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Table of Contents: Volume 10 Number 9 September 2018

ARTICLES

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Journal of Agricultural Biotechnology and Sustainable Development

Full Length Research Paper

Farmers' knowledge and perceptions of leaf spot disease of groundnut and its management in Northern Region of Ghana

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Groundnut (*Arachis hypogea* L.) is an important food source as well as cash crop for the people of Northern Ghana. The crop yield is low partly due to biological constraints which include diseases like leaf spot. A survey was conducted among 200 farmers in four districts of the Northern Region of Ghana, from June to August, 2014 using a structured questionnaire. The objectives of this study were to assess farmers' knowledge, perception and management of leaf spot disease of groundnut. Differences in farmer responses were evaluated using Chi-square test. A significantly higher (*P* =0.005) number of farmers (87.5 %) were aware of leaf spot disease of groundnut and could identify symptoms of the disease, but could not differentiate symptoms from herbicide injury. Majority (84.5 %) of the farmers reported the incidence of leaf spot disease on their farms to be 50 % and above. Most farmers (74.5 %) also reported the disease severity to be above 50 %. Male farmers (33.5 %) who used defoliation or brown spots as signs of maturity of the groundnut crop were significantly more (*P* =0.031) than their female counterparts (26 %). Farmers who used non-chemical methods (62 %) of managing leaf spot disease were significantly (*P* <0.001) higher than those who used recommended methods including the use of chemicals (38 %). It is important to educate farmers to enhance their capabilities for leaf spot disease management through farmers' field days. Also, since most of them use traditional methods such as crop rotation, appropriate spacing and mixed cropping as means of controlling the disease, and the use of effective plant extracts as an integrated management strategy would be ideal.

Key words: Leaf spots, knowledge, perception, management, Northern region.

INTRODUCTION

Groundnut is one of the most popular and widely cultivated legumes in Ghana because of its adaptation to a wide range of climatic conditions (Kombiok et al., 2012). In 2011, Ghana was ranked 10th in production

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volume (530,887 MT of in-shell groundnuts) in the world and 4th in Africa, after Nigeria, Senegal and Sudan (Ibrahim et al., 2012). It is an important cash crop in subsistence and commercial farming systems, as well as an important food source for the people in Northern region of Ghana (Tsigbey et al., 2003; Izge et al., 2007). Also, being a legume crop, groundnut helps in improving soil health and fertility by fixing N_2 and organic matter in the soil (Janila et al., 2013). It is estimated that 90% of farm families that cultivate groundnut as cash crop in Northern region of Ghana, rely on farming tools and technologies that can be characterised as indigenous, traditional and informal (Tsigbey et al., 2003; Pazderka and Emmott, 2010). Therefore, understanding agricultural knowledge structure, operations and challenges faced by rural farmers is critical because their livelihood depends substantially on their ability to make accurate agronomic assessment (Adam et al., 2015).

According to Hewitt (2000), about 10 to 20% of staple foods and cash crops are destroyed by diseases. One of such disease is leaf spot of groundnut which can cause yield losses of 50 to 70% in West Africa and up to 50% worldwide as reported by Tshilenge-Lukanda et al. (2012). In Northern region of Ghana, pod losses and defoliation due to leaf spot can reach 78 and 80% respectively (Tsigbey et al., 2001; Tsigbey et al., 2003). Leaf spot diseases are widely distributed and occur in epidemic proportions in northern region (Nutsugah et al., 2007). Thus understanding farmers' knowledge related to perceptions of crop diseases and their management practices is essential for the development of management strategies which have a high probability of being adopted by the intended users (Adam et al., 2015).

Studies have shown that most groundnut farmers often see defoliation as a sign of the crop maturity (Nutsugah et al., 2007). Many attempts have been made to develop groundnut cultivars that are resistant to leaf spot. Although researchers have developed and disseminated improved groundnut varieties to farmers, 50% of farmers in the region still cultivate and produce highly susceptible cultivars such as 'Chinese' (Ibrahim et al., 2012).

Leaf spot disease of groundnut is endemic in Northern region of Ghana because farmers rarely use fungicides to control diseases on their farms (Tsigbey et al., 2003; Nutsugah et al., 2007). Some farmers practice crop rotation, burning and burying of crop residues after harvest, removal of volunteer groundnuts and deep turning of crop debris which are seldom applied by smallholder farmers for reasons (Wilber, 2014) such as inadequate land size, lack of information especially in carrying out crop rotation and labour intensiveness (Tsigbey et al., 2003).

Consequently, control measures for pests and diseases would be more robust when more farmers' knowledge, perception and practices are taken into consideration (Heong et al., 2002. There has been increasing interest in incorporating farmers' indigenous knowledge into research and development programmes for finding workable solutions to agricultural problems (Isin and Yildirim, 2007; Obopile et al., 2008).

Despite the established critical role of farmers' knowledge in the control and mitigation of pests and diseases, very few studies have focused on this subject in the area. Secondly, farmers' knowledge and practices of controlling leaf spot of groundnut varies in different parts of the world or even in different locations within a given country due to differences in agro-ecological and socio-economic setting under which production occurs. Thus, this study sought to contribute towards filling this knowledge gap by assessing farmers' knowledge and management practices for the control of leaf spot of groundnut in Northern region of Ghana. The objectives of this study sought to;

1. Assess farmers' knowledge, perception and management of leaf spot disease of groundnut.
2. Determine the incidence and severity of leaf spot disease of groundnut on farmers' farms.

MATERIALS AND METHODS

Study area

The farm survey was conducted in communities within the Tamale Metropolis, Kumbungu, Tolon and East Gonja districts in the Northern Region of Ghana during the 2014 cropping season (Figure 1). Northern region of Ghana is located on latitude 9° 29' 59.99"N and longitude 1° 00' 0.00"W (Anonymous, 2017). It occupies a land area of about 70,384 km^2, which is approximately 30% of the total land area of Ghana. The region is bounded by Brong-Ahafo and Volta regions to the south, the Upper West and Upper East regions to the north, the Republic of Togo to the east and the Republic of La Cote d'Ivoire to the west (Badii et al., 2012).

Survey on farmers' knowledge, perception and management of leaf spot disease

The survey was conducted by administering questionnaire to groundnut farmers in four administrative districts of the Northern region of Ghana, namely Tamale Metropolis, East Gonja, Tolon and Kumbungu (Figure 1). The districts were purposively selected based on the operational areas of the Presbyterian Agricultural Station-Mile 7 (PAS-Mile 7) which is promoting the production and marketing of groundnut among smallholder farmers. A multiple-stage sampling technique was used to select the respondents for the study. First, a total of 20 communities, consisting of five from each district were randomly selected through the assistance of field staff from PAS-Mile 7. In the second stage, using the list of farmers in the institution as the sampling frame, ten farmers were randomly selected from each community, which resulted in a total of 200 respondents.

A semi-structured questionnaire designed in a closed- and open-ended manner was used to elicit information on farmers' knowledge, perception and management of leaf spot disease based on preliminary surveys and extension experience with farmers. The questions were developed on the following key aspects: farmer's demographic information, knowledge of leaf spot disease and management strategies. A pilot test was conducted with 30 groundnut farmers in two communities which were not included in

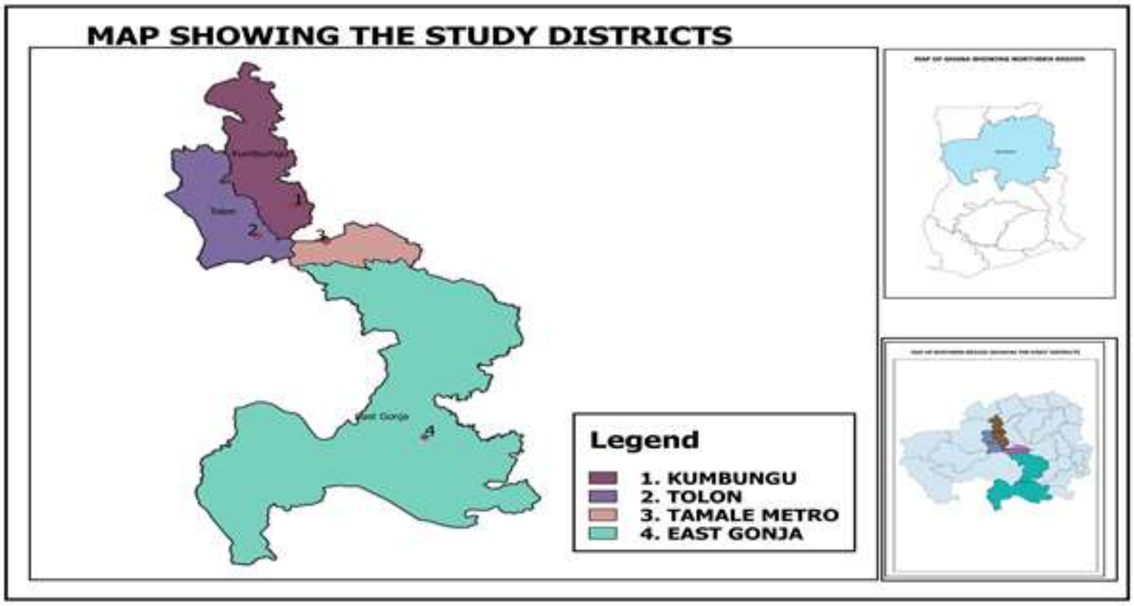

Figure 1. Map showing the study districts in Northern Region of Ghana.

Table 1. Florida 1 to 10 scale system for groundnut.

