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DETERMINANTS OF LIVESTOCK AND FEED WATER PRODUCTIVITY IN
THE MIXED CROP–LIVESTOCK PRODUCTION SYSTEM OF DEBRE
BERHAN MILKSHED, CENTRAL HIGHLANDS OF ETHIOPIA

PhD Dissertation

By

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Addis Ababa University, College of Veterinary Medicine and Agriculture

Department of Animal Production Studies

PhD Program in Animal Production

May 2018

Bishoftu, Ethiopia

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A dissertation submitted to the College of Veterinary Medicine and Agriculture of
Addis Ababa University in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Animal Production

By
Mekete Bekele Tahir

May 2018
Bishoftu, Ethiopia

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College of Veterinary Medicine and Agriculture
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As members of the Examining Board of the final PhD open defense, we certify that we have read and evaluated the Dissertation prepared by **Mekete Bekele Tahir** titled: **“Determinants of Livestock and Feed Water Productivity in the Mixed Crop–Livestock Production System of Debre Berhan Milkshed, Central Highlands of Ethiopia”** and recommend that it be accepted as fulfilling the Dissertation requirement for the Degree of Doctor of Philosophy in Animal Production.

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DEDICATION

This dissertation is dedicated to my mother Zeleka Bekele and my father Nega Alemayehu, and my late grandparents Bekelech Woldemariam and Bekele Tahir who were selflessly endured for the success of their children and other selves.

STATEMENT OF THE AUTHOR

First, I declare that this dissertation is my bonafide work and that all sources of materials used for this dissertation have been duly acknowledged. This dissertation has been submitted in partial fulfillment of the requirements for a PhD degree at Addis Ababa University, College of Veterinary Medicine and Agriculture and is deposited at the University/College Library to be made available to borrowers under rules of the Library. I solemnly declare that this dissertation is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author was born in Jamma district of Wollo in November 1967. He attended his elementary and junior educations at Degollo Elementary and Junior School, and his high school education at Woreillu Senior Secondary School. After successful completion of high school education, he joined the then Alemaya University of Agriculture in 1985 and graduated with BSc degree in Animal Science in 1989. Right after graduation, he was employed by the Ministry of Agriculture (MoA) and served until 2000 in various regions of Ethiopia at different capacities from junior to senior expert and leader positions, including as a trainer at Agarfa training center during 1992-1993. Later he served as project officer at Kobo Girana Valley Development Program office (KGVDP) in Amhara Region from July 2000 to 2005. He joined the school of graduate studies of Hawassa University in 2005 and obtained MSc degree in Animal and Range Sciences (specialization in Animal Production) in 2008. Again, he returned to KGVDP and served there until May 2009. He joined Amhara Agricultural Research Institute in June 2009 and served for a brief period as Associate Researcher–I at Gondar Agricultural Research Center. During the same year in November, he joined Debre Berhan University as a lecturer and taught many animal science courses. In 2012/13 he joined the School of Graduate Studies of the College of Veterinary Medicine and Agriculture of the Addis Ababa University to pursue his PhD study in Animal Production.

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ABBREVIATIONS

ADR	Age dependency ratio
ANOVA	Analysis of variance
CR	Crop residues
CSA	Central Statistical Authority of the Federal Democratic Republic of Ethiopia
DCP	Digestible crude protein
DM	Dry matter
DMD	Dry matter demand
DMI	Dry matter intake
ET ₀	Reference Evapotranspiration
ETB	Ethiopian Birr
ET _c	Crop Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FWP	Feed Water Productivity
GDP	Gross Domestic Product
GL	Grazing lands
Gm ³	Giga Meter Cubed
GPCC	Global Precipitation Climatology Centre
ha	Hectare
hh	Household
HHs	Households
IGAD	Intergovernmental Authority on Development
ILRI	International Livestock Research Institute
K	Potassium
k _c	Crop factor
kcal	Kilo calorie
kg	Kilo gram
km	Kilometer
LWP	Livestock Water Productivity
m ³	Meter Cubed
masl	Meters above sea level

MCC	Milk collection centers
MCL	Mixed crop-livestock
ME	Metabolizable energy
MJ	Mega joules
mm	Millimeter
MoFED	Ministry of Finance and Economic Development of the Federal Democratic Republic of Ethiopia
MoWR	Ministry of Water Resources of the Federal Democratic Republic of Ethiopia
N	Nitrogen
n	Number of respondents
NRC	National Research Council
P	Phosphorus
SD	Standard deviations
SE	Standard errors
SPSS	Statistical Package for Social Sciences
STATA	Statistics and Data
t	Ton
TLU	Tropical Livestock Unit
USD	United States Dollar
WP	Water Productivity

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ABSTRACT

The study was conducted in the mixed crop–livestock system of Debre Berhan milkshed in central highlands of Ethiopia to assess and determine agricultural water productivity related to livestock production and explore their determinants. The need to meet the growing demand for livestock products and services coupled with multiple uses of water is expected to intensify pressure on finite freshwater. Knowing the level of freshwater consumption for livestock production is relevant to devise strategies for efficient water use and allocation in the system. A multistage sampling procedure was followed to select 159 farmers from different wealth status (50 in the poor, 58 in the medium and 51 in the better-off) grouped mainly based on land and livestock ownership. Livestock products and services, and feed dry matter obtained at farm level over the year were used as numerators to estimate livestock water productivity (LWP) and feed water productivity (FWP), respectively. The volume of water evapotranspired for feed production was used as a common denominator for both LWP and FWP. Cultivated and grazing lands (GL) were major sources of feed where water use of livestock was fundamentally linked. The annual food-feed crops grown that constituted staple human food and major livestock feed were barley, wheat, faba bean and field pea. The livestock density on grazing land was almost twice that of cultivated cropland which showed the importance of crop byproducts for livestock feeding. The contribution of crop residues to total feed supply sourced on-farm and purchased combined was 55%. However, the annual feed dry matter (DM), metabolizable energy (ME) and digestible crude protein (DCP) supplies and requirements of livestock did not match at present. The livestock feed insufficiency unanimously affects farmers irrespective of wealth status, though wealthier suffered more. Overall, about 51, 19 and 38% of annual feed deficit in DM, ME and DCP were observed, respectively. On average 0.60 kg m⁻³ (ranging from 0.59

to 0.61 kg m⁻³) of FWP was obtained. However, FWP of crop residues (CR) and GL were contrastingly different across wealth groups, where better-off gained more on CR and vice versa on GL. Moreover, much of the water depleted was on GL, irrespective of wealth status. The inflow and outflow dynamics of cattle and equines over the year was not frequent and in large numbers either, rather the conceivable outputs obtained from cattle were milk, traction services and manure, and that of equines was transportation. In case of sheep the dynamics were recurrent; correspondingly the most plausible beneficial output was due to offtake. Generally low offtake rates and high death rates contributed to reduced annual benefit from livestock and impacted the LWP. Livestock water productivity was significantly different across wealth groups. On average 0.23 USD m⁻³ (ranging from 0.16 to 0.23 USD m⁻³ following wealth gradient) of LWP was attained. Access to credit and training positively influenced both FWP and LWP, while other factors explain FWP and LWP differently. Evaluation of native grasses and legumes, and improved forages for biomass productivity, nutritive value and water use; improving feeding value of CR with treatment and supplementation; maintenance of healthy productive animals; strengthen enabling institutions that support farmers such as cooperatives, credit, extension and training services and application of soil and water conservation; and proper grazing management are expected to improve water use for livestock production.

Keywords: Debre Berhan, dry matter, evapotranspiration, feed balance, livestock dynamics, water productivity, wealth.

1. INTRODUCTION

Ethiopia has been predominantly an agricultural country, and the overall economic growth of the country has been highly associated with the performance of the agriculture sector, be it from the point of view of people's occupation, of the gross domestic product (GDP), of the exportation and of the orientation of the industries (Kassa, 2000; Ayele *et al.*, 2006). Ethiopia is a country known for possession of huge livestock numbers and has an immense potential for increasing the volume of products from livestock, both for local use and for export purposes. Livestock are distributed throughout the country with highest concentrations in the highlands. The total livestock populations estimated in million heads were about 56.71 cattle, 29.33 sheep, 29.11 goats, 2.03 horses, 7.43 donkeys, 0.40 mules, 1.16 camels and 56.87 poultry with total tropical livestock unit (TLU) of 52.93 (CSA, 2015).

Livestock perform multiple economic and social functions both at the national and household levels. In the year 2010/11, agriculture accounted for about 41.1% of the GDP, 90% of the foreign currency earnings and 85% of employment (Ethiopian Investment Agency, 2013). Albeit variations among data sources, livestock contribute 15-17% of national gross domestic product (GDP), 35-40% of agricultural GDP and 37-87% of the household incomes (GebreMariam *et al.*, 2013). In 2008-09, the Ministry of Finance and Economic Development (MoFED) estimated the contribution of livestock at about 25% of the total agricultural GDP. During the same year, Behnke and Fitaweke (2011) reported that when the value of ploughing services is included, livestock provided 45% of agricultural GDP. The gap between the values reported by MoFED and IGAD suggests that the significance of livestock relative to crop production has been considerably underestimated in past calculations of the contributions of the sectors to the agricultural GDP (Behnke and Fitaweke, 2011). Moreover, livestock contribute to improve the nutritional status and income gain of the people by providing meat, milk, eggs, cheese, butter and commodities, such as live animals, hides and skins for home use and export; and avert risks in times of crop failures (GebreMariam *et al.*, 2013; CSA, 2015).

