930 intermittent and 1356 permanent rivers with Gojeb and Omo rivers among the twelve major river basins in Ethiopia.

The two zones lie between 5° 34′ 16.31″ N to 7°20′ 58.01″ N latitude and 36° 22′ 13.04″ E to 37° 51′ 26.31″ E longitude. The capitals Arba Minch of Gamo Gofa and Tarcha of Dawuro are found in about 490 and 505 km south of Addis Ababa. The total human population of these zones is about 2.66 million with a total area coverage of about 16,530 km^2. The rural population accounts for about 88% in Dawuro and 84% in Gamo Gofa. Fourteen administrative zones constitute the South Nations Nationalities Peoples' (SNNP) regional state. The study was conducted in two of the zones, namely Gamo Gofa and Dawuro zones.

Study design

The districts were stratified into three agro-ecological zones (AEZs): highland, midland, and lowland with proportions to area in each zone. Then, the districts were randomly selected from AEZ, followed by the peasant administrations (PAs), designated for its production potential based on the selected group at a lower level. According to the Global Positioning System (GPS) data tracked during a survey at the household level, distinct four AEZs (the wet highland, wet upper lowland to sub-humid, and wet and dry lowland) were further distinguished which were also statistically significant for elevation and slope.

Between February 2014 and December 2016, a survey was conducted in generic integrated crop-livestock systems database (Herrero et al., 2005, 2007) in 13 focus PAs in two administrative zones. The survey included all households, keeping at least one head of ruminant livestock. A total of seven PAs, one at wet highland AEZ in Chencha District at Losha (n=32, n=31), two at wet upper lowland to sub-humid AEZ in Bonke District at Fishto (n=32, n=32) and Gress Zala (n=33, n=33) and four at dry lowland AEZ in Mirab Abaya District at Alga (n=32, n=32), Ancover (n=32, n=32), Furra (n=6, n=6) and Para Gossa (n=19, n=25) in Gamo Gofa (n=186, n=191) zone administration were selected. Where n is respective crop and livestock. A total of six PAs, one at wet highland AEZ in Tocha District at Gmra Qema (n=29, n=29), two at wet upper lowland to sub-humid AEZ in Issara District at Guzza (n=32, n=32) and in Maraka District at Myla (n=32, n=32), and three at wet lowland AEZ in Tocha District at Qcheme Kessi (n=25, n=26), in Mareka District at Tarcha Zuri (n=9, n=10), and Loma District at Yallo Worbati (n=32, n=32) in Dawuro (n=159, n=161) zone administration were selected. A total of 345 crops related entries and 352 livestock related entries were recorded in the two zones.

Qualitative and quantitative information regarding socioeconomic, farm holdings, crops grown, herd structures of cattle, sheep, goats, poultry and the livestock products and honeybee keeping were collected during the households' interview. The plot size and type of crops, patterns of cropping and seasons of crop growing, the percentage of individual crop cover per plot during intercropping for each crop and yield per plot were gathered. The proportion and amount of fodder, weeds, residues, primary and by-products used for livestock feed and the use of animal manure for crops were recorded. Rangeland biomass in the respective site was the proportion of average farm holdings, population, and total area coverage of the sample. PA was classified according to interviews data, field experience, and other literature for the study zones.

The households were interviewed about their income from sales of crops, tree plantation, livestock products, natural capital, off-farm and other sources (such as labor, and remittance). The weekly local market price assessed during three years (2014-2016) for agricultural commodities was obtained from the zonal agriculture office (Figure 1).

Data calculation

Biomass base monthly feed dry matter supply from food crops and grazing/browsing sources in the classified LULC class was quantified with Moderate-Resolution Imaging Spectroradiometric (MODIS). Normalized Difference Vegetation Index (NDVI) average value for the period 2008 to 2015 (Food and Agriculture Organization of United Nation) was established in the equation given by Quiroz et al. (1999). The NDVI value is processed vegetation greenness for livelihood early assessment and protection for Ethiopia (from LEAP version 2.7; World Food Program/Food and Agriculture Organization, 2012). The superimposed factors for biomass production in land use types such as natural pastureland, cropland/fallow, grassland, bushland, woodland, forest, slope and soil depth as well as specific herd units were adopted from woody biomass project (SNNP, 2001).

Biomass base available and livestock dry matter requirement were computed using the procedure followed by Kassam et al. (1991) for agro-ecological resource assessment, and population and productivity performance requirements of the livestock in specific sample location. Energy allowance was maintenance unit

Figure 1. Maps of Districts in Dawuro and Gamo Gofa Zones.

given by Lalonde and Sukigara (1997), and system-specific productivity performance of interview result value of female breeding was computed separately and added together. The reference livestock standard unit given by FAO was a measure used to arrive at a consistent value of the energy required by animals (Lalonde and Sukigara, 1997). The crop residue supply from food crops was quantified from crop yield interview result computed using corresponding utilization coefficients given by Kassam et al. (1991).

The soil dataset from the harmonic world soil database (HWSD, version 1.2) software (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012) was assembled to Arc GIS 10.2 with its global projected coordinate. Following re-projecting, the dataset was extracted to point values in area extension of the zones and reprocessed on spatial interpolation in 10 m x 10 m resolutions. The major soils identified from the analysis in the zones, and corresponding soil properties were extracted to excel from HWSD (version 1.2) software before processing the original data set and after reprocessing in Arc GIS 10.2 for the purpose of comparison. The spatial dataset for the major soils (soils unit) identified and interpolated further in inverse distance weight was extracted to zonal statistics in Arc GIS, using GPS tracked elevation point value positioned in a household location during the field survey. That was used to delineate major soils identified in the specific farming system in the PA, as well as that required for statistical analysis to identify soils properties of top and sub-soils.

The draught animal power formula was devised from the study data gathered from the wet highland to the dry lowland. The difference in average value was compared to the variable calculated value and the respondent farmers' estimated average in the specific farming system. The draught animal power (day/year) required for cropland cultivated is calculated in Equation 1 and 2 as:

$$M = ff \times W \times f^2 \quad (1)$$

Where,

M=draught animal power (day/year) required for cropland area cultivated;
ff= fraction factor of cropland area cultivated/farm population in specific farm;
W=average productivity (day/year) a pair of working ox required to cultivate a hectare of cropland area, which is 6.45 days (Table 6); and
f^2= frequency of average day square required for cropping activity of aggregate crop compositions grown in a specific farming system from the first tillage to the last possible requirement of a pair of working ox for weeding/harvesting activities, which are 4.41days.

$$M = ff \times 6.45 \times (4.41)^2 \quad (2)$$

Statistical analysis

Data on land use and land cover area under annual, natural pasture, perennial and vegetable crops, and lands in communal biomass base as well as livestock composition were analyzed using descriptive statistics of chi-square frequency and percentages. The area coverage of major crops, yields, gross household income obtained from major livelihood activities, as well as productivity performance of cow and draught animal power formula were quantified and presented in figures and tables. Regression analysis was carried out on soils' properties of major soils, which were significant and further compared in independent samples multiple test comparison ($p<0.05$). Statistical analysis was done using IBM SPSS version 20.

RESULTS AND DISCUSSION

Agricultural land use land cover

Figure 2 presents land use area (ha) of annual crop in PA. Wheat was the largest annual crop in wet highland agricultural land use system (43%), followed by barley and horse bean (22% and 17% respectively).

Similarly, wheat was the largest annual crop in an area (31%) followed by maize (24%) and teff (14%) in wet upper lowland to the sub-humid AEZ. Whereas in the wet lowland maize, 53% and teff, 25%, and in the dry lowland maize 86% and cotton 11% were the major annual crops occupying the land cover area of the farm household. There was significant difference (χ^2=46.39, p=0.000, df=13, n=71) between annual crops for land use in PA. Maize, teff, wheat and groundnut/peanut were significantly higher in agricultural land area than the others, but test statistics was not significant (χ^2=6.18, p=0.10, df=3, n=25) for land use between the major dominant annual crops.

Enset was the largest perennial crop (64%) in the highland of AEZ, followed by bamboo (24%) and apple fruit and eucalyptus/juniper tree species (6%) (Figure 2). The land area share of enset in wet upper lowland to the sub-humid AEZ was 75% and bamboo, the second largest, took 15%. For the perennial crop category, coffee, tree fruit and banana cover 59%, 28%, and 10% respectively of the land area in the wet lowland. Often, banana plantation is the largest single perennial crop in the agricultural land of the dry lowland of AEZ (Figure 3). Among perennial crops in terms of agricultural land cover area, 46% of enset was the largest followed by 28% of banana and 12% of bamboo, which also revealed a significant difference (χ^2=24.53, p=0.000, df=6, n=34) compared to other perennial crops except coffee and apple fruit across the farming system.

The land cover area of vegetable crops consisted of 42% ethio cabbage, 32% garlic and 18% head cabbage in the highland of PAs (Figure 4). Ethio cabbage was dominantly horticultural crop in the midland with 68% area coverage; whereas pepper was 78% and onion, 22% in the wet lowland. While 100% of the land used for vegetable crop was onion in the dry lowland. Ethio cabbage (46%) and garlic (13%) were the leading vegetable crops in agricultural land use system, which were significant (χ^2=14.58, p=0.01, df=5, n=19) in their group for land coverage.