Scale	Interpretation
1	No leaf spot
2	Very few lesions on the leaves, none on the upper canopy
3	Few lesions on the leaves, very few on the upper canopy
4	Some lesions with more on the upper canopy, 5% defoliation
5	Lesions noticeable even on upper canopy, 20% defoliation
6	Lesions numerous and very evident on upper canopy, 50% defoliation
7	Lesions numerous on upper canopy, 75% defoliation
8	Upper canopy covered with lesions, 90% defoliation
9	Very few leaves remaining and those covered with lesions, 98% defoliation; and
10	Plants completely defoliated and killed by leaf spot

Source: Chiteka et al. (1988)

the sample, a month before the study. After the pilot test, minor changes were made in the questionnaire to enhance clarity.

Data were collected using face-to-face interview combined with farm observations, from June to August, 2014. The survey was conducted by field staff PAS -'Mile 7'. Each interview lasted for about 30 minutes. Dagbani which is mostly spoken by the farmers was used throughout the interactions with respondents. A total of 200 farmers were used in the analysis; consisting of 100 female farmers and 100 male farmers.

Determination of the incidence and severity of leaf spot

A total of 40 farmers, 10 from each of the four districts were selected using a multi-stage sampling technique. Farms were then examined to determine the incidence and severity of leaf spot. Assessment of disease incidence was done by walking diagonally across the farm and scoring groundnut plants for the presence or absence of leaf spot symptoms. Samples of leaves were also collected at every tenth pace along the diagonal walk. These leaves were used to assess severity of leaf spot using Florida scale of 1 – 10, where 1= no leaf spot and 10= plants completely defoliated and killed by leaf spots. The descriptive keys were used to determine the severity of the disease (Table 1).

Data analysis

The Statistical Package for Social Scientists (SPSS) version 16 was used to analyse the association of the responses between male and female by employing the Chi-Square test. The non-parametric Kruskal-Wallis equality-of-populations rank statistical test was employed to determine whether disease severity measured on an ordinal scale, differed based on farms.

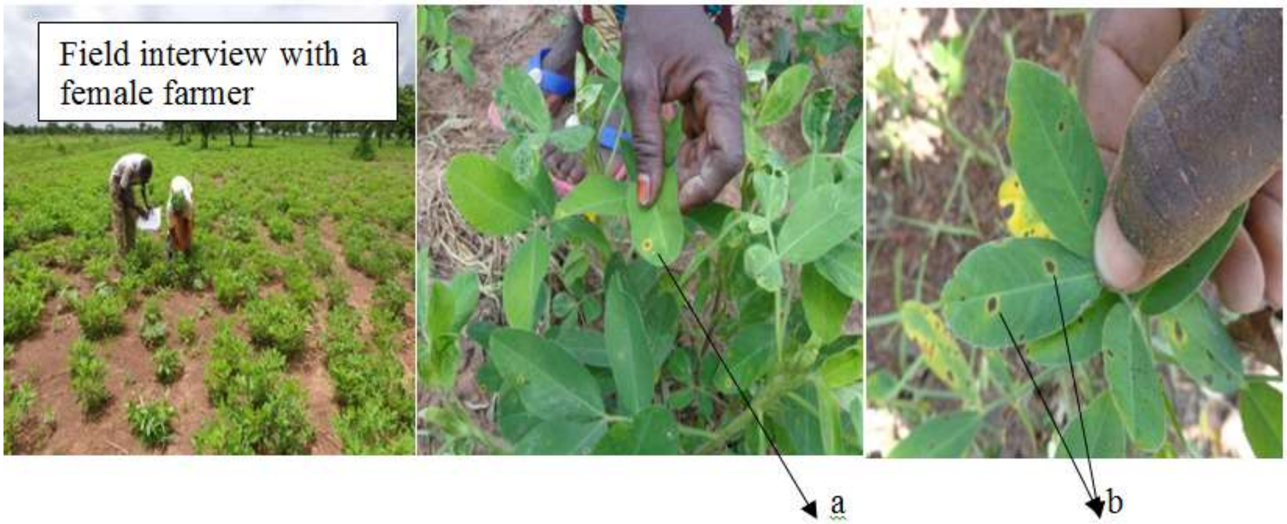

Figure 2. A Female farmer (a) and male farmer (b) in East Gonja identifying leaf spot on their farms.

RESULTS

Determining farmers' knowledge and perception of leaf spot diseases of groundnut

A significantly higher (*P* =0.005) number of farmers (87.5%) were aware of leaf spot disease of groundnut. 47% of farmers who affirmed their awareness of the disease were males whilst the rest (40.5%) were females. Among farmers who had not heard of the disease, 3% were males whilst 9.5% were females.

Majority (84.5%) of the farmers knew the symptoms of the disease. The rest (15.5%) were ignorant. A significantly higher (*P* = 0.032) percentage of male farmers (45%) knew of the symptoms of the disease. Most of the farmers (84.5%) who claimed to know the disease could identify the symptoms of the disease on their groundnut farms. More male farmers (45%) could identify the leaf spot disease symptoms than their female counterparts (39.5%). All the farmers who claimed that they knew the symptoms of leaf spot could actually identify them on their farms (Figure 2). Although more male farmers (40.5%) could identify the disease symptoms than the females (38.5%) the difference was not significant (*P* > 0.05).

Most farmers (91%) attributed the cause of the disease to poor soil fertility, high rainfall, wind or air and herbicides application while the rest (9%) attributed it to insects and drought. A significantly higher (*P* = 0.048) percentage of male farmers (47.5%) attributed the cause of the disease to poor soil fertility, high rainfall, wind or air and herbicides application. None of the farmers attributed the disease to pathogens. Majority (84.5%) of the farmers reported leaf spot disease incidence in their farms to be 50% and above whilst the rest (15.5 %) reported the disease incidence to be 20 to 49%.

Female farmers recorded a significantly (*P* = 0.003) higher disease incidence than their male counterparts (Table 2). A significant percentage of farmers (61%) observed the appearance of the disease from 1 to 3 weeks after planting (WAP) whilst the rest (39%) observed it at 4 WAP. A significantly higher percentage of females farmers (34.5%) claimed that they observed the disease earlier (that is, 1 to 3 WAP).

Farmers also reported that the disease was encountered any time they cultivate groundnut. There was no significant (*P* > 0.05) difference among farmers who encountered the disease every season or every year. Most of the farmers (74.5%) reported the disease severity to be above 50% whilst the rest (25.5 %) described the disease severity to be less than 50%.

Generally, female farmers (32%) experienced significantly (*P* < 0.001) lower disease severity compared to male farmers (42.5%). During the farm survey, it was observed that farms belonging to women were either an acre or less, free from weeds and intercropped mostly with vegetables. However, farms of male farmers were mostly more than an acre, weedy and sole cropped. Some women farmers also reported that, they sprayed aqueous neem leaf or seed extracts on their plants to prevent pest and disease from attacking their crops. All of the farmers could determine when their groundnut crops reached maturity and were ready for harvest.

Farmers who used defoliation or brown spots of the groundnut crop to determine its maturity were significantly more (*P* = 0.031) compared to those who used sample digging. Male farmers (33.5 %) who used defoliation or brown spots as a sign of maturity were significantly more (*P* = 0.031) than their female counterparts (26%) (Table 2).

Table 2. Farmers' knowledge and perception on the existence of leaf spot of groundnut.

Factor	Farmer responses	Sex of respondents			Chi-square	*P*-value
		Male (%)	Female (%)	Total		
Whether farmer has heard of leaf spot disease before	Yes	47	40.5	87.5	7.726	0.005
	No	3	9.5	12.5		
Whether farmer is aware of the disease symptoms	Yes	45	39.5	84.5	4.619	0.032
	No	5	10.5	15.5		
Whether farmer can identify diseased samples or examples	Yes	45	39.5	84.5	4.619	0.032
	No	5	10.5	15.5		
If yes, on which plant part do you observe the disease	Whole plant with symptoms	9.5	11.5	21	0.482	0.487
	Leaves with symptoms	40.5	38.5	79		
Farmer's believe of the cause of leaf spot.	Low soil fertility, high rainfall, wind /air and herbicides	47.5	43.5	91	3.907	0.048
	Insects and drought	2.5	6.5	9		
Farmer's description of the incidence of the disease in his/her farm	Low (20-49 %)	11.5	4	15.5	8.589	0.003
	High (50 % and above)	38.5	46	84.5		
What time and stage of growth farmer encounters the disease	1-3 weeks after planting	26.5	34.5	61	5.380	0.020
	4 weeks and above	23.5	15.5	39		
How often farmer encounter the disease	Every season	42.5	41	83.5	0.327	0.568
	Every year	7.5	9	16.5		
Whether farmer is aware of the effects of the disease on yield	Yes	40.5	43	83.5	0.907	0.341
	No	9.5	7	16.5		
Farmer estimates on the severity of the disease on a scale of 5	Not severe (1-3)	18	7.5	25.5	11.607	0.001
	Very severe (4-5)	42.5	32	74.5		
How farmer determines the maturity of groundnut	Leaf defoliation and brown spots	33.5	26	59.5	4.669	0.031
	Sample digging	16.5	24	40.5		

Disease management practices

Farmers who used their own methods (62%) of managing leaf spot disease were significantly more (*P* <0.001) than those who used recommended methods including the use of chemicals (38%) (Table 3). Other management strategies proposed by farmers were improved research, fertilizer/manure application, spraying with recommended fungicides / plant extracts and reporting the disease situation to Ministry of Food and Agriculture (MoFA).