Despite the huge numbers, the current contribution of livestock to the producers and to the national economy is dismal to its size. It has increasingly been unable to meet the demands for the rapidly growing population (Swanepoel *et al.*, 2010; Asresie, 2015; Shapiro *et al.*, 2015). Among the many factors that could explain this disproportionate role of the sector often mentioned are the inadequate quantity and quality of feed to satisfy the annual demand of livestock (Assefa *et al.*, 2013; Yadessa *et al.*, 2016). Moreover, the expansion and productivity was constrained by multifaceted and interacting factors; such as inadequate and imbalanced nutrition, disease outbreaks, scarcity of water, lack of appropriate and adequate livestock extension services, insufficient and unreliable data with which to plan interventions, and inadequate information on how to improve animal performance (breeding, feeding), marketing, processing and ways of suitable integration with crop and natural resources for sustainable productivity and environmental health.

Water for agricultural activities is increasingly becoming a limiting factor. The resilience of agricultural systems depends heavily on strategic approaches to water management capable of addressing constraints. Like other agricultural sub sectors, livestock depend on water, but when poorly managed they contribute to degradation and contamination of water resources (Peden *et al.*, 2007). Water is a scarce resource in most parts of Ethiopia, especially crucial during the eight dry months, in most parts of the country, extending from October to May (Sileshi *et al.*, 2003). Both people and their livestock commonly travel long distances daily to obtain the water they need thus impairing agricultural productivity (Astatke, 1993).

Livestock drink about 25-50 liters of water/TLU/day (Sileshi *et al.* 2003; Peden *et al.* 2003), but water for daily feed production can be 100-200 times greater (Peden *et al.* 2003). This is important because the prime constraint to livestock production is feed shortage, the production of which is often water dependent. Water requirement for drinking by livestock is less than 2% of water evapotranspiration for feed production (Peden *et al.*, 2003; Sonder *et al.*, 2004; Peden *et al.*, 2007). Livestock water productivity is about accounting for water consumption of livestock as a ratio of output functions including milk, meat, dung, draught power and threshing, over the amount depleted to produce them (Peden *et al.*, 2003). It is part of the overall food water

productivity and is the scale dependent efficiency of direct and indirect use of water for provision of livestock products and services (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). Water is depleted when it is consumed by evapotranspiration, is incorporated into a product, flows to a location where it cannot be readily reused (e.g. to saline groundwater), or becomes heavily polluted (Molden *et al.*, 2003).

In recent years, livestock and livestock products have been exposed for too much criticism due to a widely perceived use of large amounts of water for production and to their negative impacts on water resources and the environment. Evidence suggests that such a criticism is often unfounded or of restricted validity (Sonder *et al.*, 2004). Livestock water productivity has been challenged frequently, being described as far lower compared to crop water productivity. Most of these examples come from industrial livestock production systems where large amounts of water are being used to produce forages (Peden *et al.*, 2003; Sonder *et al.*, 2004). Livestock can be efficient and effective users of water when they depend on crop residues and byproducts and well managed rangelands unsuitable for crop production (Peden *et al.*, 2007; Haileselassie *et al.*, 2009). Mixed crop-livestock production systems typical in developing countries relying mostly on crop residues for feeds have much higher livestock water productivity than grain based production systems (Peden *et al.*, 2007).

Whereas, livestock production has been an integral and critical element of the mixed farming system because of its multifaceted roles, the attention paid by policy makers and researchers to its development has generally been very low (Kassa, 2000). Livestock have been neglected and often overlooked in the planning of research and development interventions that involve livestock's efficient uses of the scarce water resources (Peden *et al.*, 2003). Consequently, investments in water and livestock often failed to achieve maximum and sustainable returns because of lack of integration of the two sub-sectors (Peden *et al.*, 2006; Peden *et al.*, 2007).

One of the key constraints to livestock production is attributed to seasonal feed shortage, the production of which is often dependent on rainfall; the major source of agricultural water in Ethiopia. Water is a very scarce commodity for many of the

smallholder farmers and their livestock, and the situation is aggravated by high degree of spatial and temporal variability and unreliability of rainfall (Sileshi *et al.*, 2003). Demand for livestock products has risen strongly in the last decades and is expected to increase further, thus augmenting the pressure on already scarce resources and increasing the necessity to improve water productivity in sustainable ways (De Vries *et al.*, 1997; Delgado *et al.*, 1999). However, the research and development work on water as a limiting nutrient to animal production and management practices to increase efficiency are rare in Ethiopia (Sileshi *et al.*, 2003).

Much of the water depletion by livestock is for their feed production through evapotranspiration (Peden *et al.*, 2007; Haileselassie *et al.*, 2009; Descheemaeker *et al.*, 2010). However, knowledge on the impact of livestock keeping on water resources has not been adequately synthesized and applied to integrate water development and management (Peden *et al.*, 2006; Descheemaeker *et al.*, 2010). Evidence suggests that there is a huge knowledge gap and much misinformation about livestock's use of and impact on water resources (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009). Whereas, the need to feed the rapidly growing population with more diversified diets including meat and milk will place substantial new demands on agricultural water resources (Molden *et al.*, 2003), especially for feed production (Peden *et al.*, 2007). Consequently, the additional water required for agriculture will strain terrestrial and aquatic ecosystems and intensify competition for water resources (Molden *et al.*, 2003; Peden *et al.*, 2007). Application of livestock water productivity concepts may lead to some of the greatest improvements in efficiency of future agricultural water use (Peden *et al.*, 2006; Peden *et al.*, 2007). Considering the increasing water scarcity in many areas and the expected increasing demand for livestock products, there is a need to understand and define livestock water interactions and improve the water productivity of livestock related production systems.

Moreover, in the mixed-crop livestock system, livestock enhance system productivity through provision of manure and draught power. Manure is a key resource to supply nutrients to the soil and improve its condition and water holding capacity, which in turn enhances vegetation cover and reduces land degradation, thereby improving water productivity. However, in the central highlands of Ethiopia including the study area

there are competing uses of manure as biofuel and income source from sale of dung cake. Eventually, the amount of manure going for soil fertility is very scarce, which compromise the nutrient cycling benefit. Therefore, thorough investigation and understanding on how various interventions and practices in the mixed crop-livestock system affect livestock and feed water productivity is a strategic step for planning an integrated development approach. With this conception, the present study was proposed to study the performance of the mixed crop-livestock system and the implication on agricultural water productivities related to livestock production. It is hypothesized that access to resources, difference in management practices of livestock, their products and services, types and sources of feed resources and manure management and utilization will have an effect on livestock, milk and feed and overall farm water productivity. It was anticipated that revealing these connections will help to pave ways in designing integrated livestock interventions for efficient resource (water) use and sustainable livelihood support of smallholder farmers operating in the prevailing production system, while maintaining sound ecosystem services.

General objective:

The general objective of this study was to assess and determine agricultural water productivity related to livestock production and explore the determinants in the central highlands of Ethiopia.

Specific objectives:

1. To characterize the mixed crop-livestock production system of *Debre Berhan* milkshed in the central highlands of Ethiopia;
2. To estimate the livestock feed balance under mixed crop-livestock production system;
3. To quantify the magnitude of feed and livestock water productivity as affected by household resource ownership;
4. To evaluate the relative importance of different livestock species maintained by farm households on livestock water productivity; and
5. To assess the determinants of livestock and feed water productivity.

2. LITERATURE REVIEW

2.1. Livestock's Roles and Production Trends

Livestock's contribution to food security and livelihoods, particularly for those of the poor in developing countries, is well recognized (Thornton, 2010). Keeping livestock is an important risk reduction strategy for vulnerable communities, as animals can act as insurance in times of need (Herrero *et al.*, 2010) and provide a means of income diversification to help deal with times of stress (Thornton, 2010). Livestock generate income by providing both food and non-food products (such as wool, hides and skins) that the household can sale (Thornton, 2010). At the same time, they are important providers of nutrients and traction for growing crops in smallholder systems (Herrero *et al.*, 2010). Livestock are also an important source of nourishment, they provide about 17% of the global kilocalorie consumption and 33% of protein consumption, but there are large differences between rich and poor countries (Rosegrant *et al.*, 2009). For poor and under-nourished people, particularly children, the addition of modest amounts of livestock products to their diets can have substantial benefits for physical and mental health.

In addition to their food security, human health, economic and environmental roles, livestock have important social and cultural roles (Thornton, 2010). In many parts of Africa, social relationships are partly defined in relation to livestock, and the size of a household's livestock holding may confer considerable social importance on it. The sharing of livestock with others is often a means to create or strengthen social relationships, through their use as dowry or bride price, as allocations to other family members and as loans. Social status in livestock based communities is often associated with leadership and access to (and authority over) natural, physical and financial resources (Thornton, 2010).

Globally, livestock populations have been grown considerably over years. From 1979 to 2009, the numbers of cattle, goats, and sheep increased, with percentage increases of 14, 93, and 1%, respectively (Demer *et al.*, 2017). The continents of Africa and Asia experienced the largest percentage increases in cattle numbers. About a third of Africa's

stock of animals resides in Sudan and Ethiopia which includes wide ranges of agro-ecologies and production systems (Peden *et al.*, 2006). Ethiopia, besides having the largest livestock populations in Africa, the numbers grow tremendously. The trends of livestock population growth are illustrated in Figure 1. Population growth of different livestock types is more than double between 1993 and 2016 (Figure 1). The numbers of cattle increased by 102% (from 29.5 to 59.5), sheep and goats increased by 217% (from 19.2 to 60.9), equines increased by 119% (from 5.0 to 11.0) and chickens increased by 118% (from 27.3 to 59.5) (FAOSTAT, 2018).