The herd head in Tropical Livestock Unit (TLU) of the household is indicated in Figure 5. Cattle were the largest in the land use system of the smallholders with 86% of the overall herd population. The remaining 11% and 3% were taken by small ruminants and equines respectively in the land use system. Equines were significantly lower (χ^2=19.73, p=0.00) than cattle as well as than the small ruminants (χ^2=18.27, p=0.00) in the land use system.

The TLU of livestock was the largest in the wet upper lowland to the sub-humid PAs, in the Myla and Guzza, and the wet lowland in the Yallo Worbati for each equal 11 %. The herd population was also high in dry lowland AEZ; however relatively low in the wet highland land use system. Whereas, sheep production increased toward the highland gradient and goats toward lowland farming system (Figure 5).

The agricultural land area (ha) in smallholder land use system is presented in Figure 6. The LULC area of the annual crop accounted for 56% of the overall agricultural land followed by natural pasture and different types of perennial crop (17% and 15%, respectively). The difference was significant between annual crops and natural pastureland (χ^2=22.85, p=0.02) and between the perennial cropland (χ^2=22.58, p=0.02) for the agricultural land where no significant difference (χ^2=0.23, 0.98) was observed between the latter two.

The agricultural LULC area of the households was relatively high in the upper lowland to the sub-humid and the wet lowland AEZs, but reasonably low in the dry lowland and wet highland households. Similarly, the type of farm enterprises in the land use system varies across the AEZ. In the gradient toward the highland, the area coverage in perennial trees, staple food crops, and the natural pastureland increases; it is similar in the lowland gradient for major grain and root crops (Figure 6).

Communal land use and land cover area share potential in farming system

Table 1 presents the communal land area shares in the sampled household (ha/household). The communal biomass base area share was negative in the highland households, where the largest in the wet lowland in Qchem Kessi and the dry lowland in Para Gossa accounted for 20.36 ha and 18.12 ha per household (Table 1). The land cover composition in the communal biomass base consisted of a different mixture of grassland, woody grassland, bush/shrubland, woodland, forest, potential area and water body in/around the PA in AEZ (Figure 7). The area coverage of trees/forest increased toward the highland gradient similarly to the woody grassland/grassland biomass in the lowland gradient. The wet lowland biomass base typically reflects the savannah type grassland where the dry lowland is

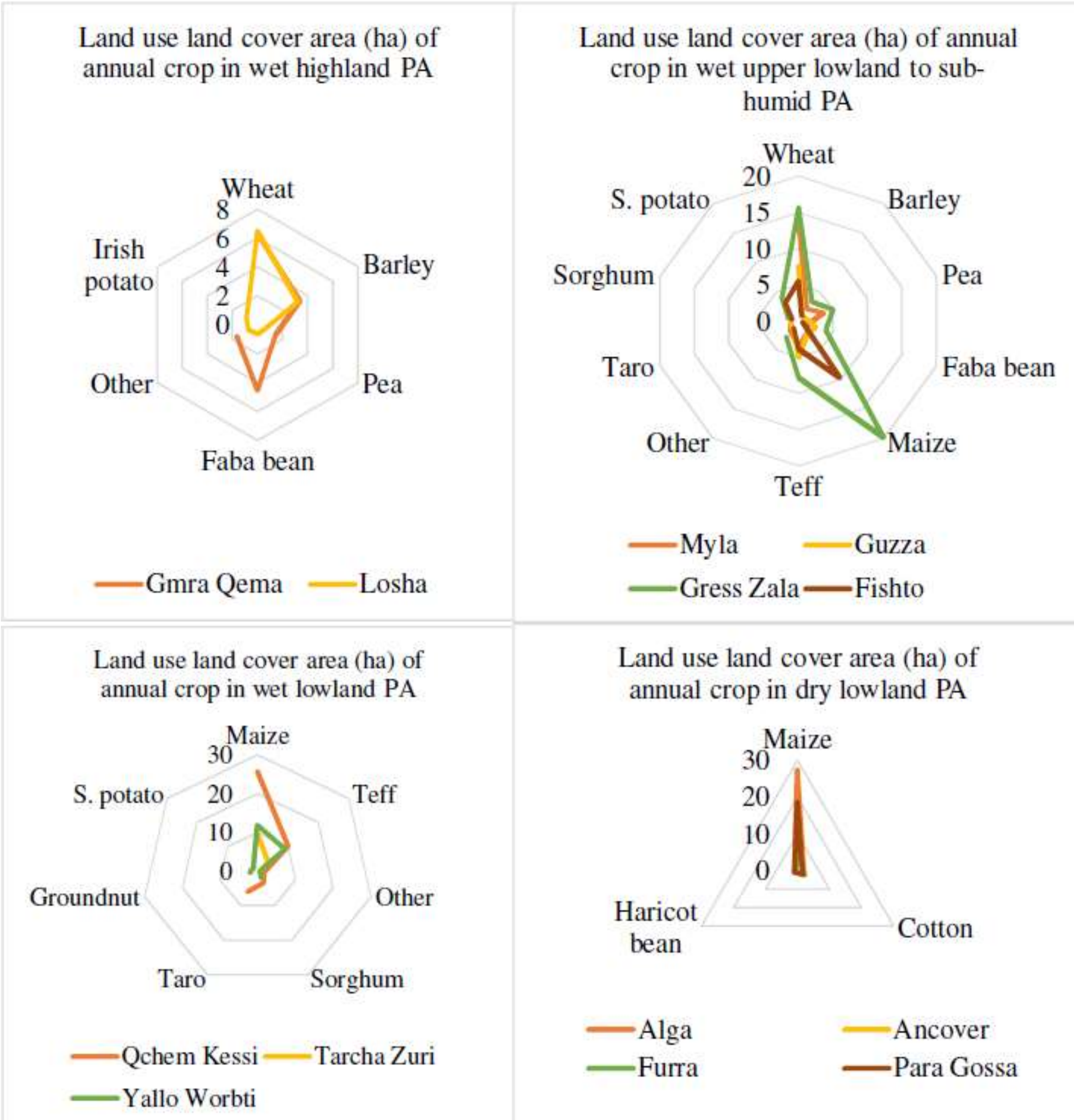

Figure 2. Annual crops in agricultural land area in agro-ecological zone in peasant administration (PA).

encroached with bush/shrub/woodland biomass by 70 and 64%, respectively (Figure 6).

Spatial pattern of major soil and its property

The spatial distribution of major soil in PA is presented in Figure 8. In the wet upper lowland to the sub-humid region, various mixes of soils were observed. The diversity in major soils was relatively high in plain areas of the lowland of AEZ. However, most of the soils in the lowlands were expansions of the upland soil (Figure 7). Apart from limited information on soil, a field experiment by Mengiste (2009) demonstrated about four soil types in 182 km^2 of watershed area between Chencha, Boreda, Mirab Abaya and Arba Minch Zuri districts in Gamo Gofa zone. The soils were cambisol, ferrasol, fluvisol, and regosol.