Incidence and severity of leaf spot

Leaf spot disease incidence or prevalence was 100 % on the farms surveyed. Based on the Kruskal-Wallis equality-of-populations rank test (as shown in Table 4), the rank sum of disease severity for farmers in East

Table 3. Farmers disease management practices on groundnut farms.

Factor	Farmer responses	Sex of respondents			Chi-square	*P*-value
		Male (%)	Female (%)	Total		
Farmers' management practices on the disease	Non-chemical methods	38	24	62	16.638	<0.001
	Recommended methods including chemicals	12	26	38		
Other ways forward to minimizing leaf spot disease as proposed by farmers	Improved research, Spray with plant extracts / fungicides	29.5	32	61.5	0.528	0.467
	Fertilizer/Manure Application and reports to MoFA	20.5	18	38.5		

Table 4. The results from Kruskal-Wallis equality-of-populations rank test.

Community name	Observation	Rank sum
Tamale metropolis	50	5727
East Gonja	50	8244
Tolon	50	4023
Kumbungu	50	2106
Chi-squared with ties	122.008 with 3 d.f. ; probability=0.0001	

Gonja Municipality (8244) was the highest, followed by Tamale Metropolis (5727) and then Kumbungu district (2106).

DISCUSSION

Farmers’ knowledge and perception of leaf spot disease of groundnut

Majority (87.5%) of the groundnut farmers in the study area knew that leaf spot is a disease. This means that more farmers are aware of the disease in their farms and its devastating effects. More males (47%) were aware of the disease than females (40.5%). This may be attributed to the fact that males are more involved in farming than females in Northern region of Ghana. The greater awareness could be due to their role as family heads who are mostly in charge of farming. It could also be that males are more resourced than females and have easy access to information on agronomic practices, pest and disease management. This confirms the report by Quisumbing et al. (1995), that although they provide 60 to 90% of the farm work as females, they usually lack technical knowledge, and often have poor access to current information, markets and credit to enable them engage in cash crop farming.

Majority of the respondents (84.5%) knew the symptoms of the leaf spot disease. This means that more farmers could identify the symptoms of the disease. The findings in this study confirm an earlier report that traditional rural farmers are able to successfully detect plant diseases through observation informed by their farming experiences in the absence of a scientific process and equipment to conduct such assessment (Adam et al., 2015). Most of the farmers (79%) were able to identify the symptoms on the leaves of groundnuts on their farms. This clearly indicates that farmers in the Northern region of Ghana have observed the disease for a very long time. It also shows that the disease is common in all groundnut growing areas and also commonly found on the leaves of the crop. The report that the leaf spot disease is commonly found wherever groundnut is grown is true (Zhang et al., 2001; Nutsugah et al., 2007; Chaube and Pundhir, 2009).

Majority (91%) of the smallholder farmers attributed the disease to poor soil fertility, high rainfall, wind or air and herbicides applications. This implies that farmers have critically observed the disease for a very long time in order to determine the factors that cause or increase the incidence and severity of the disease. However, it also shows that farmers may not be able to distinguish between herbicides injury to groundnut plants and leaf spot disease. Herbicides injury to plants is normally due to wrong time of application, wrong dosage and application under unfavourable environmental conditions.

Farmers in the Northern Region of Ghana (84.5%) rated leaf spot disease incidence on their farms to be

50% and above which confirms an earlier report that both early and late leaf spots diseases are widely distributed and occur in epidemic proportions in Northern region of Ghana (Nutsugah et al., 2007). Female farmers recorded higher percentage of disease incidence than male farmers. This can be attributed to the fact that most women are restricted to continuous cultivation on marginal lands and old groundnut farms where there is a build-up of inoculum and loss of nutrients. This supports report of Pazderka and Emmott (2010) that factors that limit yields of groundnut in Ghana include increased cultivation on marginal lands and outburst of pest and diseases. Female farmers also reported that the disease is often encountered at the early stage of vegetative growth which probably is an indication of early leaf spot.

Most farmers (83.5%) in the Northern region of Ghana encountered this disease, any season groundnut was planted and they were aware of its detrimental effects leading to significant yield losses. This agrees with the report that leaf spot is widely spread and causes pod loses of about 78% in Northern region of Ghana (Tsigbey et al., 2003; Nutsugah et al., 2007).

Farmers observed highly significant disease severity on their farms. Even though female farmers experience higher (46%) incidence of the disease their farms had a lower disease severity (32%) than those of the males. It implies that female farmers practiced better crop management than their male counterparts. Good crop management strategies can help reduce the severity of a disease. Most of the farmers (60%) used defoliation and brown spots to determine the maturity of the groundnut crop which confirms reports that farmers use the defoliation as a sign of groundnut maturity (Tsigbey et al., 2003; Nutsugah et al., 2007).

Leaf Spot disease management

More farmers (62%) relied solely on non-chemical methods for the control of the disease. This confirms the report of Bently and Thiel (1999) that farmers in developing countries have been using their own knowledge in managing plant diseases. Most of the non-chemical methods mentioned were crop rotation, spacing, and mixed cropping among others. Farmers reported that more research should be carried out on other control measures to help reduce the negative impact of this disease. This is an indication that most of the measures are old and do not help much in reducing the disease incidence and severity on their groundnut farms.

Incidence and severity of leaf spot on selected farms

Leaf spot was prevalent in all farms surveyed. There were significant differences (P<0.05) in disease severity among farms. Disease severity was highest in East Gonja (8244) followed by Tamale Metropolis (5727) and Tolon (4023). Farmers in Kumbungu (2106) experienced the lowest disease severity. This is an indication that the levels of severity differ from locality to locality, district to district and ecology to ecology due to differences in environmental conditions as reported by Nutsugah et al. (2007).

Conclusion

The study revealed that farmers were aware of the leaf spot disease and its devastating effects, and perceives it as a major constraint to groundnut production in Northern region of Ghana. Most farmers (84.5%) in the study area rated leaf spot disease incidence on the farm to be 50% and above. A notable finding from this study is that farmers may not be able to distinguish between herbicide injuries to plants and leaf spots. Farmers also expressed various opinions as the future management strategies for lessening leaf spot problem in the area which included spraying with effective plant extracts. Farmers in Northern region of Ghana rely solely on non-chemical methods for minimizing the effects of leaf spot disease. The study showed that leaf spots severity differ from one locality to another depending on environmental factors and control measures adopted by farmers. Farmers need to be educated on the practices that increase incidence and severity of the disease, how to distinguish the symptoms from herbicides injury and integrated management approach which may include the use of plant extracts since the disease is widely distributed and endemic in the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Agricultural productivity, land use and draught animal power formula derived from mixed crop-livestock systems in Southwestern 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 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 of development opportunities and constraints in crop and livestock production (Otte and Chilonda, 2002; Ryschawy

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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.

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 undermine 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 systems dynamics 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). Based on smallholders' characteristics, Cervantes-Godoy (2015) focuses on the degree at which they make use of resources most productively, instead of smallholders resource base.

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 livelihoods in smallholder mixed crop-livestock system in Southwestern Ethiopia.

The degree of integration between these units therefore significantly controls material cycles, energy flow, flow path connection and system management in a spatial structure. This in turn influences the resource use efficiency and economic return of both individual household, group of farm society and the country at large. However, this integration between systems and a complex adaptive behaviour in rural smallholder production system is not adequately adopted in the form of its existence; the agricultural system severely lacks productivity, and poverty and food nutritional insecurity still increase in most of the rural population in Ethiopia.

More often unique types of farming system are developed by adopting patterns in land use land cover, types of crop and livestock and 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 system is using. This research work used a trans-disciplinary approach, to get a holistic view on crop and livestock production, natural capital, off-farm activities and their interaction in smallholder livelihood in Southwestern Ethiopia. It aims to assess how smallholder mixed crop-livestock systems description and characterization address the livelihood systems, their interactions, and the likely impact of the natural environment in the selected sub-regions. The study work was conducted in thirteen sub-regions in seven districts of the two zones, Gamo Gofa and Dawuro in South Nations Nationalities Peoples' (SNNP) regional state between February 2014 and December 2016.

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).

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

zones (AEZs). In each zone, the districts were stratified into three AEZs: highland, midland, and lowland based on area proportion in the location. The districts were randomly selected in AEZ, followed by the Peasant Administrations (PAs), designated for its production potential based on the local authorities. Later using the spatial data tracked, four distinct AEZs (wet highland, wet upper lowland to the sub-humid, and wet and dry lowland) were identified, each being significantly different from the other. The highland has an altitude covering an area of 2200 m.a.s.l, while midland ranges between 1500 to 2200 and the lowland covers areas located below 1500 m.a.s.l.