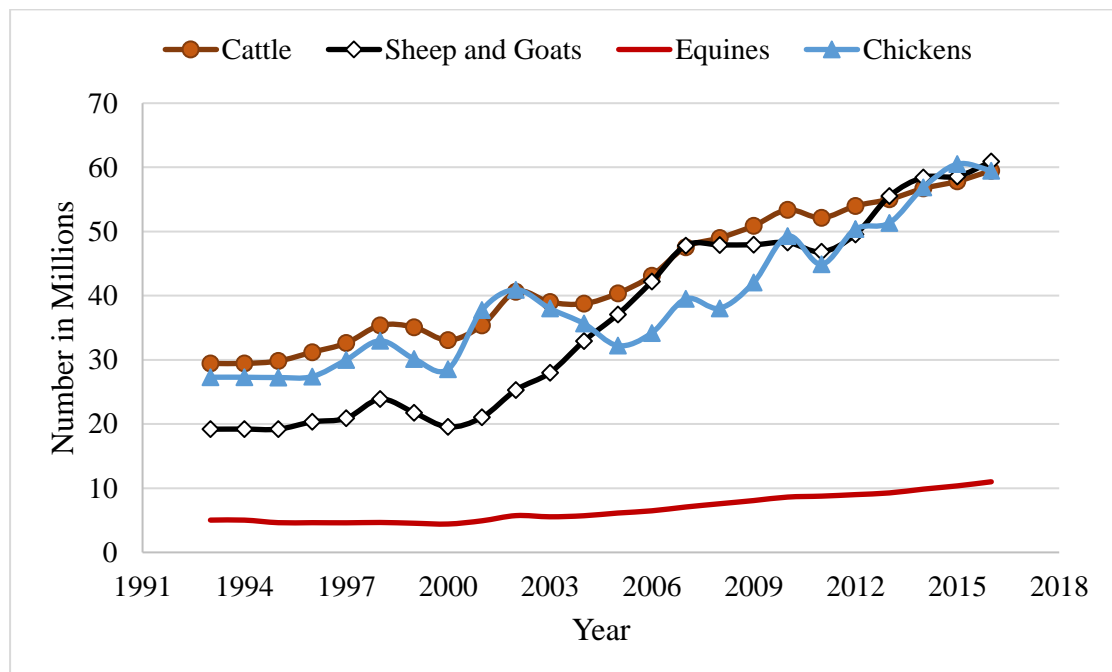


Figure 1. Livestock population growth trends in Ethiopia (FAOSTAT, 2018)

2.2. Water Resources and Ethiopian Economy

Ethiopia covers an area of 1.13 million km², of which 99.3% is a land area and the remaining 0.7% is covered with water bodies of lakes (MoWR 2002, as cited by Awulachew, 2005). Based on Global Precipitation Climatology Centre (GPCC) data, the mean annual rainfall in Ethiopia is 812.4 mm, with a minimum of 91 mm and a maximum of 2,122 mm; with a highest rainfall ranging from 1,600–2,122 mm in the highlands of the western part of the country, and a lowest rainfall from 91-600 mm in the eastern lowlands of the country (Awulachew *et al.*, 2007). The water resources potential and utilization trend over years in Ethiopia is shown in Table 1.

Table 1. Water resources and utilization in Ethiopia from 1993 to 2017

Description	1993- 1997	1998- 2002	2003- 2007	2008- 2012	2013- 2017
Long-term average annual precipitation in volume (10^9 m ³ /year)	936.4	936.4	936.4	936.4	936.4
Total internal renewable water resources (10^9 m ³ /year)	122	122	122	122	122
Total internal renewable water resources per capita (m ³ /inhabitant/year)	2004	1733	1508	1323	1227
Agricultural water withdrawal (10^9 m ³ /year)		5.20	7.00		9.69
Agricultural water withdrawal as % of total water withdrawal (%)		93.63	89.05		91.82
Total water withdrawal per capita (m ³ /inhabitant/year)		78.96	97.18		106.1

Source: (FAO, 2017).

Ethiopia covers 12 river basins with an annual runoff volume of 122 billion m³ of water and an estimated 2.6 billion m³ of ground water potential (MoWR, 2002, as cited by Awulachew, 2005). This amounts to an estimated 2,620 m³ of water per person per year in 1990 for a population of 47 million. By 2005, this has reduced to 1707m³ due to population growth for estimated 73 million and the per capita availability continues to fall. Falkerman *et al.* (1990) proposed that 1700 m³ per capita per year is the minimum amount of water required to maintain an adequate quality of life considering agricultural self-sufficiency. Same authors suggested that 1000 m³ per capita per year would cause water scarcity threatening economic development, human health or well-being. Physical and economic scarcity of water is very common, and growing, problem in Ethiopia. Based on this water-scarcity index, Ethiopia will be a water-scarce country by 2050 (Maimbo *et al.*, 2007).

Though agriculture is the dominant sector in the Ethiopian economy, most of the cultivated land is under rainfed agriculture (Awulachew *et al.*, 2007). According to the same source, as a result of water storage and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per

year and hence there are frequent crop failures due to dry spells and droughts which have resulted in a chronic food shortage currently facing the country. Water availability for livestock is critical in the lowlands. Most of the year, animals have to walk long distances in search of water and are usually watered once in two to three days. Such water stress causes energy losses and low nutrient intake of animals. Water stress is also pronounced in highland areas of the country especially in areas that receive low rainfall both in amount and distribution (Sileshi *et al.*, 2003). In moisture stressed areas, the major problems are seasonality of the pasture, the possibility of low nutrient intake and water deprivation during the dry season that have a pronounced effect on production and productivity of the animals in this environment. Improvement of water resources in such areas will have a significant impact on improving the productivity of the animals and the livelihood of farmers.

Rainfall is highly variable and unpredictable, both in time and space. The vast majority (80%) of Ethiopia's population subsists on rainfed agriculture, thus their welfare and economic productivity are linked to the volatile rains. These circumstances leave Ethiopia's economic performance virtually hostage to its hydrology. Ethiopia's extreme hydrological variability is echoed in its economic performance. The correlation between rainfall and overall GDP is strong, as can be seen in Figure 2. The study found that considering the effects of water variability reduced projected rates of economic growth by 38% per year and increased projected poverty rates by 25% over a twelve year period (World Bank, 2006).

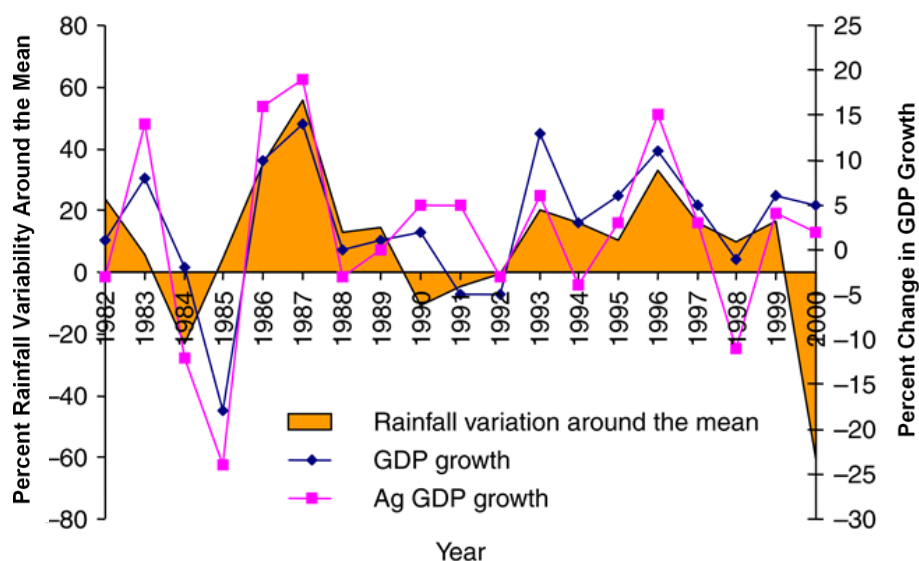


Figure 2. Rainfall, GDP and Agricultural GDP in Ethiopia (World Bank, 2006)

2.3. Global Trends in Demand for Livestock Products and Water Use

Exponentially expanding human populations raises the demand for all agricultural products and increases the stress on the resource base used for their production (Seré *et al.*, 1995). Both the growth in livestock production and demand for animal products are expected to happen more progressively in developing countries where, most of the areas are water stressed. Meeting the substantial increases in demand for food will have profound implications for livestock production systems over the coming decades (Thornton, 2010). The anticipated rapid increase in consumer demand that will motivate increased supply of animal products to urban markets will lead to correspondingly great increases in water use by the livestock sub-sector (Peden *et al.*, 2006). Managing this demand for additional water for livestock products dictates a need to integrated livestock development with investments in agricultural water development (Peden *et al.*, 2006).

2.4. Water Demands for Livestock

Agriculture is the largest user of water, accounting for 70 percent of total freshwater use (Steinfeld *et al.*, 2006). The livestock sector uses more than 8% of the global water used, with the major portion going to irrigate feed crops for livestock (7% of the global usage). However, the proportion of water used by livestock industries varies greatly between countries and production systems, just as the type and scale of livestock enterprise vary greatly (Steinfeld *et al.*, 2006; Schlink *et al.*, 2010)

Consumption of water by livestock occurs both directly through stock watering or making downstream water non-utilizable through pollution and indirectly through the production of feed as crop, sown pasture or as rangeland (Maimbo, 2007). Significant amounts of water are withdrawn for the production of feed (Steinfeld *et al.*, 2006; Peden *et al.*, 2007). Livestock also play an important role in water quality through the release of nutrients, pathogens and other substances into waterways, mainly from intensive livestock operations (Steinfeld *et al.*, 2006).