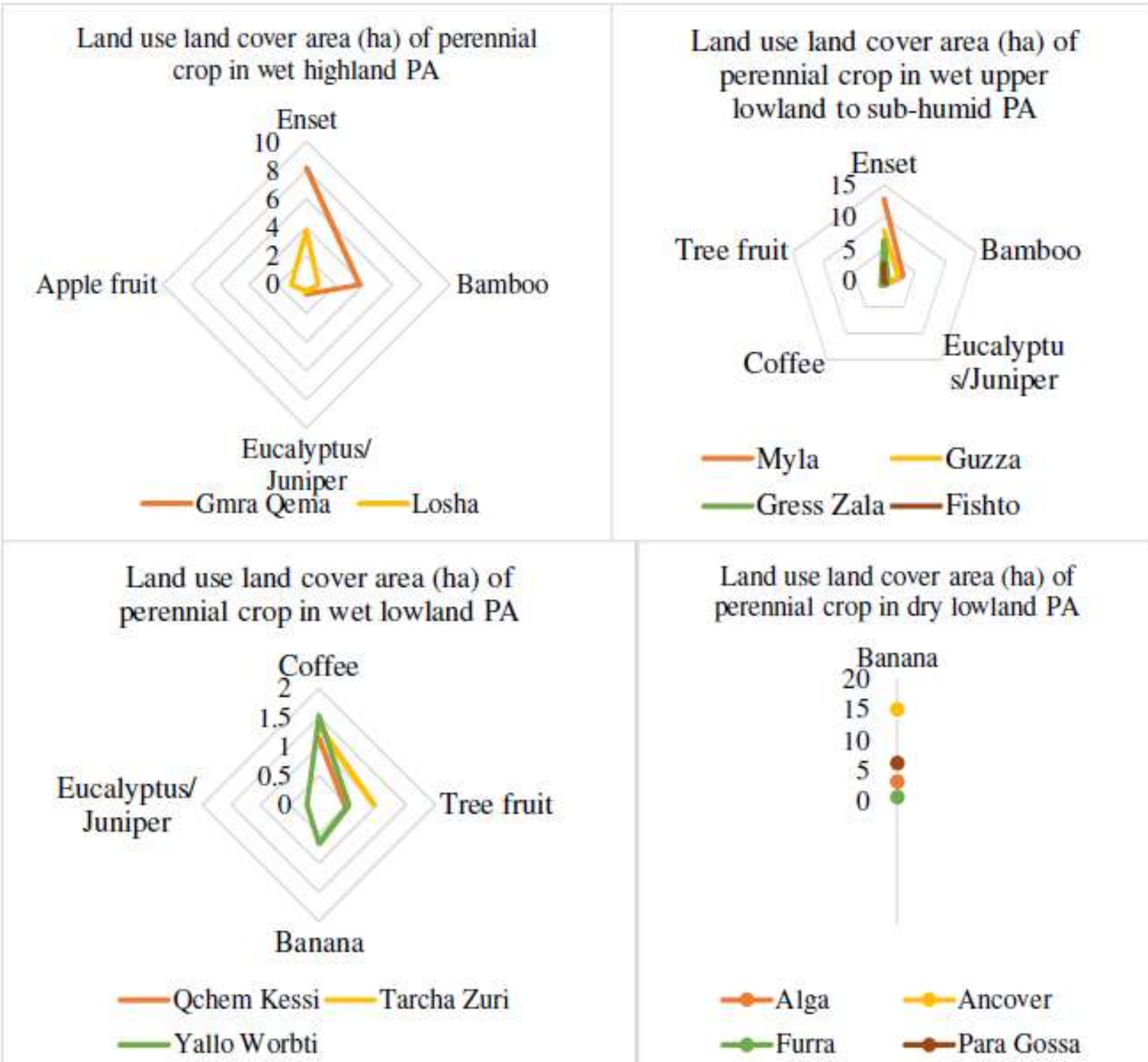

Figure 3. Perennial/plantation crops in agricultural land area in agro-ecological zone in peasant administration (PA).

Regression analysis showed that the sodicity (%) of the topsoil properties was significant (F=6.32, p=0.03) to the other attributes in the PA (Table 2). Similarly, the significant variation (F=7.59, p=0.02) was observed for the salinity (ds/m) of the topsoil of major soils. The non-parametric test statistics showed that the sodicity was found in moderately rated class for the haplic solonchaks and solonetz soils in topsoil properties, which in turn were significant (χ^2=5.92, p=0.02) for the other major soils' (Figure 7) property in the PA. The topsoil properties of haplic solonchaks and petric gypsisols soils were found in low rated salinity (2-4 dS/m), which were found significant (χ^2=5.08, p=0.02) for the other major soil (Figure 7) groups. The rest soils identified in the PA were found with very low salinity (< 2 dS/m).

The subsoil organic carbon content (% weight), pH and base saturation (%) of the major soils identified in the PA have shown a significant difference in regression analysis (Table 3). The soil organic carbon content of subsoil was significantly (χ^2=9.07, p=0.01) different for independent sample test statistics (Table 4). In group comparison, the humic nitisols, humic alisols and haplic phaeozem soils were significantly higher (χ^2=-10.5, p=0.00) in organic carbon content (moderate for subsoil and high to very high categories for topsoil properties) than the other groups of haplic solonchaks and petric gypsisols; the former group was significant (χ^2=-5.5, p=0.04) in solonetz, eutric vertisols, haplic calcisols, chromic

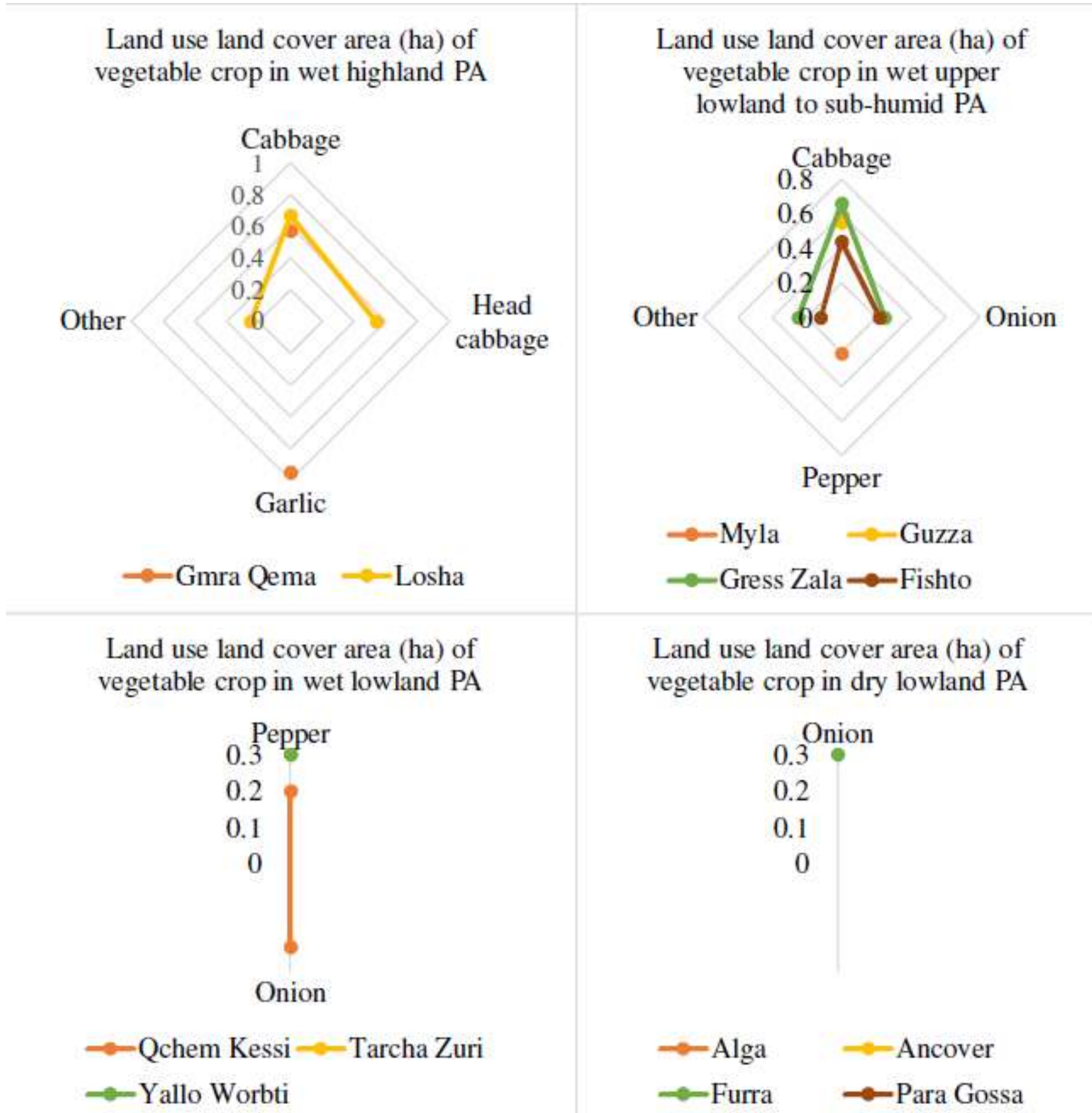

Figure 4. Vegetable/Horticultural crops in agricultural land area in agro-ecological zone in peasant administration (PA).

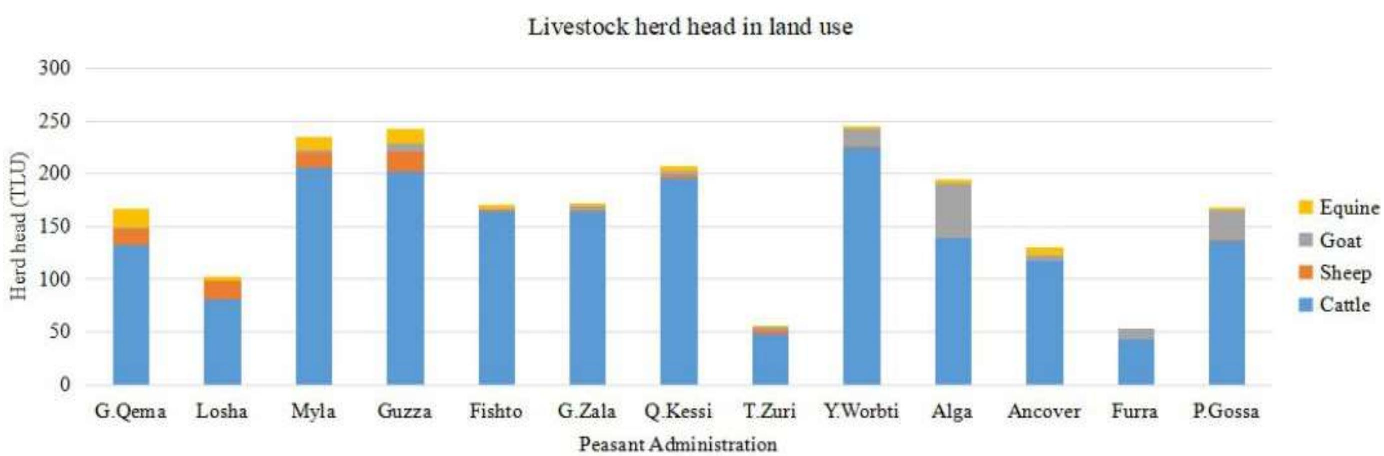

Figure 5. Herd head in Tropical Livestock Unit (TLU) in land use system in peasant administration.