There were 13 PAs (the lowest administrative unit in Ethiopia), in the two zones selected for the study. In the Gamo Gofa administrative zone, there was a total of seven Pas: one at wet highland (Losha), two at wet upper lowland to the sub-humid (Fishto and Grss Zala) and four at dry lowland (Alga, Ancover, Furra and Para Gossa). In Dawuro, there were six Pas, one at wet highland (Gmra Qema), two at wet upper lowland to the sub-humid (Guzza and Myla) and three at wet lowland (Qchme Kessi, Tarcha Zuri and Yallo Worbati). A total number of 345 crop related entries and 352 livestock related entries were recorded. The households were selected randomly (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 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:

$$M = ff \times W \times f^2 \tag{1}$$

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.

$$M = ff \times 6.45 \times (4.41)^2 \tag{2}$$

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 and 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

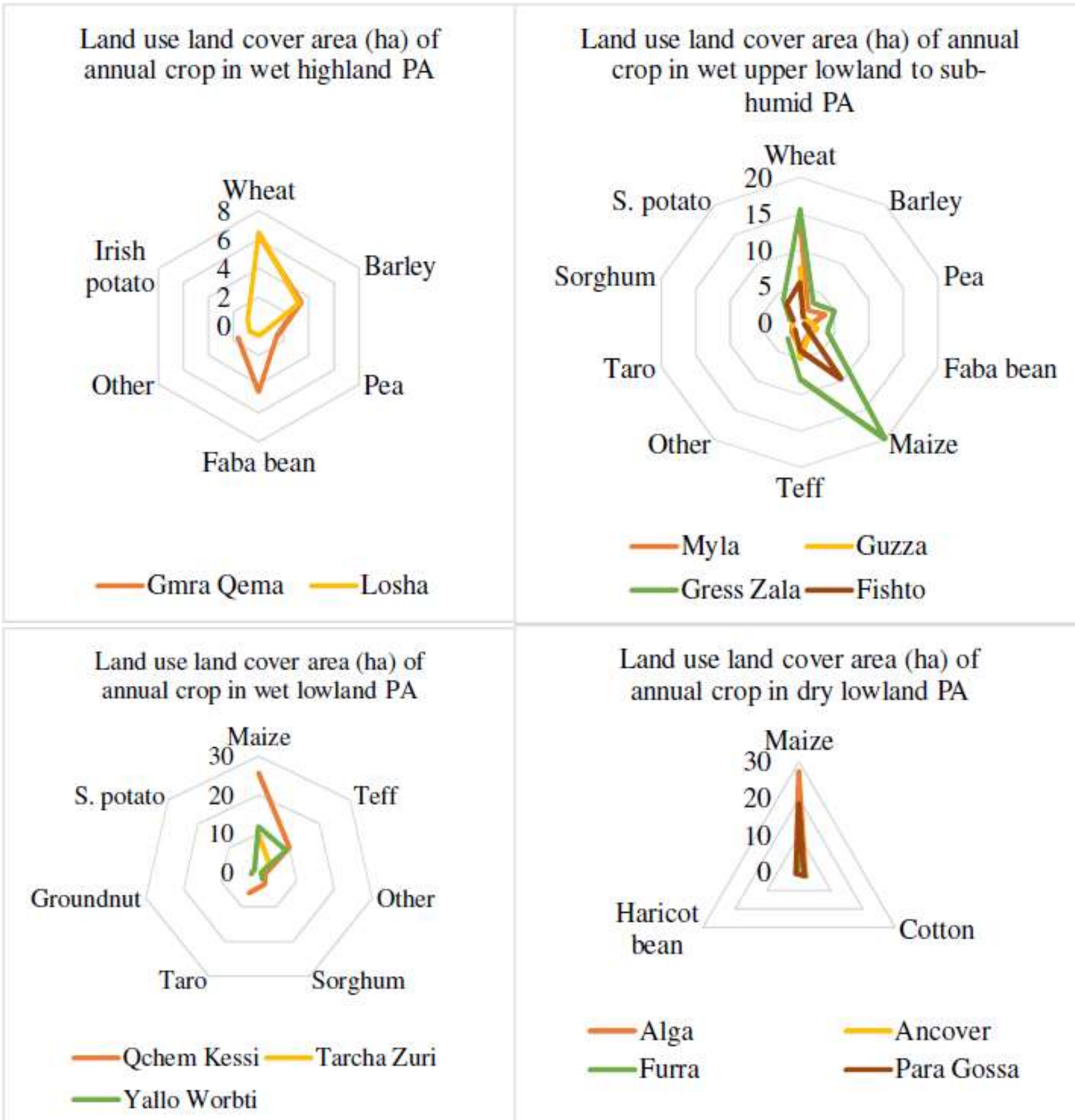

Figure 2. Annual crops in agricultural land area in agro-ecological zone in peasant administration (PA).

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

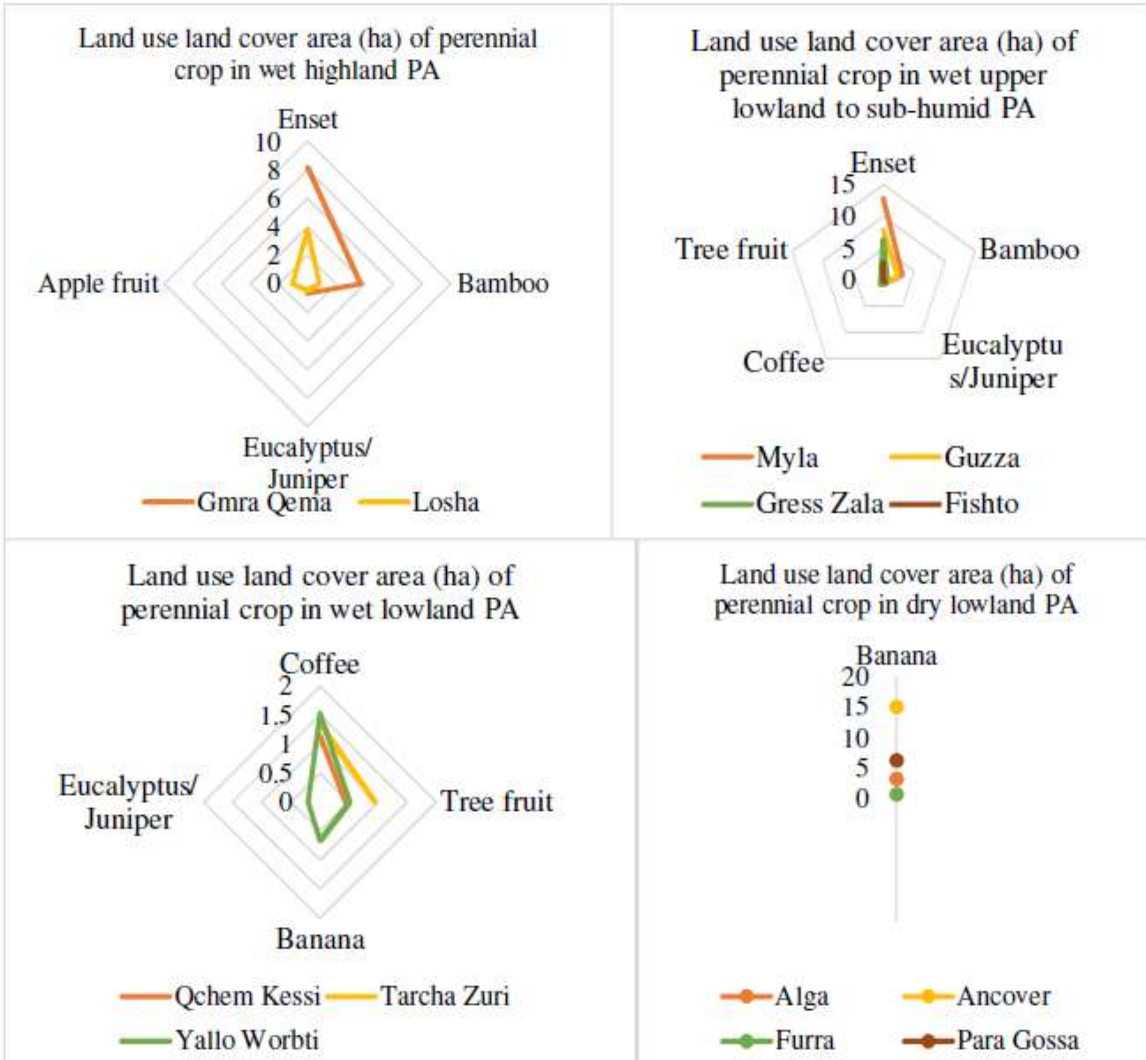

Figure 3. Perennial/plantation crops in agricultural land area in agro-ecological zone in peasant administration (PA).

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 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.