Population growth, development aspirations and a growing recognition of the importance of ecosystem support services are raising awareness that water is a key factor in socioeconomic development (Maimbo *et al.*, 2007). However, fresh water availability and its distribution is becoming a serious constraint and limiting factor to the expansion of agriculture for food production, livelihood improvement and to meeting other growing human needs (Maimbo *et al.*, 2007; Schlink *et al.*, 2010).

Competition for water between different uses and users is increasing (Bouman, 2007) due to a number of factors. Continuing in a business-as-usual mode will lead to a serious global water crisis (de Fraiture, 2007). Widespread overgrazing disturbs water cycles, reducing replenishment of above and below ground water resources. This affects sustainable uses of scarce water resources. If water use is to be sustainable in the future, then we need to make better use of the rainwater that infiltrates the soil, and we need to manage better the water-consuming vegetation systems that provide life support to livestock, humans and nature (Maimbo *et al.*, 2007).

2.4.1. *Water intake by livestock*

Water plays an important role in livestock survival and productivity. In livestock, water constitutes approximately 98% of all molecules in the body and 60-70% of the body weight (NRC, 2001). Livestock gain water through drinking, the water contained in feedstuffs and metabolic water produced by oxidation of nutrients (NRC, 2001; Pond *et al.*, 2006). The water in the feed can be of major importance. The water content of feed is highly variable and may range from as low as 5% in some dried grains or seeds to about 90% in early-growth pastures and succulent species by weight (NRC, 2001). As cited by Sileshi *et al.* (2003) on average fats, carbohydrates and proteins yield 1.07, 0.56 and 0.40 ml water per gram oxidised, respectively. For most domestic animals, metabolic water comprises only 5 to 10% of the water intake. Water is lost from the body through respiration, evaporation, urination and defecation. Water losses increase with high temperature and low humidity (NRC, 2001; Pond *et al.*, 2006).

Water is an essential nutrient which is consumed in considerably larger quantities relative to other nutrients and involved in all basic physiological functions of the body.

Water availability and quality are extremely important for animal health and productivity. Drinking water quality and quantity may affect feed consumption and animal health. Low-quality water may have direct effects on the acceptability (palatability) of drinking water and will result in reduced water and feed consumption (Lardy *et al.*, 2008; Olkowski, 2009). The most common water quality problems affecting livestock production include high concentrations of minerals, sulphates, nitrates and nitrites, bacterial contamination, heavy growth of blue-green algae and chemical contamination associated with agricultural and industrial activities (Lardy *et al.*, 2008; Olkowski, 2009). In developing countries, most of the water resources set for livestock and human drinking lacks water quality standards (Lardy *et al.*, 2008).

Water requirements and consumptions are influenced by several dietary, physiological and environmental factors including: type and size of the animal, rate and composition of weight gain, pregnancy, lactation, activity level, type of diet, feed intake, water quality, salt content, ability to conserve water and environmental temperature (NRC, 2001; Pond *et al.*, 2006). In very general terms, animal will consume 2 to 5 kg of water for every kg of dry feed consumed when they are not heat-stressed (Pond *et al.*, 2006). Reduction of water intake results in lower meat, milk and egg production. Deprivation of water quickly results in a loss of appetite and weight, with death occurring after a few days when the animal has lost between 15 to 30 % of its weight (NRC, 2001; Pond *et al.*, 2006).

2.4.2. *Water for feed production*

Livestock drink on about 25-50 liters of water /day/TLU (Sileshi *et al.*, 2003; Peden *et al.* 2003), but this constitutes only small fraction of its daily water requirement (Peden *et al.*, 2003). Agricultural water used for feed production is much greater than drinking water consumed by animals. Peden *et al.*, (2007) and Haileselassie *et al.*, (2009) suggested that the water consumed directly by livestock amounts to about 2% of the total water used to provide products and services under small-scale mixed farming systems. Studies by Peden *et al.*, (2003) indicate that the prime user of water resources for livestock production is through transpiration for the production of feed. This is important because the prime constraint to livestock production is seasonal feed

shortage, the production of which is often water limited and mainly dependent on rainfall. Increased animal production results in heightened demands for agricultural water.

African livestock use about 200 billion m³/year of rain and irrigated water most of which (99%) is depleted through transpiration in the process of producing feed (Peden *et al.*, 2006). Transpiration is not the only form of depleted water associated with feed production. Water evaporates from plant and soil surfaces. Some estimates suggest that evaporation can be up to six times more than transpiration, particularly in heavily grazed areas with little vegetative cover (Sonder *et al.*, 2004). In irrigated and rainfed pastures, it is important to maintain complete vegetative cover to ensure that as much water as possible is depleted through productive transpiration rather than non-productive evaporation. A key requirement is to limit grazing pressure to levels that does not reduce plant cover (Peden *et al.*, 2006).

As a baseline, livestock ingest about 2% of their live body weight (5 kg/TLU/day) in terms of dry matter intake to meet basic maintenance requirements in a thermo-neutral setting. This does not include additional energy demands associated with thermoregulation, reproduction, lactation, parasite infection, growth, walking, working. With all of these included, food intake can double to about 10 kg/day/TLU of dry feed (Sonder *et al.*, 2004). Assuming that one m³ of transpired water generates 4 kg of dry feed; water for feed production will vary between the maintenance levels of about 450 to about 900 m³/year or about 1200 to 2400 liters per day. Thus, the transpiration depleted water in using animal feed is about 50 to 100 times greater than what animals drink (Peden *et al.*, 2006).

Adequate feed supply largely determines livestock productivity while the quality and quantity of feed and the way the feed is produced and supplied to the animal affects the water productivity of livestock and ecosystem services (Hailelassie *et al.*, 2010). Given the overarching scenario of rapidly increasing water scarcity globally and rapidly growing demand for animal products in the developing world, research and development investments at the water, food and livestock intersection should have significant payoff in terms of overall benefits for people, livestock and the environment.

Increasing agricultural water productivity (gaining more yield and value from water) is an effective means of intensifying agriculture and reducing environmental degradation (Molden *et al.*, 2007), and integrating improved and appropriate livestock keeping practices into efforts to increase livestock water productivity will be part of the solution.

2.5. Livestock Water Productivity: Concepts, Definition and Scales of Consideration

2.5.1. Water productivity

Productivity is a measure of system performance expressed as a ratio of output to input. For agricultural systems, water productivity (WP) is a measure of output of a given system in relation to the water it consumes. In a broad sense, productivity of water is related to the value or benefit derived from the use of water (Molden *et al.*, 2003).

$$WP = \frac{\text{Agricultural Benefits}}{\text{Water Use}} \dots\dots\dots \text{eq. (1)}$$

Agricultural water productivity measures the ability of agricultural systems to convert water into outputs like food or feed. Assessment may be required for the whole system or parts of it, defined in time and space. Estimates of WP for single activities are called partial WPs. WP of larger areas containing complexes of multiple land use requires integration of partial WPs for each activity contained within them. It is normal to represent WP in units of kg/m³. If production is measured in kg/ha, water use is estimated as mm of water applied or received as rainfall, convertible to m³/ha (1mm = 10m³/ha). Alternative notations include food (kcal/m³) or monetary value (\$/m³).

Increasing productivity of water is particularly important where water is a scarce resource. By growing more food with less water, more water will be available for other natural and human uses (Molden and Rijsberman, 2001; Rijsberman, 2001 as cited by Molden *et al.*, 2003). Increasing the productivity of water in agriculture will play a vital role in: easing competition for scarce resources, prevention of environmental degradation and provision of food security and important pathway for poverty reduction (Molden *et al.*, 2003).

2.5.2. *The concept and definition of livestock water productivity*

Water productivity is not a new concept in the crop sector, where it has been successfully used for many years (Kijne *et al.*, 2003; Bouman, 2007; Rockström and Barron 2007; Clement *et al.*, 2010). Plant breeders and agronomists have applied concepts of genetics and plant physiology to develop varieties which are adapted to drought-prone regions and responsive to irrigation inputs. They have also identified phenotypic traits that could be used to identify appropriate inbred lines and gene pools to extract the desired genes and transfer them to the ideotypes and preferred crop varieties (Amede, 1998). On the other hand, Livestock Water Productivity (LWP) is a new concept that is still under development (Peden *et al.*, 2007) and much of the above-mentioned interventions have not been applied yet or evaluated in its context. Traditionally, water productivity concepts have been applied mainly to crop production. There is a knowledge gap related to water productivity of livestock. Investigating this gap addresses a critical need to simultaneously and coherently manage livestock and water resources for food security and poverty reduction, especially in areas where livestock are critically important (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009).

Livestock-water productivity is part of overall productivity of water for food production and is a scale dependent efficiency of direct and indirect use of water for provision of livestock products and services. It also takes into account the impact of livestock keeping on water quality, availability and value to subsequent uses and users (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). There are two general driving factors of livestock water productivity: the impact of livestock on water resources depletion in the process of feed production and the efficiency with which the different livestock management practices help to convert this invested water, to produce feed, into useful products.

2.5.2.1. *Definition*

Livestock water productivity (LWP) is defined as the ratio of livestock-related products and services to the water depleted in producing these (Peden *et al.*, 2007):

$$\text{LWP} = \frac{\sum \text{Livestock products and services}}{\sum \text{Water depleted and degraded}} \dots\dots\dots \text{eq. (2)}$$

LWP can be expressed in different units, depending on the beneficial outcomes that are considered. Physical water productivity is defined as the ratio of mass of an agricultural output or concentration of nutrients to the amount of water used. Economic water productivity is defined as the value derived per unit of water used. Hence, if only livestock meat or milk is considered, this physical LWP could be expressed in kilograms per cubic meter of water or in liters per cubic meter of water, respectively. Other notations include food, expressed in kilocalories per cubic meter of water or the monetary value, expressed in (Birr or Dollars) per cubic meter of water (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). The assessment of LWP is not straightforward because: 1) it comprises different components both at the numerator and the denominator side of the ratio, 2) it is strongly scale-dependent, and 3) it depends on the socioeconomic group, the agroecological zone and the type of livestock production system that is considered in the analysis (Peden *et al.*, 2003; Peden *et al.*, 2007; Cook *et al.*, 2008; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009).