Table 1. Population and total area and communal land area share of the sampled household in PA.

PA	N	Average farm size (ha/HH)[a]	Population total [b]	Area total (ha/total HH)[c]	Area total (ha/total HH)[a*b]	Land area change (ha/PA)[c-a*b]	Communal share area (ha/HH)
Gmra Qema	29	1.76	327	538.48	575.52	-37.08	0
Losha	32	0.99	407	398.2	401.15	-2.95	0
Myla	32	2.35	710	2599.25	1666.95	932.3	1.31
Guzza	32	1.58	304	1139.57	480.8	658.78	2.17
Fishto	32	1.35	1070	4741.55	1441.16	3300.39	3.08
Gress Zala	33	2.94	672	2001.55	1977.92	23.63	0.035
Qchem Kssi	25	2.67	231	5321.38	617.32	4704.06	20.36
Tarcha Zuri	9	2.83	381	3092.4	1079.5	2012.9	5.28
Yallo Worbti	32	1.29	342	1822.14	440.93	1381.21	4.04
Alga	32	1.23	548	1460.67	675.92	784.75	1.43
Ancover	32	1.13	1352	2015.27	1527.76	487.51	0.36
Furra	6	1.67	343	2485.08	571.67	1913.41	5.58
Para Gossa	19	1.7	244	4836.25	414.16	4422.09	18.12
Total	345	23.49	6987	32427.79	11967.6	50160.2	61.765

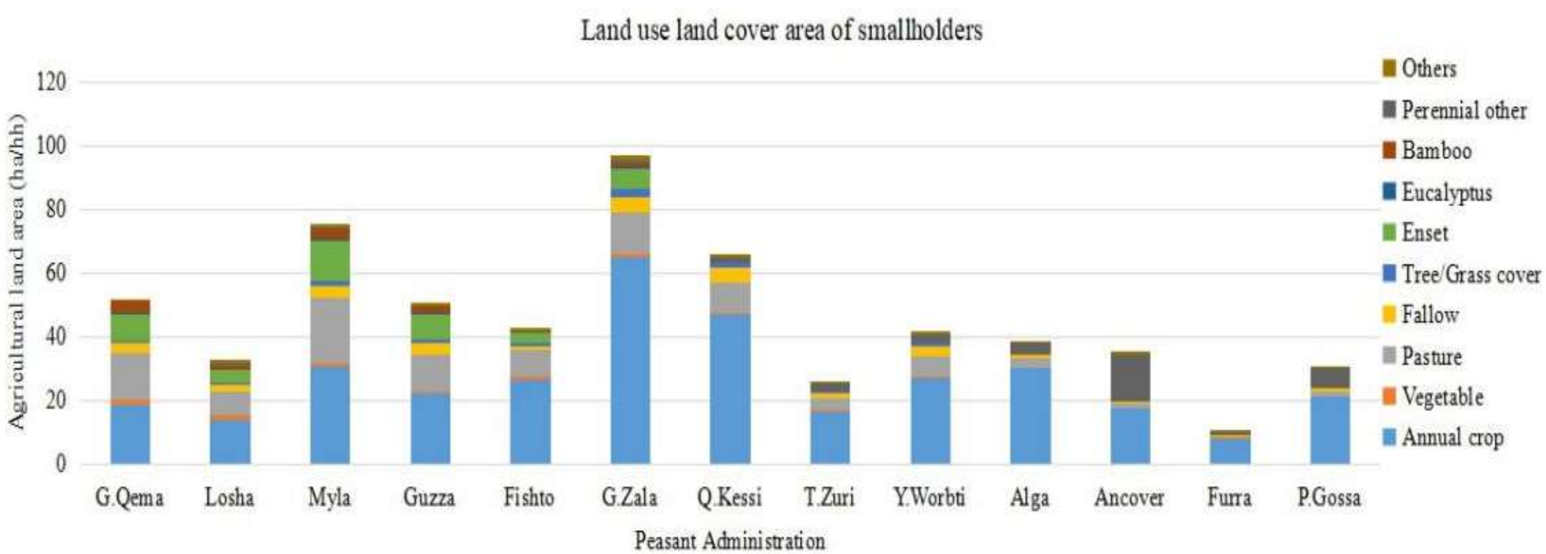

Figure 6. Agricultural land area (ha/farm enterprise type) in land use system in peasant administration.

Table 2. Regression analysis of topsoil properties of fourteen major soils identified from spatial analysis in peasant administration.

Topsoil property	X (SD)	DF	R	R^2	Adj R^2	F	p<0.05
Soil depth (cm)	93.57 (23.81)	1	0.31	0.1	0.02	1.27	0.28
AWC (mm)	138.57 (35.9)	1	0.3	0.09	0.02	1.21	0.29
Sand fraction (%)	42.79 (11.89)	1	0.22	0.05	-0.03	0.63	0.44
Silt fraction (%)	27.21 (5.5)	1	0.12	0.02	-0.07	0.18	0.68
Clay fraction (%)	30 (11.5)	1	0.29	0.08	0.01	1.1	0.32
Ref bulk density (kg/dm^3)	1.36 (0.08)	1	0.26	0.08	0	0.98	0.34
Bulk density (kg/dm^3)	1.32 (0.09)	1	0.41	0.17	0.1	2.45	0.14
Gravel content (%)	4.79 (9.77)	1	0.28	0.08	0.003	1.04	0.33
Organic carbon (% wght)	0.97 (0.66)	1	0.46	0.22	0.15	3.29	0.1
pH (H_2O)	6.77 (0.92)	1	0.49	0.24	0.18	3.88	0.07
CEC (clay) (cmol/kg)	45.86 (17.97)	1	0.48	0.23	0.17	3.67	0.08
CEC (soil) (cmol/kg)	16.71 (8.81)	1	0.01	0	0.08	0.001	0.98
Base saturation (%)	82.43 (23.12)	1	0.48	0.23	0.16	3.54	0.08
TEB (cmol/kg)	14.09 (9.15)	1	0.27	0.07	0	0.97	0.35
Calcium carbonate (% wt)	1.31 (1.76)	1	0.34	0.12	0.04	1.55	0.24
Gypsum (% weight)	0.66 (1.71)	1	0.45	0.2	0.14	3.03	0.11
Sodicity (ESP) (%)	3.14 (3.59)	1	0.59	0.35	0.29	6.32	0.03*
Salinity (ECe) (dS/m)	0.55 (0.76)	1	0.62	0.39	0.34	7.59	0.02*

*Topsoil properties of major soils in each row are significantly different.

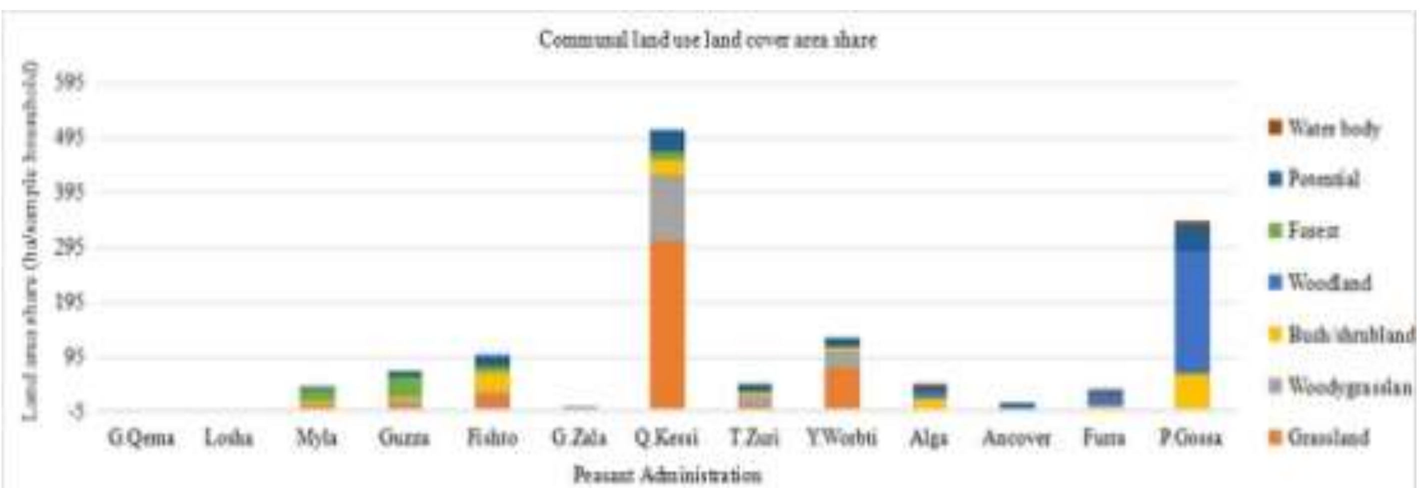

Figure 7. Communal biomass base land use and land cover area (ha/sampled household population) share in peasant administration.

cambisols, chromic luvisols, eutric fluvisols, eutric regosols and haplic ferralsols, found in poor to moderate organic carbon content groups in the PA. Whereas, the comparison between the latter two categories showed no significant difference (χ^2=-5.0, p=0.10) in the PA for organic carbon content.