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

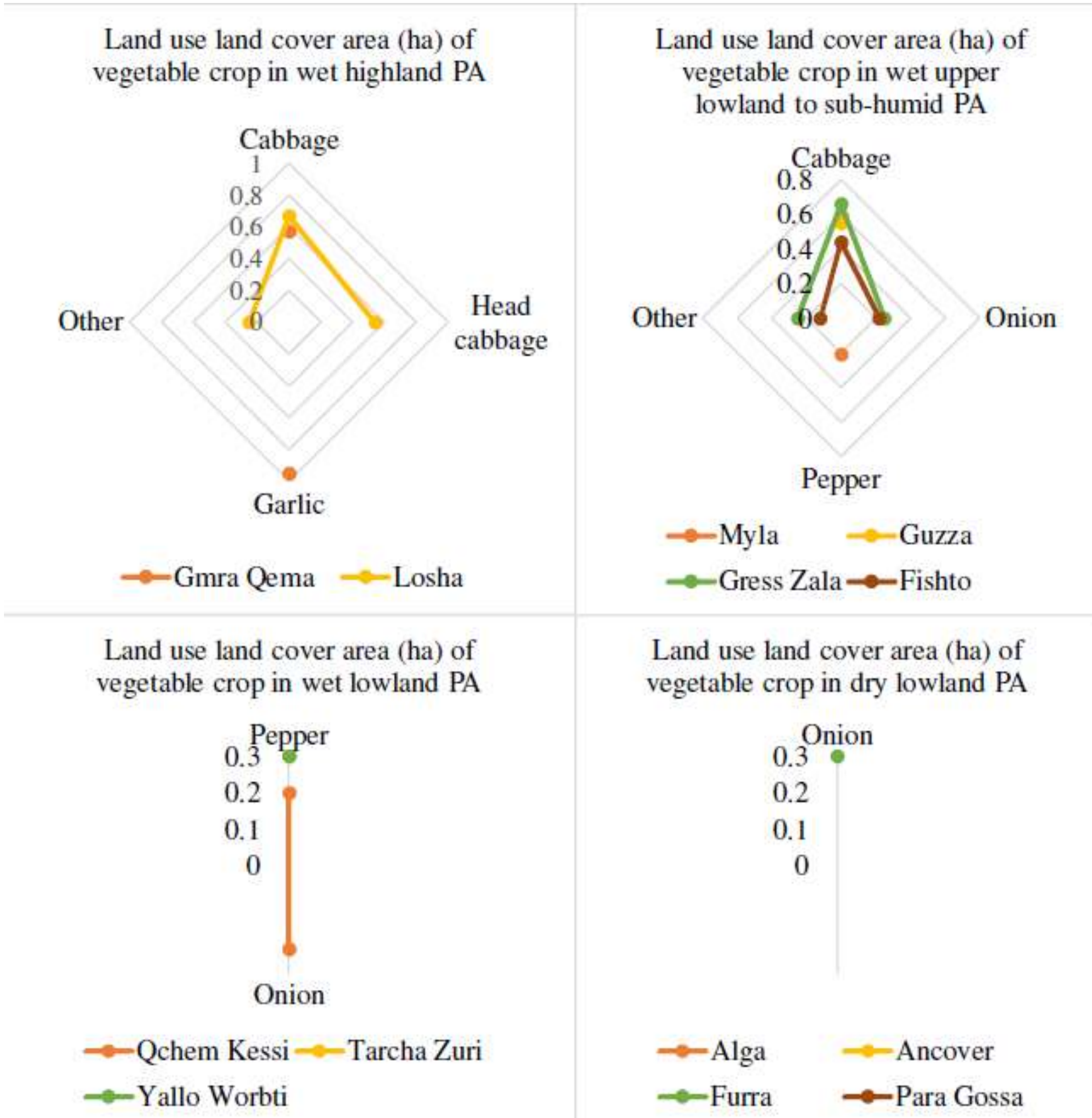

Figure 4. Vegetable/Horticultural crops in agricultural land area in agro-ecological zone in peasant administration (PA).

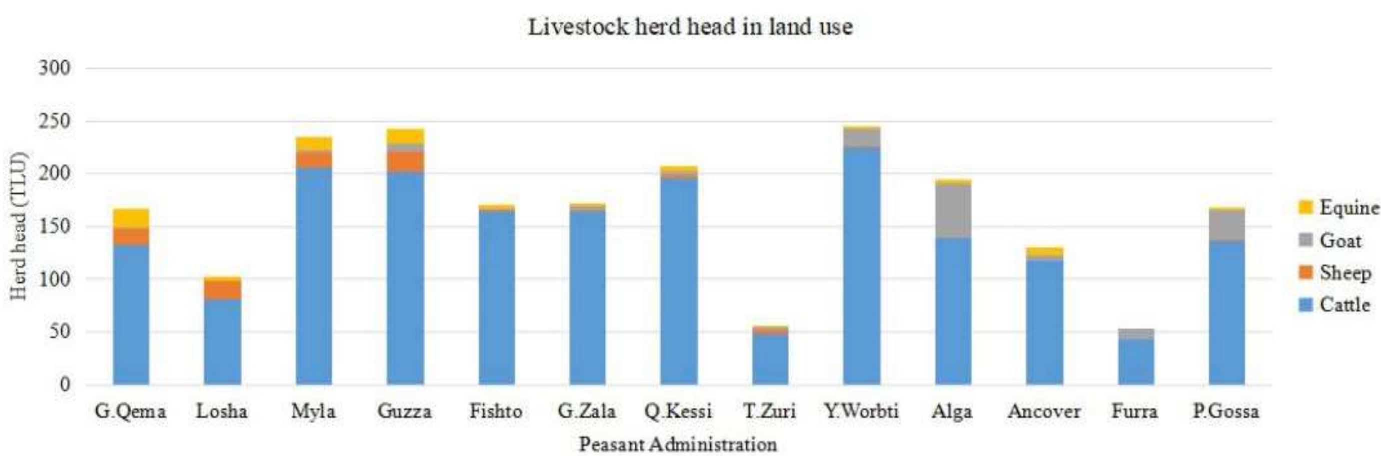

Figure 5. Herd head in Tropical Livestock Unit (TLU) in land use system in peasant administration.

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

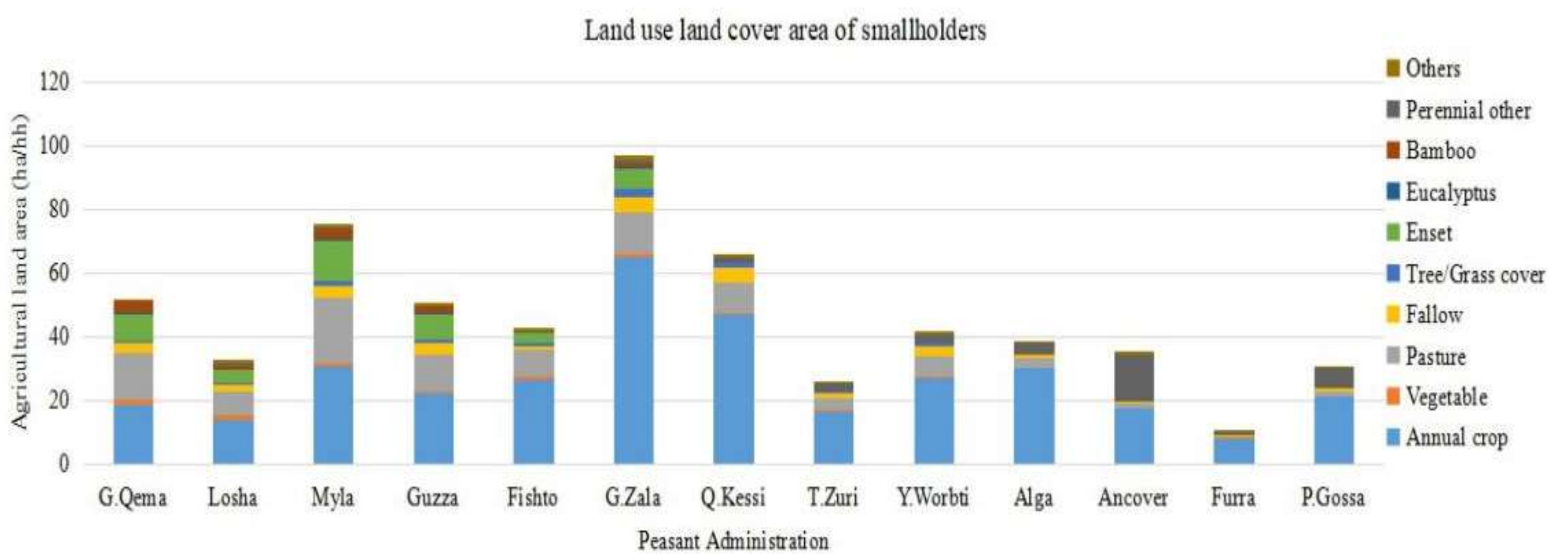

Figure 6. Agricultural land area (ha/farm enterprise type) in land use system in peasant administration.

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.

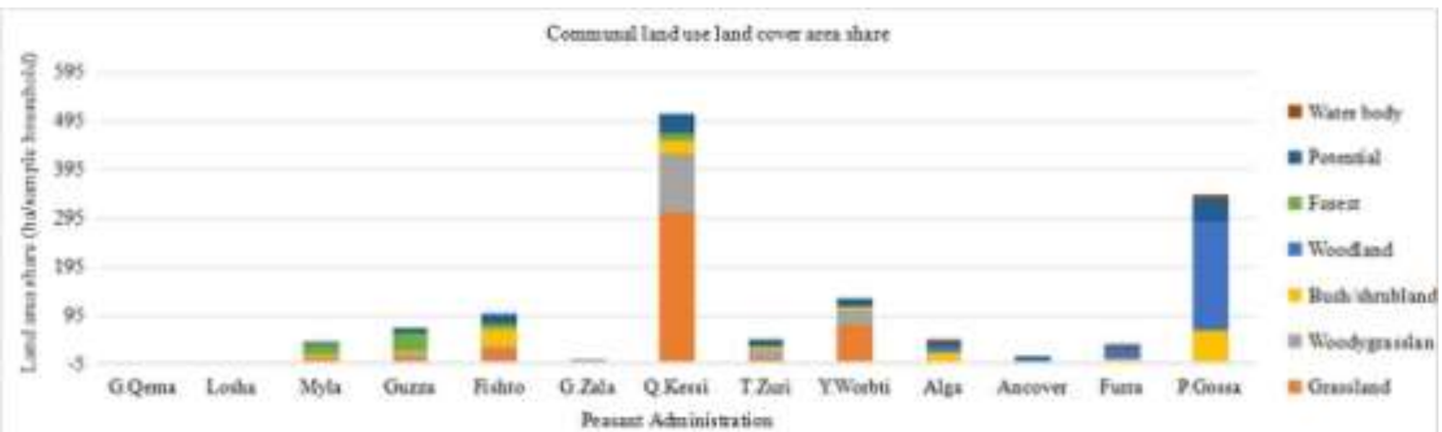

Figure 7. Communal biomass base land use and land cover area (ha/sampled household population) share in peasant administration.