The multiple products and services obtained from livestock production systems can be of physical, economic, environmental and socio-cultural in nature (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). The numerator of the productivity term includes products such as milk, meat and eggs, but also manure as fuel and for use as fertilizer, services such as draught power, and social benefits of livestock (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). Clearly, the water productivity concept is more complicated in livestock production systems than in crop production. Assessing the non-economic benefits of water used by livestock production systems can be significant, but more difficult due to the fact that unlike direct products they can comprise indirect benefits such as social benefits and environmental flows (Cook *et al.*, 2008). However, the growing potential for payment for environmental services offers scope to include non-economic benefits in assessments of water productivity (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). Besides that, the strong interaction between livestock and water on the one hand and other natural resources (vegetation, soil, ecosystems and

climate) on the other shapes the interpretation of LWP (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009).

The water depleted for the production of livestock feed at field scale is computed as the amount of water that is lost through evapotranspiration for the growth of different types and sources of livestock feed crops (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). The amount of water used for plant growth is estimated based on the particular crop characteristics and climatic parameters. Crop evapotranspiration (ET_c) is the amount of water a crop needs for growth. It is the start of all calculations for determining agricultural water demands (Maimbo *et al.*, 2007).

$$ET_c = K_c * ET_0 \dots\dots\dots \text{eq. (3)}$$

Where; ET_c = Crop evapotranspiration
 K_c = Crop factor
 ET_0 = Reference evapotranspiration

2.5.2.2. Scales of Consideration

Water use and management in agriculture cross many scales: crops, fields, farms, delivery systems, basins, nations and the globe (Molden *et al.*, 2003). The issues of scale heavily influence concepts of water productivity. The processes and scales of analysis are different at each scale. Actions at one scale often influence what happens at a different scale (Molden *et al.*, 2003). When comparing water productivity values, both the produced commodity and the water flow components included in the analysis should be clearly defined, as these can vary greatly with the scale of the analysis, the system concerned and the interests of stakeholders. By analogy with the spatial scales (plant, field, agricultural landscapes) identified for crop water productivity (Bouman, 2007), the relevant spatial scales for LWP are animal, field, herd, farming system, catchment and basin scale (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009). Water accounting provides a means to generalize about water use across scales, and to understand the water productivity better. Water accounting can be applied at all scales of interest; however, it requires the definition of a domain bounded in space and time dimensions (Molden *et al.*, 2003).

2.5.3. *The livestock water productivity framework*

Many people and institutions are working to increase the productivity of water but the effort remains disjointed with integrated livestock production. Part of the reason is that there is no common conceptual framework for communicating about water productivity in terms of livestock (Peden *et al.*, 2007). Livestock water productivity (LWP) is a “systems” concept with each production system having a unique and dynamic set of structure and mix of processes (Peden *et al.*, 2003). Given the complex nature of livestock systems, a conceptual framework (Peden *et al.*, 2003) was developed in order to analyze LWP. This framework allows accounting for the multiple benefits from livestock production, the different water flows that are involved and the various factors (not only biophysical but also institutional and socioeconomic factors) influencing LWP (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009).

Key livestock water productivity principles are illustrated in Figure 3 derived by Peden *et al.* (2007). The water-accounting procedure classifies the inflow and outflow components into various water-accounting categories (Molden *et al.*, 2003; Peden *et al.*, 2007). In estimating water productivity, we are interested in water inflows (comprise precipitation, surface water and ground water, or just rainwater in rain-fed agriculture) and water depletion (evaporation and transpiration (Molden *et al.*, 2003)). Degradation and contamination also deplete water in the sense that the water may be too costly to purify for reuse (Peden *et al.*, 2007). Virtual water is taken into account only when feed is imported (Molden *et al.*, 2003; Peden *et al.*, 2007). The water flowing into the system is used for biomass production, drinking, and processing and servicing. It allows the system to produce animal outputs by using the different feed types produced by transpiration and relying on other natural resources and inputs (Peden *et al.*, 2007). Animal outputs then contribute to livelihoods and environmental services. This contribution is positive if managed well, but could also be negative if managed badly on water storage, depletion and on the beneficial water dependent outputs from the domain (Sonder *et al.*, 2004). The effect on environmental services creates feedback loops because of the influence on feed production, on other natural resources such as soils and vegetation and on the water inflow itself (Peden *et al.*, 2007).

The water that flows into the system also flows out one way or another. This outflow comprises much more than the water contained in animal urine or faeces. Transpiration, evaporation, contaminated water and degraded runoff water all form part of depleted water flows, which cannot be used by the system anymore. On the other hand, non-degraded discharge and deep percolation out of the root zone flow out of the system, but might be used by other systems downstream or after recycling (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Haileselassie *et al.*, 2009).

An integrated framework can help to identify sets of options to enable more effective and sustainable use of water for livestock (reducing water depletion and increasing goods and services associated with animal keeping (Peden *et al.*, 2007)). Livestock water productivity framework has been a useful tool for comparing different schemes. At household level, it was found to be a good way of identifying the contribution of the different components of livestock production to the livestock water productivity (Peden *et al.*, 2007).

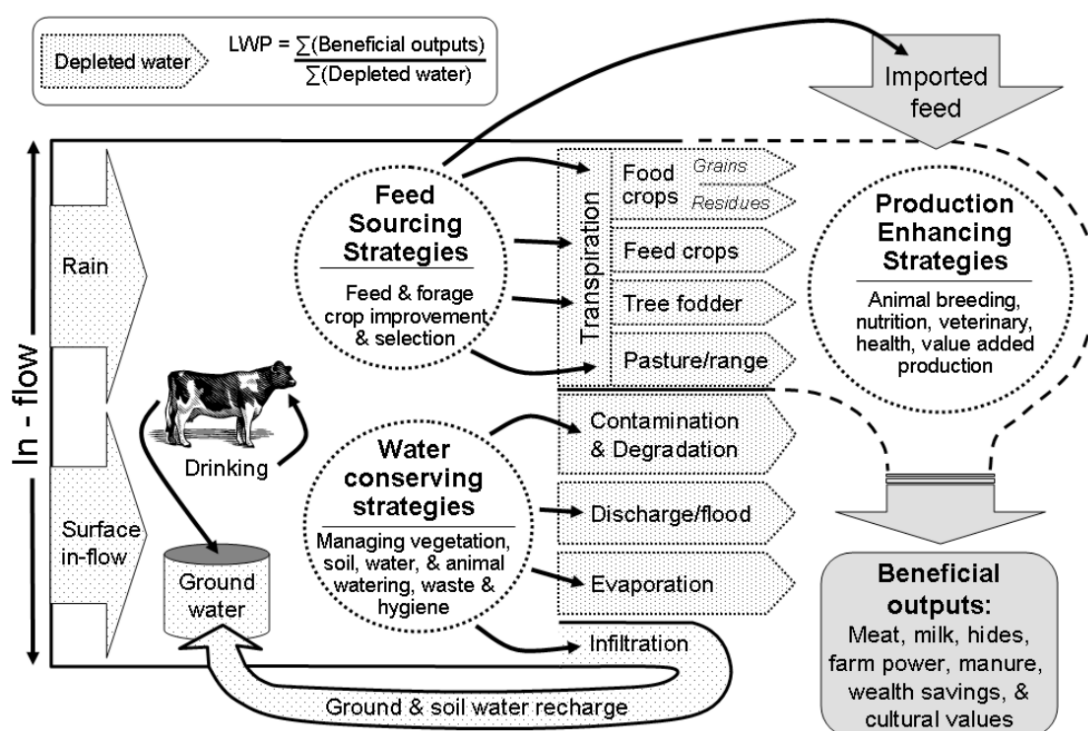


Figure 3. Simplified framework for assessing livestock-water productivity (Peden *et al.*, 2007)

Generally, basic strategies that help to increase livestock water productivity directly include: improving feed sourcing, enhancing animal productivity, and conserving water (Figure 3). Providing sufficient drinking water of adequate quality also improves livestock water productivity (Peden *et al.*, 2007). Focusing on a single strategy may not be effective. A balanced, site-specific approach that considers all the strategies will help to increase the benefits derived from the use of agricultural water for the production of animal products and services (Peden *et al.*, 2007).

2.5.4. Variations in livestock water productivity

Different researchers observed livestock-water productivity variations across different scales including: farming systems, farm resource holdings (wealth status), and feed resources types. Some of the observations are presented as follows:

2.5.4.1. Livestock water productivity across farming systems

For different farming systems, Bekele (2008) and Haileselassie *et al.* (2009) reported LWP values ranges of 0.06 – 0.08 and 0.1– 0.6 USD¹ m⁻³, respectively. Even for similar mixed crop-livestock systems in the Ethiopian highlands, reported values for LWP largely vary from 0.06–0.08 USD m⁻³ (Alemayehu *et al.*, 2008) to over 0.3–0.6 USD m⁻³ of water (Gebreselassie *et al.*, 2008). In addition, Bedasa (2012) reported LWP ranging from 0.15 to 0.19 USD m⁻³ for farming system typologies in the highlands of the Blue Nile Basin. Moreover, up to 4.8 USD m⁻³ of water is reported by Tulu *et al.* (2008). Water productivity analysis for milk in physical terms, in the Indo-Ganga Basin for the year 2003 showed that the highest milk returns for a litre of water depleted was achieved in the intensive systems (0.4-0.9 litre m⁻³), while range of 0.2-0.4 litre m⁻³ is for the semi-intensive system (Haileselassie *et al.*, 2011). Same study revealed LWP analysis across livestock groups showed the highest value for crossbreed cows followed by buffalo and local cows were the least. Using water foot printing concept in life cycle assessment frame, Alemayehu *et al.* (2017) reported low LWP ranging from of 0.057 to 0.066 USD m⁻³ across mixed farming systems in *Gumara* watershed of the Upper Blue Nile Basin. In Alemayehu *et al.* (2017) study, the determination of LWP covered

¹ 1 USD = 20 Ethiopian Birr in 2014

the period between birth and end of productive age for breeding stock, and between birth and time of offtake (slaughter or sale) for non-breeding stock. It is done to account for water depleted for feed consumed for the period before reaching productive age.