The pH of subsoil properties was found significant (χ^2=10.18, p=0.01) (Table 4). The subsoil property indicated a very acidic condition in haplic ferralsols and humic nitisols soils; it is also significant (χ^2=-9.00, p=0.01) in carbonate rich soil groups of chromic luvisols, eutric regosols, petric gypsisols, haplic solonchaks, eutric vertisols and solonetz. The humic alisols, chromic cambisols, haplic calcisols, eutric fluvisols and haplic phaeozems soils were acid to neutral categories with significant difference (χ^2=-5.50, p=0.02) in carbonate rich soil category of subsoil properties in the PA. Whereas the test statistics showed no significant difference (χ^2=-3.50,

Table 3. Regression analysis of subsoil properties of thirteen major soils identified from spatial analysis in peasant administration.

Subsoil property	X (SE)	DF	R	R^2	Adj R^2	F	p<0.05
Bulk Density (kg/dm^3)	1.40 (0.09)	1	0.23	0.53	-0.03	0.61	0.45
Gravel Content (%)	3.54 (9.54)	1	0.06	0	-0.09	0.04	0.84
Organic Carbon (% weight)	0.43 (0.21)	1	0.62	0.39	0.33	7	0.023*
pH (H_2O)	6.97 (0.86)	1	0.65	0.43	0.38	8.23	0.015*
CEC (clay) (cmol/kg)	44.77 (18.19)	1	0.49	0.24	0.18	3.58	0.09
CEC (soil) (cmol/kg)	16.31 (9.41)	1	0.04	0	-0.09	0.02	0.9
Base Saturation (%)	81.69 (21.71)	1	0.64	0.41	0.35	7.5	0.019*
TEB (cmol/kg)	13.83 (9.89)	1	0.35	0.12	0.04	1.56	0.24
Calcium Carbonate (% weight)	2.23 (3.28)	1	0.41	0.17	0.09	2.2	0.17
Gypsum (% weight)	1.02 (3.05)	1	0.4	0.16	0.09	2.14	0.17
Sodicity (ESP) (%)	2.46 (3.30)	1	0.46	0.21	0.14	2.93	0.11
Salinity (ECe) (dS/m)	1.56 (3.12)	1	0.52	0.23	0.2	4	0.07

*Subsoil properties for major soils in each row are significantly different.

Table 4. Independent samples test statistics on top and subsoil properties of major soils identified in peasant administration.

Property	N	χ^2	Df	p
Topsoil				
Sodicity (%)	3	12.68	2	0.02
Salinity (dS/m)	2	5.08	1	0.02
Subsoil				
Organic carbon (% weight)	3	9.07	2	0.01
pH in water solution	3	10.18	2	0.01
Base saturation (%)	2	6.82	1	0.01

p=0.28) between very acid and acid to neutral soil categories of the subsoil. The major soil identified in the study area failed in two categories for base saturation properties; haplic ferralsols, humic nitisols, and humic alisols in base saturation corresponding to acid conditions; the rest in saturated conditions sometimes sodic or saline soil also showed a significant difference (χ^2=-6.82, p=0.01) in the sub-region (Table 4).

Agricultural production productivity

In the wet highland, households' wheat and barley share 6.52 and 6.33 ha, and 3.19 and 3.37 ha of the annual cropland area respectively in Losha and Gmra Qema PAs (Figure 1). The household estimated yield of each of these crops was 17 quintals/ha. The pulse crops cover area in Losha and Gmra Qema by 0.65 and 4.53 ha, and 0.57 and 1.4 ha (Figure 1), with production yield of 15 and 14 quintals/ha for horse bean and pea respectively. Irish potato is an important crop with high turnover in land use system; it shares 0.89 ha of the area and 250 quintals/ha with average sales of 75% production yield in the household in Losha PA.

Wheat of 14.47 ha in Myla and 7.56 ha in Guzza, and maize of 19.94 ha in Gress Zala and 9.65 ha in Fishto of the wet upper lowland to the sub-humid in PAs were the largest among the annual croplands area coverage. Wheat and teff in the latter three PAs and pea and teff in Myla have also substantiated holdings of the production area (Figure 1). The production of wheat and barley of 19 quintals/ha, and 16 and 15 quintals/ha of horse bean and pea in this region was the highest yield/ha area than the highland in AEZ. The production yield of taro of 200 quintal/ha in Myla and Guzza and sweet potato of 300 quintals/ha in Gress Zala and Fishto households were

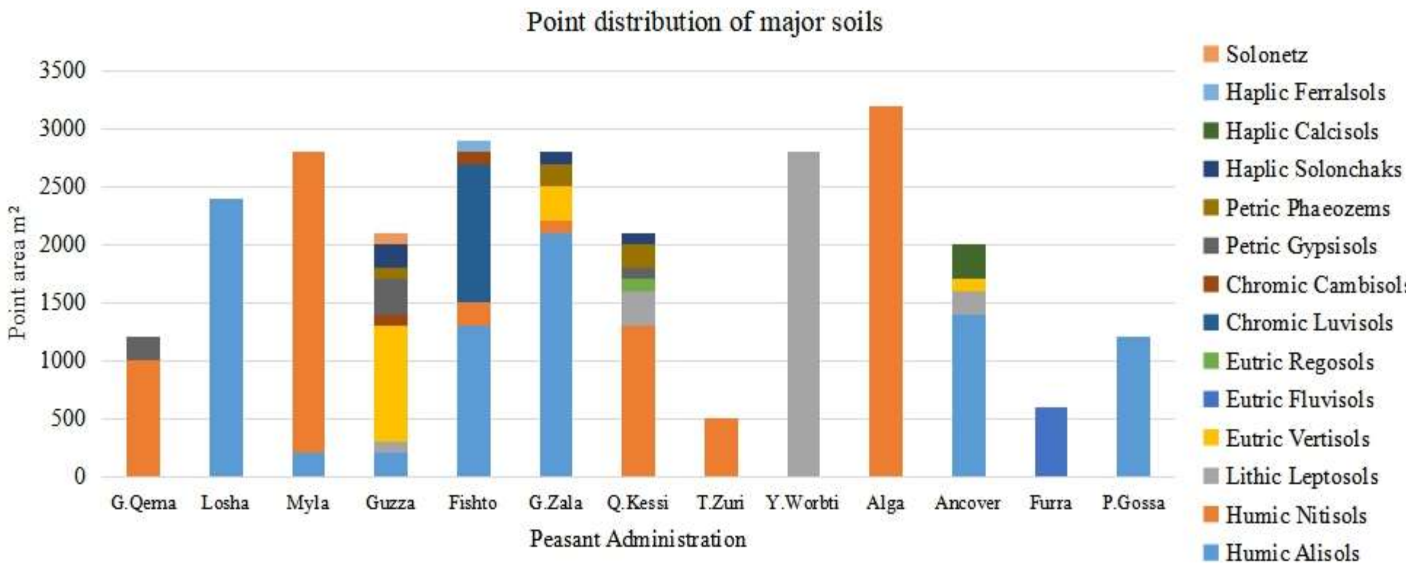

Figure 8. Spatial pattern of major soil extracted to point value in GIS 10.2 in peasant administration.

major components of staple food with 15% of the farm products used for commercial purpose in the household. The average sales amount of farm production was 45% of horse bean, 50% of pea, and 70% of each wheat and barley equal in both households of the highland and the midland. However, 80% of teff and 45% of maize (mainly from fresh harvest) were additional sources of household income from annual crop category in the latter AEZ households.

In the wet lowland PA, maize and teff took a prominent place in the agricultural land area with 25.59 and 10.06 ha in Qchem Kessi, 9.53 and 3.49 ha in Tarcha Zuri and 11.81 and 8.92 ha in Yallo Worbati household respectively (Figure 2). Whereas, groundnut of 1.95 ha with 12 quintals/ha production yield was lucrative cash crop with 80% used for commercial purpose in Yallo Worbati household. Maize was as equally important in the dry lowland PAs in the production area where only about 35% of the production yield used for business in a household was lower than that of 55% in the wet lowland. The average yield of maize of 42 quintals/ha in the wet lowland was also better than that of 38 quintals/ha in the dry lowland and 28 quintals/ha in the midland.