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 cambisols, chromic luvisols, eutric fluvisols, eutric regosols and haplic ferralsols, found in poor to moderate organic carbon content groups in the PA. Whereas, the

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

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, 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

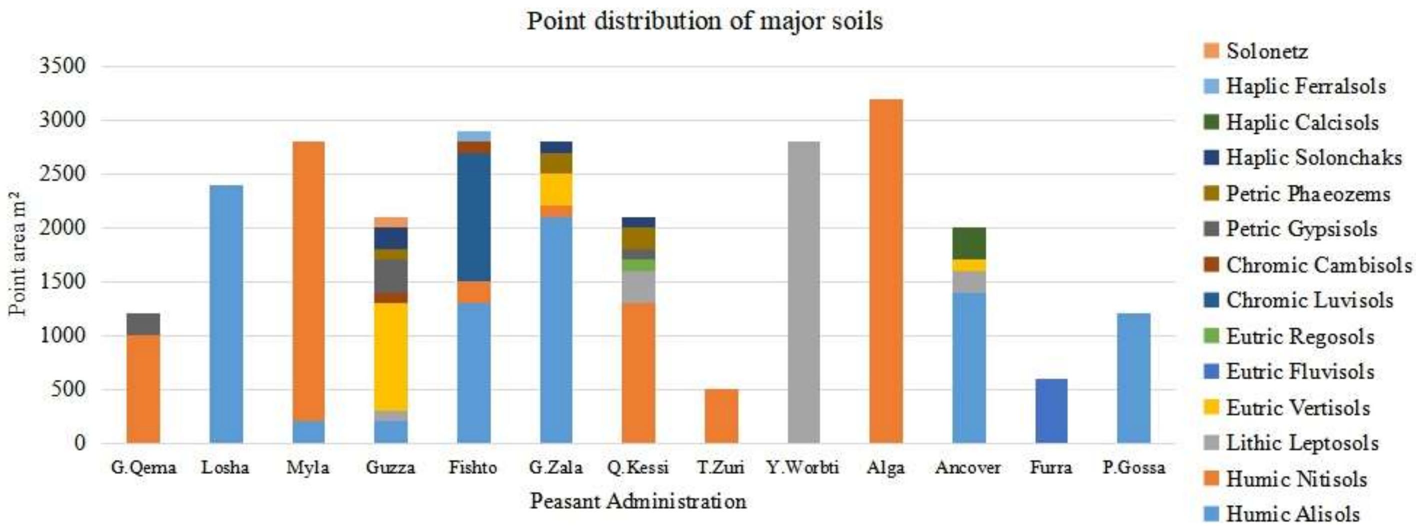

Figure 8. Spatial pattern of major soil extracted to point value in GIS 10.2 in peasant administration.

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 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

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

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.

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

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

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 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 (Table 1) 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

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

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 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 biomass 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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Full Length Research Paper

Genetic diversity of chickpea (*Cicer arietinum* L.) cultivars from Ethiopia by using ISSR markers

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Inter Simple Sequence Repeat (ISSR) markers were employed to reveal genetic diversity and relatedness among 27 chickpea (*Cicer arietinum* L.) cultivars in Ethiopia. Four di-nucleotide repeat primers amplified 24 clear and reproducible bands of which 22 were polymorphic (91.67%). The genetic variation among 27 chickpea cultivars including 12 kabuli and 15 desi verities is high; in which desi type exhibited a genetic diversity of 75% with Shannon index of 0.47, while the kabuli type chickpea had 91.67% genetic diversity and Shannon index of 0.50. Unweighted Pair Group of Arithmetic mean (UPGMA) dendrogram and NJ trees with Jaccard's similarity coefficient showed three major clusters. This was also recovered by 3D principal coordinates analysis, although some cultivars were intermixed. Analysis of molecular variance (AMOVA) demonstrated highly significant (p < 0.001) genetic diversity within cultivars (97.71%) than among cultivars (2.29%). The distinct cultivars (Aererti, Tejie, Fetenech and Maryie) can serve as parents for future genetic resources conservation and Chickpea breeding program in Ethiopia.

Key word: Chickpea cultivars, genetic diversity, ISSR markers, Ethiopia.

INTRODUCTION

Chickpea (*Cicer arietinum*) belongs to family Leguminosae and comprises 43 species; of which nine are annuals while others are perennial (Gautam et al., 2016). It is originated in south-eastern Turkey and adjoining Syria as primary centre of diversity at the Fertile Crescent, but now it is cultivated throughout the semi arid regions of the world (Thudi et al., 2016).

Chick pea, the only cultivated self pollinated species within the genus Cicer, is a diploid plant with 2n = 2x = 16. It ranks third among food legume production after common bean (*Phaseolus vulgaris*) and field pea (*Pisum sativum*), and second in area coverage among pulses grown in Ethiopia proceeded by faba bean (Varshney et al., 2013). There are two main types of chickpea cultivars: desi type and kabulitype chickpea grown in temperate regions and semi-arid tropics, respectively. In Ethiopia approximately, more than 85% of the area is covered with desi type; whereas the rest of 15% is kabuli

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type (FAO, 2013). The cultivated species is found in West Asia and North Africa covering Turkey in the north to Ethiopia in the south, and Pakistan in the east to Morocco in the west (Aggarwal et al., 2015). Chickpea is valued for its high dietary protein content, ability to fix atmospheric nitrogen and the absence of major anti-nutritional factors (Gautam et al., 2016). This makes it an important component of cropping system and considered as a nutritious and healthy food.

Analysis of genetic diversity and population structure relatedness among germplasm is the key for successful breeding program, effective plant conservation and, for elucidating the genetic relatedness of crop species. This can be carried out by using different markers like morphological characters, biochemical and molecular methods (Atnaf et al., 2017). Molecular markers are widely used to study the genetic diversity, identify redundancies in germplasm collections, test accession stability and integrity, and resolve taxonomic relationships (Zulhairil et al., 2015). Molecular markers for assessments of genetic variation in plants have shown many advantages. They are neutral, not related to age and tissue type, and not influenced by environmental conditions, have feasibility and lower costs, and are more informative than morphological markers. Thus, molecular markers can be considered to be a more effective approach compared to morphological markers, to identify plant genotypes (Choudhary et al., 2013).

Moreover, polymerase chain reaction (PCR) based markers are currently available for genetic study this includes amplified fragment length polymorphism (AFLP), random amplified polymorph DNA (RAPD), simple sequence repeat (SSR) and inter simple sequence repeat (ISSR) (Aggarwal et al., 2015). ISSR-PCR technique is a simple and quick method that combines the advantages of AFLP and RAPD. These sequences are abundantly dispersed throughout the genome and highly polymorphic in comparison with other markers. Due to their reproducibility, no gene sequence information required prior genetic studies and ISSR markers were used in this study (Deepankar et al., 2014).

The genetic diversity of released chickpea cultivars were not studied in Ethiopia at molecular level beyond their productivity through conventional breeding, this may lead to erosion of novel genes used for biotic and abiotic stresses tolerance. Therefore, this study aimed to assess the genetic diversity and relationship among Ethiopian chickpea cultivars, in order to provide basic information for future genetic resource conservation and chickpea breeding program.

MATERIALS AND METHODS

Plant materials

In this study, 29 cultivated chickpea cultivars consist of 14 kabuli type and 15 desi type varieties collected from 3 High Land Pulse Crop Improvement Programs / DebrZiet, Holeta and Sirinka/ in EIARC were used (Table 1). Among these Holeta ARC varieties were breeding lines. Ten chickpea seeds of each cultivar were sown in 20-25 cm diameter plastic pots containing black vertisol soil with organic manure and watered daily. Unfortunately, two of the kabuli type cultivars (Akuri and ICC-4973) spoiled by powdery mildew were excluded from the analysis. Five grammes (5 g) of healthy and young leaf samples were harvested and dried in silica gel.

DNA extraction

DNA was extracted using Invisorb® spin plant mini kit extraction prot ocol (Robert, 2009) with slight modifications in concentrations, incubation and centrifugation period at genetic research laboratory of Addis Ababa University. The isolated DNA quality was checked on 0.83% agarose gel electrophoresis under UV light trans illuminator BioDoc Analyzer apparatus and the gel picture was taken. Genomic DNA samples with high band intensity were selected for PCR analysis as seen in Table 2.

ISSR analysis

A total of 21 ISSR primers were tested for ISSR amplification on five representative cultivars. The total volume of PCR reaction was 25 µl containing, 14.6 µl ddH_20, 1.5 µl dNTPs (0.2 mmol/L), 2.6 µl buffer (10x), 1.2 µl $MgCl_2$ (2 mmol/L), 1µl primer (20 pmol/µl), 0.5 µl Taq Polymerase (5 µ /µl) and 1µl template DNA. The profile of PCR reaction program was 4 min preheating and initial denaturation at 94°C, followed by 40 cycles at 94°C for 15 s transition, 1 min annealing at 48°C, 1½ min initial chain elongation at 72°C and ended with 7 min extension phase at 72°C. The amplified PCR products were resolved on 1.67% agarose gel with 1X TBE buffer at 100 V for 2 h. The resultant gel and bands were visualized and acquired under UV light Biodoc Analyzer documentation system. The size of amplified product was estimated using 500 bp DNA ladder on each side of the gel as a marker.