2.5.4.2. *Livestock water productivity across farmers wealth status*

Hailelassie *et al.* (2011) observed the volume of water depleted to produce a similar type of animal product varies among systems and is affected by the type of inputs and management practices used, which in turn depends on available resources at HH level. For instance, Ayele (2012) reported variable values of LWP across the farming systems and wealth category classes at household level in the Blue Nile Basin; on average lower LWP values for relatively poor HHs (0.08 USD m⁻³) and higher LWP value (0.24 USD m⁻³) for better-off farm clusters. More interesting is a huge gap between the minimum (0.001) and maximum values (0.627 USD m⁻³) of LWP. In addition, Bedassa (2012) reported LWP ranging from 0.08 to 0.24 USD m⁻³ across farm households clustered in to wealth status in the highlands of the Blue Nile Basin. In view of this it can be concluded that there is huge potential to improve LWP in mixed crop livestock systems of the Blue Nile Basin, through building the capacity of the poor farm households.

2.5.4.3. *Livestock water productivity relation to feed resources*

Adequate feed supply largely determines livestock productivity while the way feed is produced affects the sustainable use of water. Descheemaeker *et al.* (2011) noted strong linkage between WP of livestock to that of feeds. The feed sources and the efficiencies with which feed is utilized within the animal determine the amount of water required to produce livestock products and services. In the crop-livestock systems of India, Hailelassie *et al.* (2011) observed the largest component of total water consumption in livestock systems was the production of irrigated fodder while the smallest component was use of crop residues and the WP of livestock positively correlates with the percentage share of crop residues in the diet. The feed water productivity in the Indo-Ganga Basin in 2003 reported by the same author was 0.3-2.6 kg m⁻³ for green feeds (grass from communal grazing, fallow land, grazing under forest), 0.5-2.7 kg m⁻³ for concentrates and 3.1-5.0 kg m⁻³ for crop residues. Hailelassie *et al.* (2011) reported

livestock and feed water productivity in the Indo-Ganga basin and the volume of water depleted varied among intensification gradient of crop-livestock production systems and was highly affected by the type of feed. In the north eastern Ethiopia under irrigated and rainfed farming systems, Bekele (2008) reported that more than 73% of agricultural water depleted at household level was through livestock feed production, of which more than 52% was on grazing lands and the rest from crop residues.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location and physical characteristics

The study was conducted in *Debre Berhan* milkshed in North *Shewa* administrative Zone of the *Amhara* National Regional State, central highlands of Ethiopia. *Debre Berhan* town, the administrative and commercial center of North *Shewa* Zone and *Basona Worana* district, is 130 km away to the Northeast of *Addis Ababa*, on the paved highway of *Addis Ababa* to *Dessie*. The topography of the study area is predominantly characterized by undulating hilly landscape with gentle slopes (North *Shewa* Agriculture Office, unpublished). The study area is located between $9^{\circ} 30'$ and $9^{\circ} 50'$ latitudes and $39^{\circ} 20'$ and $39^{\circ} 44'$ longitudes (Figure 4). The elevation ranges from 2840 to 2943 masl (Molla, 2013).

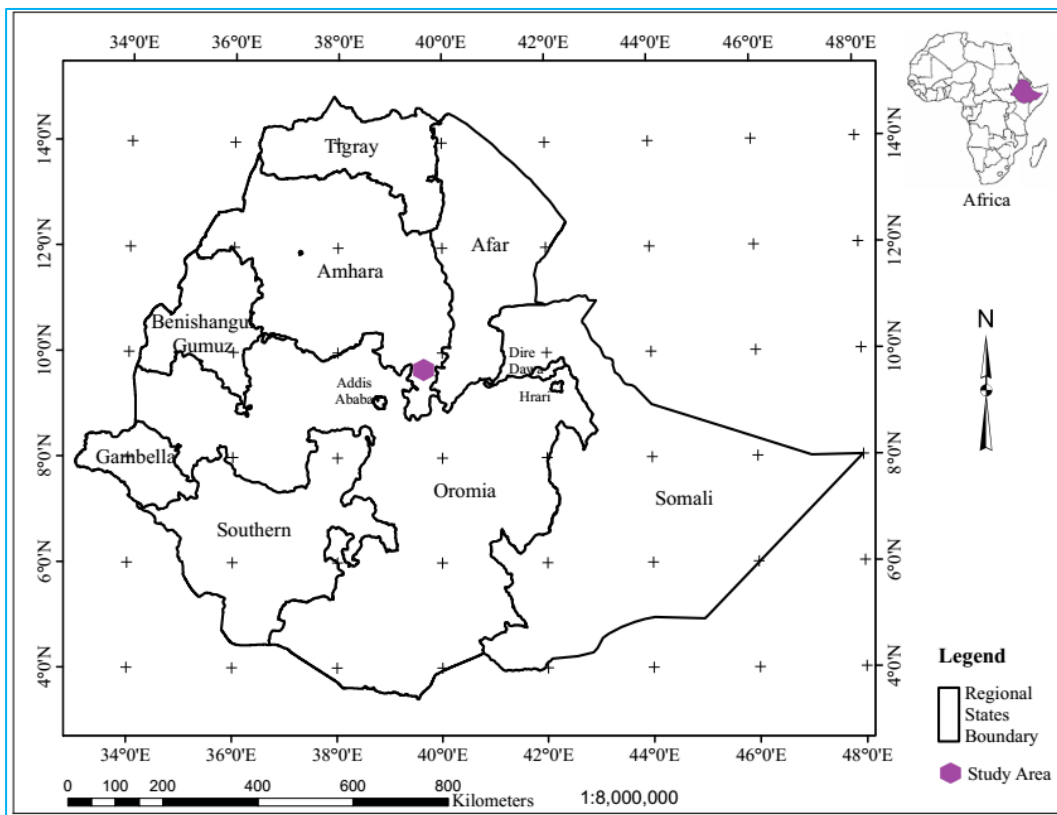


Figure 4. Map of Ethiopia showing location of the study area

3.1.2. Agro-climatic conditions

The climate in most parts of the area is characterized by cold temperatures. The mean annual minimum and maximum temperatures averaged between 2000-2014 years are 6.7 °C and 19.9 °C, respectively. The mean annual rainfall within the span of the same years is 1026 mm with a potential evapotranspiration of 1396 mm. Rainfall distribution is bimodal, usually the long rains (*meher*) last from June to the beginning of September, and the period of the short rains (*belg*) falls between February and May. About 86% of the annual rain falls between June and September which is the main cropping season (Figure 5). Most of the study area is covered by moderately and poorly drained soils, predominantly black Vertisol (Amsalu *et al.* 2007; Molla, 2013).

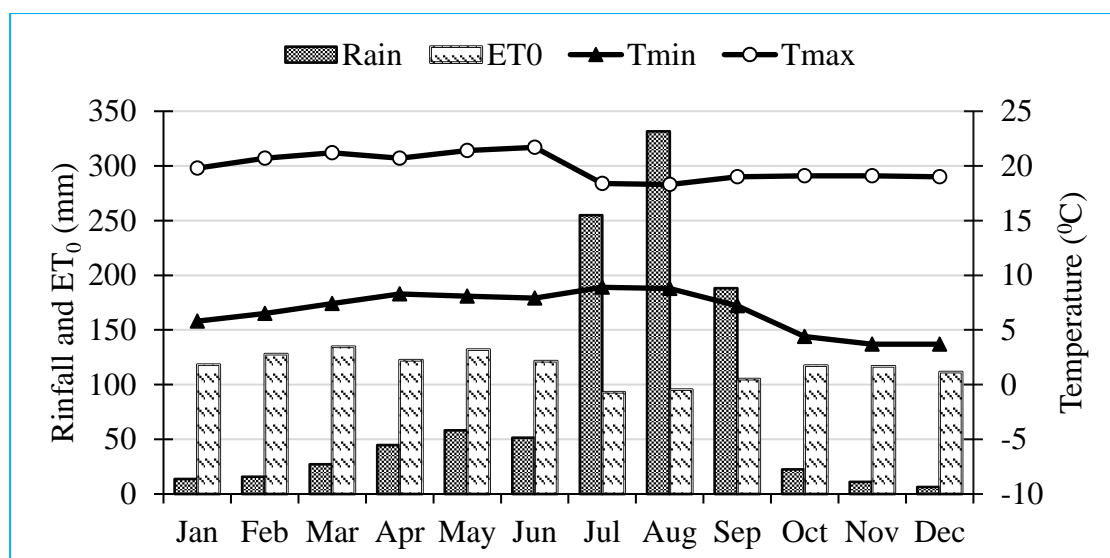


Figure 5. Average monthly rainfall, potential evapotranspiration (ET₀), maximum (T_{max}) and minimum (T_{min}) temperatures at *Debre Berhan* weather station (monthly data averaged from 2000 to 2014)