The most staple food crop, enset plantation was most typical in Myla, Gmra Qema and Guzza PA households with 12.76, 8.17 and 7.88 ha in land cover area (Figure 2). Banana occupied 15. 07 ha of cropland area, growing toward the area with specialized farming system in Ancover PA in the dry lowland. Although growing steady currently 1.04 ha of apple tree covering area in Losha household has been most promising for both household income, agro-industrial batch and as source of breeding stock for the entire country (Figure 2). Similarly, coffee plantation has been a reasonable allocation of land use system with mid-term level response to household income in the wet lowland. Although gradual turn over to household income, bamboo, eucalyptus and juniper trees were a substantial contribution to area coverage and household income in upward gradients to the highland (Figure 2).

The cropland cover area of the ethio cabbage was almost uniform from the wet upper lowland to the highland household holdings (Figure 3). However, it varies in its function, which in enset dominant production system was prominently used for household dietary supplement; where households relatively in the right position to consumer market such as Losha, Gress Zala and Fishto different compositions of vegetable growing to provide additional support in the household incomes with better turn over in land use system. Similarly, garlic has been household adapted crop with added value in Gmra Qema and groundnut in Yallo Worbati, in the highland and lowland land use system respectively. In the agricultural land cover area, crops such as maize, teff, wheat, groundnut, Irish potato with other different sorts such as cabbage, garlic, coffee, banana and the apple fruit contributed a significant high amount to household income, compared to crops of similar categories in land use system in any specific farming system (Amejo et al., 2018).

The diversity of livestock and products, chicken, and honey production plays a vital role in the household economy. The livestock sector household earnings consist of 60% cattle and 20% small ruminants (sheep and goats). Livestock product, butter and cottage cheese of 7% and buttermilk of 6% vary between the farming systems accounting for the household income. Butter in wet lowland in Dawuro zone household and buttermilk in the dry lowland household in Gamo Gofa zone are commodities valuable in cash income.

Table 5. Productivity performance of cow in peasant administration.

Peasant administration	Milk yield, kg/day	Milk yield, kg/lactation	Lactation Length, day	Fertility rate
Gmra Qema	1.83	495	270	0.87
Losha	1.83	467	255	1.00
Myla	1.67	902	540	0.68
Guzza	1.63	731	450	0.81
Fishto	1.55	557	360	1.00
Gress Zala	2.12	509	240	0.76
Qchem Kessi	2.00	776	390	1.00
Tarcha Zuri	2.08	624	300	1
Yallo Worbti	2.51	902	360	0.87
Alga	2.00	597	300	1.00
Ancover	2.02	544	270	1.00
Furra	1.95	585	300	1.00
Para Gossa	2.00	597	300	1.00
Total average	1.94	637.38	333.46	0.92

Table 6. Formula for draught animal power (day/year) for cropland cultivated in peasant administration.

PA	N	A	ff	X	f	W	A*f	E	$M=ff*6.45*(4.41)^2$
Gmra Qema	29	18.78	0.65	12.00	3.50	5.48	65.73	71.00	81
Losha	32	14.02	0.44	8.00	4.00	7.01	56.09	68.00	55
Myla	32	30.76	0.96	24.5	3.89	4.88	119.6	149.00	121
Guzza	32	22.4	0.70	22.00	3.89	3.96	87.11	135.00	88
Fishto	32	26.5	0.83	28.00	3.89	3.68	103.1	107.00	104
Grss Zala	33	64.84	1.96	22.00	3.89	11.46	252.2	182.00	246
Qcheme Kessi	25	47.20	1.89	28.50	4.40	7.29	207.70	159.00	237
Tarcha Zuri	9	16.58	1.84	9.50	5.50	9.60	91.16	126.00	231
Yallo Worbati	32	27.19	0.85	22.50	4.40	5.32	119.60	137.00	107
Alga	32	30.22	0.94	14.50	5.00	10.42	151.10	175.00	118
Ancover	32	17.28	0.54	14.50	5.00	5.96	86.40	43.00	68
Furra	6	8.10	1.35	5.50	5.00	7.36	40.50	101.00	169
Para Gossa	19	21.28	1.12	19.00	5.00	5.60	106.40	125.00	140
Average	26.54	26.55	1.0	17.73	4.41	6.45	114.36	121.38	125

Note: a=total hectare area of cropland requiring draught animal power, f=frequency of average day requiring a pair of working ox for aggregate composition of crops grows, ff=fraction factor of total cropland area, W=average productivity day of a pair of working ox per hectare of cropland, X=a pair of ox available, A*f=variable calculated average days/year for a pair of working oxen, E=framers' estimate average days/year for a pair of working ox to cultivate cropland, N=sample househ

A cow productivity performance impartially increases in the gradient toward the lowland (Table 5), the dairy and lactation milk yields, as well as the fertility rate higher in lowland AEZ. The productivity performance average of cow milk yields, 1.94 kg/day and 637.38 kg/lactation as well as 92% fertility rate in the wet highland and wet upper to sub-humid households was below the population average of the sample in PAs (Table 5). This probably associates with the resource potential in the AEZ. In the zones, the lowland gradients mainly comprise grassland, shrublands and woody browsing species, which on the other hand entertain extensive grazing and browsing.

Agricultural productivity is regularly calculated by the partial productivity of land (value of agricultural output per hectare of agricultural land) and partial productivity of labor (value of agricultural output per agricultural worker, including self-employed). An aggregate, the partial measures into one index that allows for the entire basket of resources and inputs used in agriculture is total factor productivity. While, both could have a limitation in the area context of present study due to several compounded factors. However, one can describe the agricultural productivity in the current study area as part of the result compositions and specialized forms of agriculture

Figure 9. Percentage of annual average and grand gross income obtained between household and on-and off-farm activities in peasant administration.

production systems maintained in the farm household and adapted in the AEZ.

According to Ruthenberg (1971), farming within each system is carried out in holdings, which are more or less distinct managerial units. Thus, it is difficult to measure agricultural productivity straight, and land productivity can vary for its own various different reason in smallholder system. As observed in this study a 0.25 ha area of farm holdings in banana growing area in the dry lowland can sustain the household livelihood with substantial numbers of a family member in case current farm level price of banana continues to increase steadily than the average holdings of 0.99 ha in the highland household. Another experience given was the role of a small farm 0.3 ha supporting livelihood in a non-graze dairy system in Kenya (Prinsley, 1990).

The overall percentage of relative agricultural productivity in gross average income in different LULC, for instance, between households and the livelihood activities in the PAs is presented in Figure 9. A comparison showed that the LULC area in the annual cropland was significantly higher than the other farm enterprises in the study PAs. However, the household annual gross income contributed from livestock sector (40%) was significantly *(χ^2=1.38, SE=0.19, p=0.85)* as equal as that of the annual crop production earned (46%).

Therefore, it is not only the farm or land size alone that determines agricultural productivity, particularly in smallholder system. There are also other factors playing a prominent role in smallholder agricultural productivity that could relate to the locally available and accessible resources; also infrastructures with necessary facilities, relative productivity of the land in relation with pre-historic population settlement trend, farm-level prices, AEZ, environment, etc are important determinants. The differential changes in the relative distribution of land, livestock, natural resources (rangeland biomass, forest flora, rivers, streams, and lakes) in specific farming have to lead to striking differences and changes in the structure of agricultural production.

For over 20 years, for instance, in most of the highland gradient PAs, local dairy production was carried out conjointly with artificial insemination service. However, in the lowland production system local cows yet fundamental in a dairy production also depicted highest average productivity performance of population (Table 5). This fact could supposedly be related to the availability of feed and water resources through extensive grazing. This also supports our assumption that local livestock productivity performance could be improved through improvement of feed and feeding management (Amejo et al., 2018).

There is no debate for increased farm size accompanied by management objective and the determinant factors mentioned above can increase agricultural productivity in smallholder households. An implication of this fact in the current study could be the Losha household in the wet highland PA. In this household of the major livelihood strategies identified off-farm, remittance and labor categories relatively contributed the largest with 28% (main of these were traditional cloth making), followed by annual crop, 26%, livestock, 12% and perennial crop plantation, 10% of the gross annual income. This shows that the household livelihood activities more or less contributed to equal as important as and interactively to the household income. However, the lowest average of 0.99 ha farm size (Table1) severely limited the household income with a grand average of 76% in a range between a minimum of 54% and a maximum of 143% (Figure 9).

The other striking evidence could be the land area of

Fishto PA, in the midland AEZ, which is the second largest in population and the third in total land area of all the study PAs (Table 1). The land biomass existing in communal biomass base was the largest than the household holdings. This is also in contrast with the adjacent PA, Gress Zala in which the land area evidenced was exclusively in farm holding level (Table 1). The household income gained was the third largest with 131% in the latter PA whereas the former the lowest of all with 54% from a range of a minimum and a maximum as mentioned above. The high slope surface, with the mean rise of 32.9% and confidence interval of 27.90-37.92 has been most likely affected by soil fertility. The soils observed were found to have poor organic carbon content, and others very acidic suffering from aluminum toxicity in case of Fishto PA. That could probably contribute less interaction effect to income from the livelihood activities mainly from farm-based sources in this PA. Proximity to urban area, road and transportation accesses, market stimuli to produce crops with relative better turnover have provided resilience and adaptability capacity in the household with small farm size such as Losha PA. A specialized type of production system with farmer objectives, for example, was observed in crops such as cabbages, garlic, groundnut, apple fruit, and Irish potato between the PAs and AEZs. The household had a specialized type of adaptation in these crops, and the crops also depicted a significant difference in some specific production system than the others.