Statistical analysis

ISSR reproducible amplified fragments which appear and are distinct were scored as ‘1’ for presence, ‘0’ for absence. The genetic diversity for varieties was measured by a number of polymorphic loci, percent of polymorphism, gene diversity (*h*) and Shannon diversity index (*i*) with POPGENE ver 1.32 software. Analysis of molecular variance (AMOVA) was used to calculate variation among and within cultivars using Areliquin ver 3.01. It was done by computation of the distance between “haplotypes”of each individual`s data pattern (Excoffier et al., 2006). The Jaccard’s similarity coefficient for clustering analysis was calculated as follow (Jaccard, 1908):

$$Sij = \frac{a}{a+b+c}$$

where, 'a' is the total number of bands shared between individuals` i` and `j`, 'b' is the total number of bands present in individual `i` but not in individual `j` and 'c' is the total number of bands present in individual `j` but not in individual`i`.

The Cluster analysis was performed based on Unweighted Pair Group of Arithmetic mean (UPGMA) using NTSYS- pc ver 2.02 (Rohlf, 2005), and Neighbor Joining (NJ) method (Saitou and Nei, 1987) to compare individual cultivars clustering pattern using

Table 1. Twenty nine (29) chickpea varieties collected for this study.

Kabuli varieties	Year of release	Breeder/maintainer	Source	Seed color
DZ-104	1974	DZARC/EIARC	Ethiopia	White cream
Arerti	1999	DZARC/EIARC	ICARDA	White cream
Shasho	1999	DZARC/EIARC	ICRISAT	White cream
Chefe	2004	DZARC/EIARC	ICRISAT	White cream
Habru	2004	DZARC/EIARC	ICARDA	White
Ejeri	2005	DZARC/EIARC	ICARDA	White
Teji	2005	DZARC/EIARC	ICARDA	White
Acos Dubie	2009	DZARC/EIARC	Mexico	White cream
Yelibie	2006	SRARC/ARARI	ICRISAT	Yellowish
Kobo	2010	SRARC/ARARI	ICRISAT	Yellowish
Kaseche	2010	SRARC/ARARI	ICRISAT	White
Akuri	2011	SRARC/ARARI	ICRISAT	Cream
ICC-4973	Breeding line	HARC	India	White
ICC-19180	Breeding line	HARC	ICRISAT	White
DZ-10-11	1974	DZARC/EIARC	Ethiopia	Brown
Dubie	1978	DZARC/EIARC	Ethiopia	Grey
Mariye	1985	DZARC/EIARC	ICRISAT	Brown
Worku	1994	DZARC/EIARC	ICRISAT	Golden
Akaki	1995	DZARC/EIARC	ICRISAT	Brown
Naatolii	2007	DZARC/EIARC	ICRISAT	Light Golden
Minjar	2010	DZARC/EIARC	ICRISAT	Golden
Mastewal	2006	DZARC/ EIARC	ICRISAT	Golden
Fetenech	2006	SRARC/ ARARI	ICRISAT	Reddish
Kutaye	2005	SRARC/ ARARI	ICRISAT	Red
ICC- 4948	Breeding line	HARC	India	Dark Brown
ICC- 15996	Breeding line	HARC	ICRISAT	Reddish
ICC- 5003	Breeding line	HARC	India	Dark Brown
1CC- 4918	Breeding line	HARC	India	Brown
Pm- 233	Breeding line	HARC	ICARDA	Light Brown

DZ: Debre Ziet, SR: Sirinka, H: Holeta, EIAR: Ethiopian Institute of Agricultural, ICARDA: International Center for Agricultural Research in the Dry Area Research Center and ICRISAT: International Crops Research Institute for the Semi Arid Tropic.

FreeTree 0.9.1.50 Software (Pavlicek et al., 1999). The principal coordinated analysis method (PCO) was performed based on Jaccard's similarity coefficient to further examine the patterns of variation among individual cultivars (Jaccard, 1908). The Jaccard's similarity coefficient was calculated with PAST software ver 1.18 for 2D ordination and the first three axes were latter used to plot the 3D PCO with STATISTICA ver 6.0 software (Hammer et al., 2001).

RESULTS AND DISCUSSION

Out of 21 ISSR primers tested initially, only 4 di-nucleotide repeat primers were screened for the analysis. They were able to produce polymorphic banding pattern and were chosen to distinguish chickpea cultivars (Figure 3). But 17 primers did not amplify any of the genomic DNA and as such, non-amplifying primers are also reported in other crop plants (Bhagyawant and Srivastava, 2008). A total of 24 markers were generated in polymorphism in 22 bands (91.67%). The number of polymorphic loci ranged from 2 (UBC-840) to 8 (UBC-849) where $(GA)_8$ repeat motif gave the least and $(GT)_8$ gave the most amplification in chickpea genome. The size of amplified fragments ranges from 500 to 3500 bp. UBC-830 and UBC-849 showed 100% polymorphism means that all loci of the scored bands detected to be diversified in the genome of chickpea (Table 2).

In this study, Gene diversity and Shannon diversity index was also calculated using 27 *Cicer arietinum* cultivars, where UBC-849 showed the highest values (0.46 and 0.65) and UBC-842 showed the least values

Table 2. List of 4 di-nuclotide ISSR primers Selected for polymorphism detection.

ISSR primers		Number of loci		Percent of variation	With individual primers	
Name	**Repeat motif**	**Total**	**Polymorphic**	**polymorphism**	**H±SD**	**I±SD**
UBC–830	(TG) 8 G	7	7	100	0.39±0.12	0.57±0.13
UBC–840	(GA) 8 YT	3	2	66.67	0.27±0.25	0.40±0.35
UBC–842	(GA) 8 YG	6	5	83.33	0.25±0.18	0.39±0.24
UBC–849	(GT) 8YA	8	8	100	0.46±0.04	0.65±0.04
Average	-	6	5.5	87.5	0.34±0.15	0.50±0.19
Total	-	24	22	91.67	-	-

H: gene diversity, SD: Standard deviation and I: Shannon diversity index for each selected primers.

Table 3. AMOVA for detecting genetic diversity within and among chickpea cultivars.

Source of variation	d.f	SS	Variance components	% of variation	Fixation indices	P
Among cultivars	1	1.293	0.02304 Va	2.29	0.02285	0.00
Within cultivars	25	24.633	0.98533 Vb	97.71	-	0.00
Total	26	25.926	1.00838	100	-	-

SS: sum of square, d.f: degrees of freedom and P: P-Valuefor each cultivar types.

(0.25 and 0.39) respectively. The study showed higher genetic diversity in kabuli type (*h*=0.33 and *i*=0.50) than desi cultivars (*h*=0.30 and *i*= 0.47) even though kabuli chickpea cultivars were originated from the desi type in the Mediterranean basin through natural mutation and selection (Hawtin and Singh, 1981). As chickpea plant is highly self-pollinated species, higher genetic diversity was expected among cultivars than within cultivars. However, the AMOVA analysis showed larger genetic diversity within cultivars (97.71%) than among cultivars (2.29%). This is attributed to the fact that the multiple evolutionary forces like mating types, gene flow, genetic drift, evolutionary history, mode of reproduction and natural selection (Table 3).

Similarly, Aggarwal et al. (2015) work on Indian chickpea and Edossa et al. (2010) on lentil support the higher genetic diversity within populations than among population. The morphological and molecular diversity of Ethiopian lentil using 4 ISSR primers found 56.28% diversity within population than among population (43.72%). This could be attributed to mutation of SSR loci, random genetic drift and differential selection pressure on the loci. Dendrogram resulted from cluster analysis of UPGMA and Neighbour Joining by similarity coefficient which revealed three distinct clusters and sub clusters in each to discriminate all varieties each other (Figure 1).

Cluster - I forked into two sub-clusters at about 76% similarity coefficient and consisted of almost all the desi type chickpea cultivars except Arerti and Kobo cultivars, in which they showed about 66% and 79% similarity with the second sub cluster respectively. This might be due to the fact that kabuli cultivars are hybrids of wild and cultivated desi chickpea and hence these cultivars might have close genetic similarity with desi type chickpea.

Cluster - II consisted of all Kabul cultivars and spliced into two distinct sub-clusters around 60% similarity coefficient, where Worku and Mariye show 82% and 70% closely relatedness with second sub-cluster of kabuli cultivars. Clustering of Fetenech in the third group negates the expectation that it would be grouped in desi type cluster.

Individuals escaped from each cultivar type in dendrogram might have accumulated adaptive gene complexes for environmental change and can serve as a parent in future chickpea breeding program. PCO analysis confirm the result of UPGMA clustering, where the lengths of coordinates axis given by Eigen values and predict how individual cultivars are related to each other. The first three coordinates with of 2.43, 1.93 and 1.31Eigen values accounted 13.23, 10.52 and 7.14% variation respectively. This used to construct the three dimensional (3D) representation for better grouping of individuals in to their respective cultivars type (Figure 2).

Conclusion

Generally, ISSR markers showed higher genetic diversity in kabuli type than desi type chickpea cultivars. But the total genetic diversity is narrower in Ethiopia. Therefore, the National Breeding Program should target on kabuli cultivars (Arerti and Tejie) for selecting individuals with desirable traits to broaden the genetic base of the chickpea in the country. This will support future conservation and improvement programs.