Rainfed mixed crop-livestock (MCL) farming system, where close interdependence between crop and livestock sub-systems exists is the dominant system practiced primarily to meet the subsistence requirements for most of the farmers with their families. Small-scale irrigated farming is limited to few farmers with small patchy areas along *Beressa* River producing mainly vegetables. The staple food crops widely grown include barley (*Hordeum vulgare*), wheat (*Triticum durum*), faba bean (*Vicia faba*) and field pea (*Pisum sativum*). The cereals which covered the largest portion of the cropped area during the main season are the major sources of crop residues (CR) for livestock

feeding. The cultivation of teff (*Eragrostis tef*), lentil (*Lens culinaris*), chickpea (*Cicer arietinum*), oat (*Avena sativa*), linseed (*Linum usitatissimum*) and vegetables are intermittent on small plots of cropland. Crop residues and natural grazing land (GL) are the major livestock feed resources, while fallow land, crop aftermath and concentrates are occasionally available feeds (Hassen *et al.*, 2010; Bekele *et al.*, 2017). The livestock species reared include indigenous cattle (*Bos indicus*) and their crosses with temperate origin (*Bos taurus*), sheep (*Ovis aries*), goats (*Capra hircus*), donkeys (*Equus asinus*), horses (*Equus caballus*), mules (*Equus mule*) and poultry (*Gallus gallus domesticus*). Cattle production with indigenous and crossbred animals predominates the livestock production followed by sheep production (Hassen *et al.*, 2010; Bekele *et al.*, 2017).

3.1.3. Human and livestock populations and land use

The total human and livestock populations in the three districts (*Debre Berhan Town, Basona Worana and Angolela ena Tera*) in which the *Debre Berhan* milkshed is located, are presented in Table 2. Human population comprises of 50.4% male and 49.6% female. Of the total cattle population in the three districts, 13.3% are crossbreds of the locals with Holstein Friesian of variable exotic blood levels (North *Shewa Zone* Agriculture Office, 2013 unpublished).

Table 2. Area, human and livestock populations of the districts in which the *Debre Berhan* milkshed is located, central highlands of Ethiopia

Description	Districts			Total
	<i>Debre Berhan Town</i>	<i>Basona Worana</i>	<i>Angolela ena Tera</i>	
Area (km ²)	139.3	1150.4	836.3	2126.0
Human Population (numbers)	78733	130536	89642	298911
Male	38228	66835	45519	150582
Female	40505	63701	44123	148329
Livestock Population (numbers)				
Cattle	15864	156652	125052	297568
Sheep	26954	106792	119321	253066
Goats	13713	71737	12223	97672
Donkeys	3345	30245	27092	60682
Horses	1912	10506	9288	21706

Source: North *Shewa Zone* Agriculture Office (2013, unpublished).

The land use categories of the three districts in which *Debre Berhan* milkshed is located are summarised in Table 3. Much of the land in the study areas is used for food-feed crop production.

Table 3. Land use of the districts in which the *Debre Berhan* milkshed is located, central highlands of Ethiopia

Land Use (ha)	<i>Debre Berhan</i> Town	<i>Basona Worana</i>	<i>Angolela ena Tera</i>	Total
Cultivated (food crops)	3669	51569	32983	88221
Forest and shrubs	560	35643	18462	54666
Grazing	355	8713	10711	19780
Others*	9343	19117	21474	49935
Total	13928	115043	83630	212601

* Settlements, roads, water bodies, degraded lands unsuitable for agriculture.

Source: North *Shewa* Zone Agriculture Office (2013, unpublished).

3.2. Wealth Status Classification Criteria

Criteria setting for wealth status was made in consultation with district experts, development agents and was confirmed through focus discussions with local farmers. Multiple criteria focusing on physical ownership of key assets and their anticipated values at the time of the study were used rather than precarious annual cash income. Ownership of houses with corrugated iron or thatched grass roofs, number and types of livestock, area of land and the capability of farmers to satisfy household basic needs throughout the year were the major focuses. Nonetheless, setting an absolute cut-off point to each criterion was not possible, and an overlap in the range of values for the set criterion was evident. Instead of fixing the judgment based on the value of a single criterion, the contribution of the whole was assessed together to group a farmer under one of the three wealth categories (better-off, medium and poor). The descriptions of each criterion are summarized in Table 4.

Table 4. Description of wealth status grouping criteria generalized based on farmers' perspectives in the mixed crop-livestock system, central highlands of Ethiopia

No	Criteria	Wealth group		
		Better-off	Medium	Poor
1	Cropland holding (ha)	>1.50	1-2.5	0.25-1.5
2	Number of ploughing oxen	>2	≥2	≤1
3	Number of milking cows (local and crossbreds)	>2 most of crossbreds	At least 2, few crossbreds	<2 and usually local breeds
4	Number of sheep (adults)	10-50 or more	5-20	≤10
5	Number of equines (adults)	A mule, a horse and donkeys	At least a horse and donkeys	No mule and horse may be donkey
6	Roof of houses			
	Corrugated iron sheet	Yes	Yes (often)	No
	Grass thatched	Yes	Yes	Yes
7	Quantity of annual food production and supply to sustain household	Enough with more surplus	Enough but meagre surplus	Not enough, in need of support

3.3. Survey Design and Data Collection

For the study, milkshed, milk collection centers and sample respondent households were selected according to the following procedures.

3.3.1. Sampling procedures and sample size

A multistage sampling procedure was employed to select sample farmers engaged in MCL farming and deliver fluid milk to the nearby milk collection centers (MCC). *Debre Berhan* milkshed was purposely selected based on its accessibility and potential representativeness of the MCL system in central highlands of Ethiopia. Besides milk production potential, the milkshed has good market accessibility in the local community, the zonal center *Debre Berhan* town and milk processing enterprises in *Addis Ababa*. Households who own livestock and engaged in mixed farming were involved in the formal survey questionnaires. Each household was considered as a

sample unit. In the milkshed, from thirteen milk collection centers (MCC) found in Debre Berhan and Basona Worana districts, six representative MCC serving about 48 villages were selected using simple random sampling procedure. Farmers sample size was determined using G*power 3.1.7 software considering the farmer wealth group as fixed effect and assuming 0.25 effect size, $\alpha=0.05$ and 80% power of the statistical test (Faul *et al.*, 2007). List of farmers obtained from the selected MCC was categorized into three wealth groups to form the sampling frame. The number of sample farmers in each wealth group was based on the probability proportional to size sampling technique (Alam *et al.*, 2015). Finally, a total of 159 farmers (50 in the poor, 58 in the medium and 51 in the better-off wealth status) were selected using systematic random sampling with whom the questionnaires were administered.

3.3.2. *Data collection and sources*

A socio-economic survey using pretested semi-structured questionnaires was carried out via a face to face interview in 2014 and 2015. The questionnaires used for individual household interview covered data on: household demographic characteristics, land and livestock ownership, livestock species composition and herd structure, livestock management and productivity, incoming animals due to births, purchased, received or given in, and outgoing animals due to offtake (sold, slaughtered, given out), death and loss into and out of the livestock herds and flocks over a year, livestock traction services delivered per year (ploughing, threshing and transportation), manure management and utilization, types and sources of livestock feeds, area of private and communal GL, types of food-feed crops grown and cropping pattern, area covered under each crop type cultivated and agronomic practices, land leased under local agreements, agricultural inputs used, crop yield per cultivated cropland, availability and accessibility of credit and training services, current farm gate and market price for inputs, crop and livestock products, sales and consumption of livestock products, conception of constraints of livestock and crop production, and household division or share of labour. Question checklists were prepared for group discussions on the major factors influencing crop and livestock production, land use, wealth group categorization, trends of livestock and crop production. Focus group discussions were conducted at each of the selected MCC. A total of 40 farmers (six to eight per session) representing the different wealth status

have participated in six sessions. Knowledgeable farmers from all wealth groups were selected anticipating an effective communication between the moderator and within themselves. Key informants' interviews were undertaken with the zonal and district level livestock production experts, local development assistants, knowledgeable farmers and community leaders in the selected MCC. The secondary data were extracted from previous studies and information documented at agricultural development and research offices. Data enumerators recruited were agricultural development agents, who were then trained to assist on primary data collection during face to face interview and group discussions. Local climate data were obtained from *Debre Berhan* Agricultural Research Center weather station.

3.4. Dataset Management and Analyses

The following subsections give details of the steps and procedures that were used in estimating the dry matter (DM), metabolizable energy (ME) and digestible crude protein (DCP) contents of the major feeds available and demands for the prevailing livestock, feed balance, depleted water for feed production, livestock beneficial outputs and water productivity of feed and livestock at farm level.

3.4.1. Estimation of annual feed availability (supply)

Quantity of feed DM available per year was estimated from the major feed resources in the study area including CR, crop aftermath (stubble that remain after harvest) and GL. Crop residues DM obtained was derived from grain yield, harvest indices and area of cropland cultivated. Conversion factors derived from harvest indices; 1.5 t/ha for wheat and barley, and 1.2 t/ha for faba bean and field pea (Keftasa, 1988; Kossila, 1988; FAO, 1987) were used to estimate the amount of crop residues from grain yields obtained. The amount of DM collected from CR per year by an individual farmer was extrapolated based on the size of plot of cropland allocated to grow a particular crop type during the cropping season. Given the feed shortage and farmers priority to the use of CR in the highland MCL systems it is assumed that about 90% of the CR used as feed and 10% for other purposes and wastage (Tolera and Said, 1992).