It appears that to cultivate frequently in a year between seasons increases the land use efficiency, family cash income flow and most of the crops production 'purely' for cash or little parts (component) used for consumption. Its specialized adaptation in some production environment is also describable. For instance, the apple fruit introduced earlier has been well adapted in the highlands of Chencha (for example, in Losha PA), with significant cash value. Expansion effort to this crop has been made earlier in Gmra Qema PA (almost in the similar agroecology). In the Losha PA, the production of Irish potato together with the composition of other vegetables intensifying the system has given an opportunity for critical shortages of the farmland. That advanced with relative availability in road accesses and transportation in positions to Arba Minch town, which comprised about over 125,000 populations.

The production practices of Irish potato are overshadowed in Gmra Qema of similar agro-ecology, due to disease related to the crop and the soil moisture stress condition. But garlic in Gmra Qema as the most adopted and flexible crop is farmed twice in March to May and October yearly; it is supplied to either local or reachable consumers and carried by pack of animals or family labor. Its influence also explained a significant difference between the land use systems of the PAs and income values of crops in the similar category. The turnover of the income driven by the crop could be much more important for the household given that the production system is heavily intensified by crops like enset known to prolong provisions of household food demand. Tree plantation like bamboo, juniper, eucalyptus, etc. might take time to create income and compounded factors like infrastructural facilities. The disease condition and wet stress make less cropping opportunity twice in a year in bimodal rainfall often usual in many parts of Ethiopia. A remarkable result was shown in the number of farmers' cropping activity in two seasons (main rainy and *belg* season) in Gmra Qema compared to the other PAs. The positive sign in practices, however, farmers use the cropland for aftermath grazing season to season.

In contrast, in Tanzania, for instance, households cultivating maize on wrong soil or increasing landholding for the purpose of increasing output provided to soil resulted in low yields and therefore, more land is needed for better harvest (Hepelwa, 2010). According to that study, there was no much increase in landholding byhouseholds but the only feasible means to increase agricultural production is via improving technical efficiency.

Constraints like land shortage, disease, market limitation, rising production cost, lack of labor and shortage in improved verities were important factors pronounced by the respondent households in the sub-regions. In addition, soil data analyses from metadata source showed that the major soils identified in the PAs were problem of sodicity and salinity and some others were very acidic and poor organic carbon content except humic nitisols, humic alisol, and petric phaezems. The declining soil fertility conditions in the highland are also related to the long history of human settlement in Ethiopia.

Farm activities, its specific function designated to the household strategy could result in influences of the ecological environment on local knowledge and the economy. The farming system functioning would value remarkably the land efficiency, labor productivity, and supplement income. Its role should be encouraged and transformed into a diversified form. Livelihood strategies are dynamic and are composed of activities that generate the means of household survival (Ellis, 2000). A positive relationship with the landholding and socioeconomic factors such as income, primary education, age, household size, family labor, remittances (Hepelwa, 2010) was indicated.

System interaction

Livestock production is the primary input source of agricultural production in a smallholder production system, hence the livestock production could be claimed as a by-product of agricultural enterprises in mixed crop-livestock systems. From highland to dry lowland, in the patchy surface, to the machine, oxen have taken a proper position in the number of thousands hectare of area cultivated in the present study place.

Table 6 presents the formula for draught oxen power (day/year) used in cropland cultivated. The draught power used in the PAs to cultivate annual crop including horticulture was on average 125 days/year. This was the product of average productivity of 6.45 days for a pair of working ox per hectare area of cropland cultivated and the square of average frequency of 4.41 days for various aggregate crops growing required a pair of working ox from first tillage to the last with possible weeding/ harvesting activities yearly from highland to the lowland of AEZs. Similarly, farmers' interview result for their experience on a pair of working ox used for cropland cultivated was 121.38 days/year and that the variable calculated average was 114.37 days/year from the highland to the lowland AEZs (Table 6). The difference observed was 3.62 days for the farmers' experience estimation and 10.63 days for the variable calculated average compared to the formula derived from draught animal day.

In another study in Nepal, cultivation in hill zebu for 62 days and swamp buffalo for 130 days per year (Oli, 1985) was estimated. According to Gebresenbet et al. (1997), small-scale farming is the most important sector of agricultural production in most Sub Saharan countries and about 80% use human or animal power in the production of their food and income needs. Animal power used for thousands of years in Ethiopia is unique in Sub-Saharan Africa compared with the rest of Africa where animal traction for cultivation has been introduced within the recent past as one of several technical interventions (Gebresenbet et al., 1997).

The annual crops requiring working oxen in the highland AEZ include wheat, barley, pea, horse bean, lentil and some other oil crops. Crops such as potato, garlic and other vegetable orchid could also engender oxen plough depending on plot size and access. The wet upper lowland to the sub-humid PA households use working oxen to cultivate crops such as teff, maize, root crops, wheat, barley, pulse and some other crops. Teff, maize, sorghum, root crops and groundnut in wet lowland and maize, cotton and bean in either intercropping or single unit require oxen power in the dry lowland.

The pattern of crop cultivation in terms of oxen use seems to be more cyclic toward the lowland gradient in Gamo Gofa PA households; however, it seems like more season based cropping activity and crops carried out in Dawuro zone PAs, broadly between the two seasons when cropping activity is done. In the former, the households mostly follow the rainfall patterns and cultivate cropland at the slightest signs of rainfall; the farmers have adaptability capacity to change and varied climate change. While in the latter case, it is supposed to be due to moisture stress and catering to relative rest period in the cropland.

The fraction factor of draught power, 1.96 in the Grss Zala, in wet upper lowland to the sub-humid zone and 1.89 in the Qchem Kessi in the wet lowland was the largest that used oxen for cropland ploughing per year. This value was low in wet highland in Losha 0.44 and in dry lowland in Ancover 0.54. The difference reflected in fraction factor between AEZs and PAs could be due to farm and plot sizes available for cultivation. Otherwise draught power requirement for traction could depend on the suitability of cropland for plough, the aggregate compositions of the crops cultivated by oxen in particular farming systems and the frequency farmers use oxen during cropping activities. This means that a pair of working ox is used to cultivate one hectare of cropland area per year from first tillage to growing an aggregate type of annual/temporal crops; weeding and harvest was done in mixed crop-livestock system from highland to lowland AEZ for an average of 125 days. The estimated average number of working hour/day recorded for a pair of working ox during the rice planting season in the hills was eight hours and the area ploughed was 0.25 ha/day; that for swamp buffalo was seven hours and 0.37 ha/day (Oli, 1985).

The formula could, therefore, be used directly or with slight modification in Ethiopia or elsewhere; oxen traction is common for cropland cultivation. Oxen power value estimate in agricultural production is the major difficulty Ethiopia is currently facing. This result, however, provides a remarkable opportunity to the sector. Animal traction provides almost a quarter of the total area under crop production in the level of global estimate (Swanepoel et al., 2010). On the other hand, Oli (1984) estimated that the draught power used for cultivation in Nepal was equivalent to about 1.37 million kilowatts of energy and contribution of those animals was worth about Nepal currency 1,300 million at 1984 prices. In another, during a serious economic crisis for the Cuban society approximately 385,000 oxen were substituted 40,000 tractors (Henriksson and Lindholm, 2000). The fundamental issue raised on monetary valuing of a draught power has been mentioned earlier by IGAD Livestock Policy Initiative paper (Behnke, 2010; Behnke and Metaferia, 2013).

Manure is another livestock output which farmer households much rely on as a means to soil fertility improvement in their production system, and apply to identified crops associated with yield perfection (Amejo et al., 2018). Peasant farmers in the highland due to stressed soil condition, small plot size, and increasing fertilizer debt have the tendencies to carry livestock wastes over distance crop field, allowing tethering by small ruminants in the ploughed plot prior to sowing period. However, the production level of manure dry matter (DM) matches the herd holdings as well as the crop residue DM supply to the annual cropland area in the household (Table 7).

Livestock production, on the other hand, bears the

Table 7. Annual cropland area, percent of household cultivated annual cropland area per season and farm output supply dry matter (DM) in peasant administration (PA).