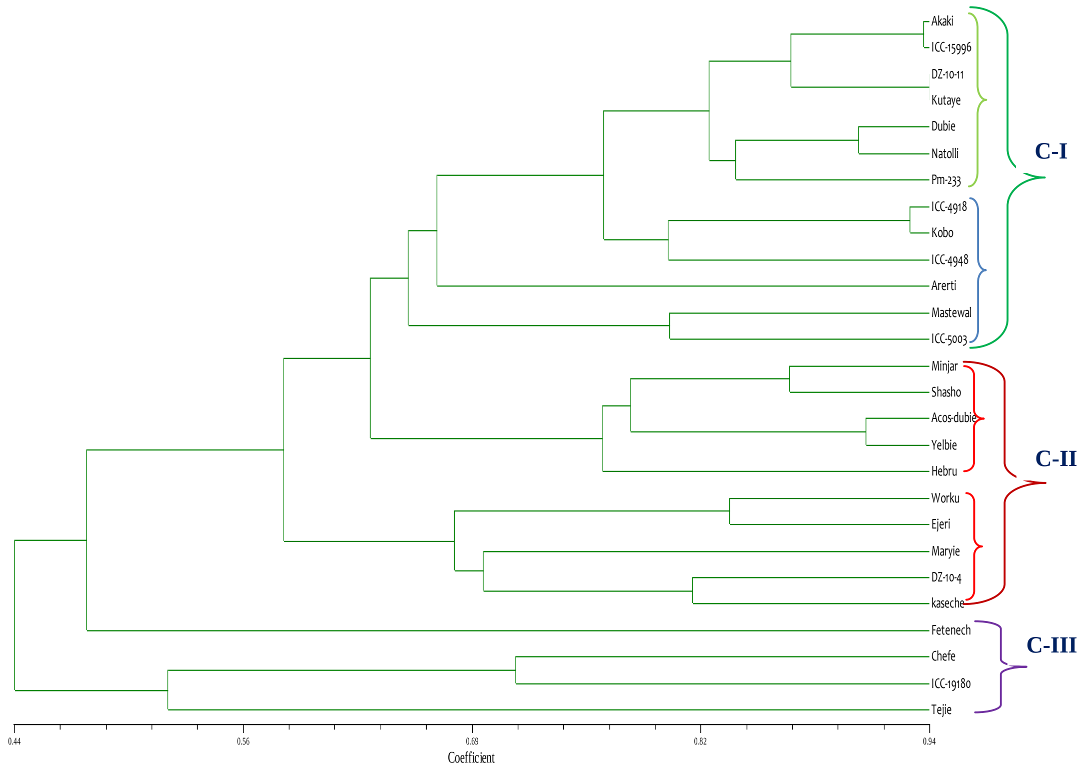

Figure 1. Dendrogram of 27 Chickpea cultivars based on UPGMA cluster analysis depicting their genetic relationship.

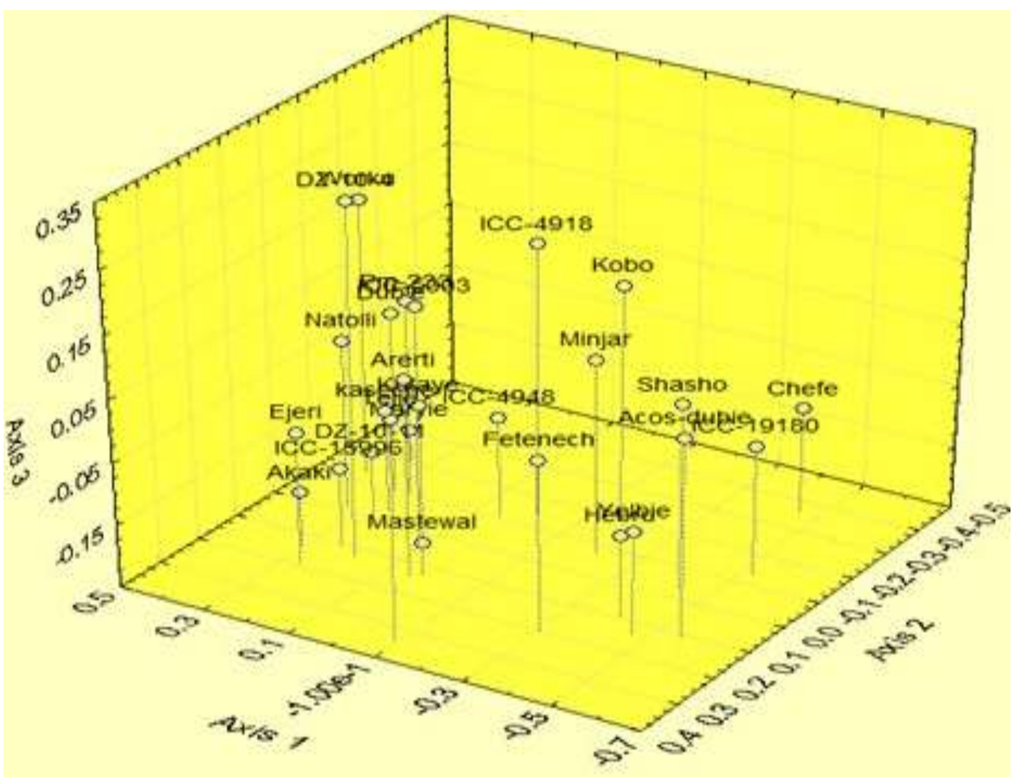

Figure 2. 3D representation PCO analysis of genetic relationship among 27 chickpea cultivars.

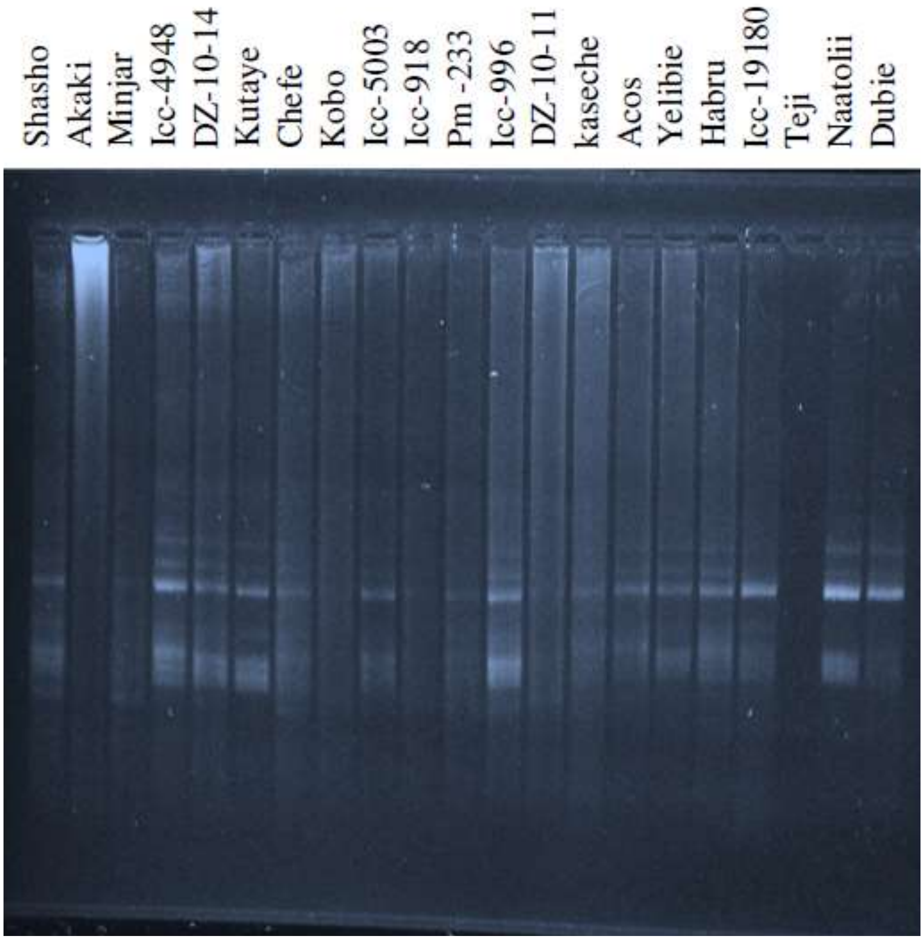

Figure 3. Bands generated from 21 representative chickpea cultivars using primer UBC–849.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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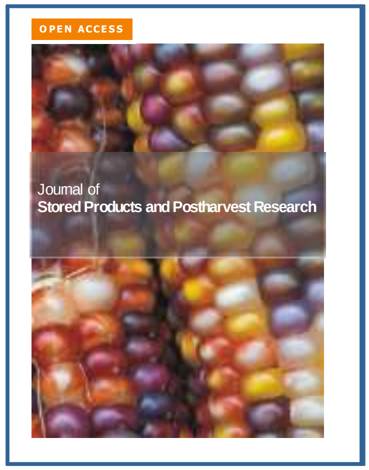

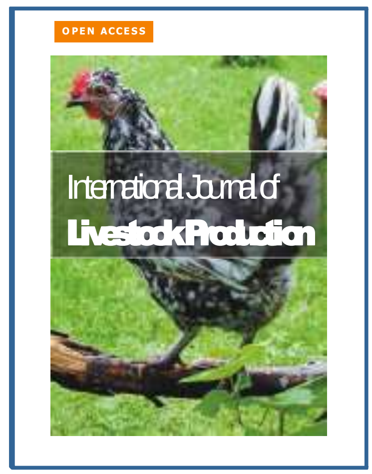

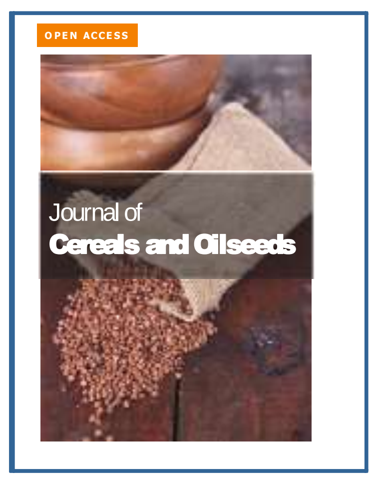

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