PA	Annual cropland area, ha (%)	Household cropping activity between season		Farm level output supply	
		% household in Belg season	% household in Meher season	Crop residue DM (%)	Manure DM (%)
Gmra Qema	17.26 (34)	0	100	37 (3)	57.58 (7)
Losha	12.56 (40)	53	100	33 (3)	33.89 (4)
Myla	30.01(40)	25	100	77 (6)	83.58 (11)
Guzza	21.85 (43)	19	100	55 (4)	81.93 (11)
Fishto	25.73 (60)	78	56	114 (9)	64.17 (8)
Grss Zala	63.74 (66)	72	75	229 (18)	69.10 (9)
Qcheme Kessi	46.68 (70)	61	39	208 (16)	80.62 (10)
Tarcha Zuri	15.56 (61)	57	43	72 (6)	18.43 (2)
Yallo Worbati	26.89 (65)	57	43	109 (8)	98.39 (13)
Alga	30.22 (76)	100	47	147 (11)	60.87 (8)
Ancover	17.28 (46)	100	47	80 (6)	50.02 (6)
Furra	7.8 (78)	100	33	29 (2)	17.77 (2)
Para Gossa	21.28 (66)	100	32	101 (8)	56.27 (7)
Total	335.75	822	815	1289.81	772.62

burdens of labor, abets risks arisen due to market limitation for crop commodities in far distance households, topographies of the location in the corridors bounded by water logs across each regions and gives compensation for crop miscarry due to climate change. The farm household in the Gmra Qema PA in particular and mostly toward highland gradients in the Dawuro zone, for instance, did not practice *belg* season cropping activities in the plots of the annual crop (Table 7). The variation in the household cropping activity could probably be stress related to soil condition. Our standardized precipitation index (SPI) analysis also evidenced other causes like wet event extremity in this region in addition to drought event. The respondent households in the Grma Qema PA also disclosed soil related problems in growing some root crops. However, in Gmra Qema (100%), livestock production has provided a positive attribute in the land use system through grazing from season to season (Table 7).

The livestock feed supply from food crop production accounted for 8% of the total annual in the study area. The value indicated was apart from feeds from aftermath grazing of cropland, weeds harvested from different land use types or livestock graze directly on it. Grazing/ browsing base, both food and non-food production biomass systems presented the dominant share of livestock feed supply which accounted for 92% of the total amount quantified in relations to herd population and levels of their physiological feed requirements in the specific farming system. The variability in biomass base availability is high within and between the AEZs and PAs.

In the highland, feed resources and crop residues are wheat, barley, and legumes, tubers, and leftovers of the arched of vegetable, enset, bamboo, and tree leaves. Maize, teff, sorghum, field bean, root crops, coffee leaves, tree plantations and banana left over after fruit cut in the lowland were all important sources of livestock feed in wet and dry seasons. Whereas, feed resources supply from food crop production in the mid-altitude comprehensively constitute that of the highland and lowlands.

However, households' use of crop residue as livestock feed was inconsistent and inefficient, despite its limited potentials in nutritive value. On the other hand, enset and bamboo that are grazed results in land shortage during cropping season, filthiness of grazing areas due to heavy rainfall and frequent grazing on the same pasture and dry period are invasive in the highland to sub-humid regions. All the land use systems occupied by various items of crops are an alternative means that could provide significant strategic opportunity in the face of a critical shortage of grazing land particularly in highland household.

The highland livestock feed supply was basically described in land held by private ownership where farm holdings were significantly low as well as natural pasture land; these are strikingly unmatchable to the number of livestock herd head in the system. Other studies expressed similar evidence in northern highland of Ethiopia (Yimer, 2009). However, multifarious mixes of the crops in different forms of land use system, magnitudes of range in inter-seasonal cropping activities in a certain area due to disease and wet stress systematically are arranged. Types and species mixes of the livestock, regime and scheme in a grazing system for the different groups of livestock and farmers' tendencies to harvest, collect, store and use crop residue and other fodder cut through scarcity, function together influence land shortage. In contrast, in the lowland there is sufficient stack of rangeland biomass with wide varieties of grasses, shrub and abundant browse species.

Relating livestock and biophysical resources, a study emphasized different categories of land, such as total land, arable land, arable and permanent crops, permanent or non-permanent pastures, and non-arable pastures. The proportion of each land type and its evolution over time in relation to total land is important, especially that of permanent pastures need to be considered (Swanepoel et al., 2010).The farming system is congenital in the area, yet adopted in the AEZs, for instance, sheep, and mare production is typical in the highland and goat system in the lowland. The diversity together with land use allocation in various cropland strikingly maximized the opportunity for livestock production not only in areas with abundant grazing but also in the highland where grazing land is rare. Land and grazing resources availability often determines the type of livestock that can be kept, the way they are managed, and the extent to which livestock production can expand further (Swanepoel et al., 2010).

Conclusions

The present study set out to characterise smallholder rural mixed crop-livestock systems subdividing various AEZs into LULC classes in Gamo Gofa and Dawuro zones. The major livelihood strategies identified in the community are farm system (crops and livestock production), collecting (forest product and fishing) and non-farm (such as traditional clothes making, local small trading, remittance, and labor) activities. The assets and activities in these categories are predominately and solely evolving steadily and diversely in natural environment and experiences of farm household. In a way, labor and family health are invariably important for households to derive their livelihood means.

Despite fragmented holdings, structures on land use allocation of the farm entity provide particular options on integrity and utilization of the household owned resources in the subregions. In terms of provision of food, income and feed, small plot size holding, scale of production and intra-seasonal based production due to bi-modal rainfall distribution in the area annual crops had the largest agricultural land cover area in the subregions of PAs. The components and elements of crop and livestock type existing within AEZs are similar. The difference resulted in similar AEZ probably due to the existence of a minor level of manipulation on the system, soil and on awareness development of the farmers. This deviation lays an opportunity for developing interventions that can address common features in the area. Whereas, the basic difference associated with the farming system and the household were the difference in agro-ecological conditions, geo-location, and distance to marketing point where a substantial number of consumer market exists to dispose farm households supply and their demand.

The non-food production rbiomass consisted of two-thirds of the total, in which 18% exist in the mid-land AEZ, and annual draught power use for the cultivated area fraction marked the highest despite the high slope surface. Agricultural land use efficiency might be impeded due to high slope surface in wet upper lowland to the sub-humid agro-ecology. The highest non-food production biomass, 82% was found in the wet and dry lowland. While the economic contribution is comparable lower in land productivity in the lowland region due to inefficient use and utilization of this biomass base. The highest average gross income of livestock in this drought-prone area largely capitalizes resilience and responding capability of livestock agriculture to major supply-side difficulties generally in the current study area.

Moreover, livestock production is an important component of current mixed crop-livestock systems; its role is beyond that of the usual provision of milk and meat. Livestock production supplements numerous supply-side difficult factors observed in the current study. Through changes and several deriving force, farmers are aware that their land fertility is less efficient to gain enough yield. They have the desire to use fertilizer as the level of their yield increases. However, production cost (full package soil fertilizer cost) and family demand are limited by plot size and the output per holdings.

Therefore, smallholder farmers estimate the amount of manure they can gain per head of animal they have, plot size to cultivate particular crop and the amount of mineral fertilizer they can afford to blend with animal manure. This experience is emerging particularly in the highland farming system. The high proportion of income obtained from livestock sector shows that livestock can be remarkably intensifying systems without the associated effects of land-based intensification. This also clearly implicates the land-livestock productivity per hectare basis. The high income from crops reveals the sales of high-value cash crops (such as maize, wheat, teff, bean, cabbages, apple, banana, etc).

The range and balance of resource, assets and enterprise combinations that are reflected in any specific farming system are limited by a number of constraining factors. Several constraining factors increase agricultural productivity from land holdings alone, in smallholder agriculture production. On the other hand, many smallholders' peasant production insinuates small plot size in developing countries.

The role of the livelihood strategies identified in crop-livestock systems to household economy is crucially important for agricultural development. The efforts towards strengthening infrastructural facilities to link marketing opportunities, undertaking investment in agricultural research for development, improving the linkage between agriculture and natural resources like water, rangelands and disease control promote not only farm household economy from the existing potential but also foster availability and access to food security between smallholder rural producers and consumers. Without a significant approach to development support, the future will be very pessimistic to farm household in high-altitude.

Scope for future work

The data of the current study could be useful in crop and livestock modeling and management decision by interlinking each other in several modeling tools. Future study in these lines can explore livestock productivity per land area; compare and evaluate an area where animal manure is commonly used for crops such as enset, root and other horticultural crops, its population density and diversity, production level and yield and trends of change in these attributes over time as well as soil-microbe population and diversity; the level of manure production, proportion used for crops, proportions of cropland fertilized, farmers' desire and levels of manure supply in a supplement to mineral fertilizer amount in the household; the monitory value of manure and draught animal power in agricultural production; rangeland evaluation for management objective. Also farm animals' demographic characteristic should be assessed in details for local farm animals in mid-term records of demographic data. An argument was developed from this study: the milk yield of the cow toward lowland gradient was higher than that of the highland. In the latter case artificial insemination service is common from exotic or improved breeds. Therefore, this result implicates that better milk yield in the lowland supposedly is associated with local resource availabilities rather than the imported input. Integrated analysis to ensure the roles, extent and potential demand of the resource base can confer certainty of long-term impact on increased efficiency of food production, and sufficiently high economic return to merit the land capability. The co-existence of traditional mixed crop-livestock systems evolves with soil-plant-animal-atmosphere in combination with the entire systems of genetic material.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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