Available DM of crop aftermath grazing from croplands was estimated using conversion factor of 0.5 ton DM/ha per year (FAO, 1987) and the area cultivated. Available feed DM from GL is estimated by taking the private and communal ownership pattern into account. Farmers are eligible to use whole of available feed on their entitled private GL but can only share certain amount of feed from openly accessible communal GL. Livestock are left to graze freely on communal grazing lands, where there are no local ground rules applied in sharing of the feed resource to assume equitable share. It was assumed that the amount of feed DM share from communal grazing is a function of livestock density, which is ascribed to the size of livestock ownerships that had access to use this communal resource. A livestock density of 14.8 TLU/ha derived based on data on the size of livestock and GL area was used to allocate the communal grazing to each livestock owner relative to livestock possession. The total area of privately owned and part of the communal GL allocated were considered to estimate the available feed DM from GL per household per year. The feed DM productivity on GL was estimated based on multiplier of 2 t/ha established from previous GL condition and productivity studies (FAO, 1987). Utilization factor of 75% as suggested by WBISPP (2002), for extensive grassland is used to quantify the DM that would be utilized by livestock.

The quantities of ME and DCP of feed resources were calculated based on the *in vitro* digestibility of organic matter in dry matter (IVDOMD) and crude protein (CP) contents of each feed types reported by Wondatir *et al.* (2011) in the study area. The following equations were used to estimate the annual energy and protein supply at farm level in relation to the type of feed resource and amount obtained per year.

$$\text{ME (MJ/kg DM)} = 0.015 * \text{IVDOMD (g/kg)} \text{ (MAFF, 1984); eq. (4)}$$

$$\text{DCP (g)} = 0.929 * \text{CP (g)} - 3.48 \text{ (Church and Pond, 1982). eq. (5)}$$

The seasonal availability of feed resources was assessed based on farmers judgment and scores given for a particular feed type in each month throughout the year. Availability of feed over the year was scored on a scale of 0-10, where 10 = excess feed available, 5 = adequate feed available and 0 = no feed available (ILRI, 2014).

3.4.2. Estimation of livestock feed requirements (demand)

Livestock holdings per household were aggregated into TLU considering the annual average livestock ownership derived based on the number of animals at the beginning and end of the study year. This was done to take into account the annual inflow and outflow dynamics of livestock at farmer level. Species specific TLU conversion factors of 0.7 for cattle, 0.1 for sheep and goats, 0.5 for donkeys and 0.8 for horses were used (Jahnke, 1982). The dry matter demand (**DMD**) was estimated based on the expected daily dry matter intake (**DMI**) suggested for the standard TLU of 250 kg at 2.5% of the body weight, which is equivalent to 6.25 kg per day or 2280 kg per year (Jahnke, 1982). Comparable rate of DMI was also suggested by Kears (1982). The ME and DCP requirements for maintenance were calculated according to the daily average recommendations given by Kears (1982). Based on metabolic body weight 118.0, 93.0 and 103.45 kcal of $ME/W_{kg}^{0.75}$ and 2.86, 1.72 and 2.51 g of $DCP/W_{kg}^{0.75}$ per day for cattle, sheep and goats, respectively were used for maintenance (Kears, 1982). Accordingly, the daily nutrient requirement tables for maintenance recommended for ruminants in developing countries by Kears (1982) were used to estimate the annual ME and DCP requirements for cattle, sheep and goats. In the case of donkeys and horses the daily ME and DCP maintenance requirements of 14.9 and 27.6 MJ and 0.18 and 0.37 kg recommended by McCarthy (1986) as cited in Wondatir *et al.* (2011) were used, respectively. Then farm level DM, ME and DCP requirements for maintenance per year were extrapolated relative to the livestock ownership per household.

3.4.3. Livestock feed balance

Livestock feed balance at individual farmer level over the entire production year was determined as the difference between the annual feed DM, ME and DCP supply estimated from major feed resources and the annual feed DM, ME and DCP demands for the annual average livestock holding of farmers.

3.4.4. Estimation of water depleted for livestock and feed production

Methods and procedures followed by several authors, example (Peden *et al.*, 2007; Descheemaeker *et al.*, 2009; Hailelassie *et al.*, 2009; Kebebe *et al.*, 2015) were used to estimate the beneficial outputs of livestock, amount of feed sourced, water evapotranspired for feed production and water productivity of feed and livestock.

Feed DM yield and associated water depletion in the production process are important indicators for performances of livestock in terms of water resources economy. As the drinking water for livestock is not more than 2% of the water needed for the feed production (Peden *et al.*, 2007; Hailelassie *et al.*, 2009), only the amount of water used for livestock feeding was accounted as depleted water. Estimation of the volume of water depleted for livestock feed production in a given system requires assessment of feed types, sources, utilization rate, crop coefficients and climatic parameters. In this study, estimation of dry matter yield and consequent water depletion for livestock feed production were depending on grazing lands and food-feed croplands. The area of grazing lands and ownership pattern per farm household, grazing land productivity (FAO, 1987) and utilization factor (WBISPP, 2002) were used to estimate the volume of water depleted for livestock feed production on grazing lands. To estimate the dry matter production of crop residues (Keftasa, 1988; Kossila, 1988; Tessema *et al.*, 2003) and associated depleted water, the harvest index approach (Hailelassie *et al.*, 2009; Descheemaeker *et al.*, 2011) and utilization factor (Tolera and Said, 1992) were used, as the whole crop residues dry matter produced may not be totally recovered and used by livestock.

Water depleted for feed production: It refers to the amount of water that is lost through evapotranspiration to produce feeds was considered as productive use of water by livestock. Meteorological and crop data are used as an input for CROPWAT 8.0 computer program (FAO, 2009) to estimate crop water requirement. CROPWAT uses the Penman-Monteith equation to calculate the reference evapotranspiration (ET_0) of a hypothetical grass using meteorological data from which the actual evapotranspiration of other crops is extrapolated. It is recommended as a standard and valid method for the definition and computation of the reference evapotranspiration (ET_0) and globally

accepted method for the prediction of crop water requirements (FAO, 1992). To calculate the local reference evapotranspiration (ET_0) the long term monthly average climate data (minimum and maximum air temperatures, relative humidity, wind speed, sunshine duration and rainfall) were obtained from *Debre Berhan* weather station. Effective precipitation was estimated using the fixed percentage (potential evapotranspiration/precipitation ratio) method in the CROPWAT model. Agronomic data such as the types of cultivated crops, area covered per crop type and the length of growing period of crops (planting date and harvesting date) were obtained from local farmers. The actual evapotranspiration (ET_a) per period associated with the crop biomass production was estimated by relating the reference evapotranspiration (ET_0) with the crop coefficient (K_c) (Allen *et al.*, 1998). The crop coefficients (K_c values) at each growth stages in the length of growing period of the crops were extracted from FAO irrigation and drainage paper No. 56 (Allen *et al.*, 1998). Crop grain yield of each crop type during the main cropping season was obtained from farmers and used to derive crop residue collected and associated water use. On the crop field, depleted water serves both for the grain and residues. The harvest index approach (Hailelassie *et al.*, 2009; Descheemaeker *et al.*, 2011) was employed for partitioning of depleted water between grain and crop residues. Depleted water on grazing land was estimated based on the area of grazing land, K_c value for extensively grazed land (Allen *et al.*, 1998) and the length of growing period generated using New_LocClim software (FAO, 2006).

The following procedures and equations show mathematical relations of the different datasets that were used in estimating the volume of water depleted for livestock feed production.

1. Crop evapotranspiration: The water requirements of different crops as volume of water evapotranspiration per unit of time can be estimated based on the methodology given in FAO irrigation and drainage paper No. 56 (Allen *et al.*, 1998).

$$ET_c = K_c * ET_0 \quad \dots\dots\dots \text{eq. (6)}$$

Where,

ET_c = Crop evapotranspiration or crop water requirement (CWR) in mm per unit of time

K_c = Crop coefficient (Crop factor)

ET_0 = Reference crop evapotranspiration in mm per unit time at a given location.

2. Crop biomass water requirement: This refers to the volume of water requirement of a particular crop in any given area during its growing period. In this study, agricultural land used for livestock feed sourcing i.e. cultivated cropland and grazing lands used by sample households were considered.

$$CBWR_{ji} = [(ET_{ci} * LGP_i) * GA_{ji}]/1000^2 \dots\dots\dots \text{eq. (7)}$$

Where,

$CBWR_{ji}$ = Crop biomass water requirement (depleted water for crop biomass production) in m^3/ha of the i^{th} crop type per j^{th} household.

$[ET_{ci} * LGP_i]$ = Crop water requirement in mm per m^2 for the growing period.

ET_{ci} = Total water depleted in mm per m^2 per day of the i^{th} crop type.

LGP_i = Length of growing period (length of growth cycle in days) of the i^{th} crop type.

GA_{ji} = Growing area (m^2) covered under the i^{th} crop type per j^{th} household.

3. Water depleted for crop residues used for feeding livestock: This is derived by partitioning of the total water depleted for biomass production into product fractions (grain and crop residues) based on harvest index and utilization factor.

$$WDCR_{ji} = [CBWR_{ji} * (1 - HI_i)] * CR_{ui} \dots\dots\dots \text{eq. (8)}$$

Where,

$WDCR_{ji}$ = Water depleted in m^3 for crop residue of the i^{th} crop type per j^{th} household farm utilized by livestock.

HI_i = Harvest index of the i^{th} crop type (the ratio of grain yield to total above ground biomass of i^{th} crop type).

CR_{ui} = Utilization factor (%) of crop residue of the i^{th} crop type.

4. Water depleted on grazing lands: This refers to the volume of water depleted on a given area of grazing lands used for livestock grazing.

$$WDGL_{ji} = [(ET_{ci} * GLA_{ji}) * GL_{ui}]/1000^3 \dots\dots\dots \text{eq (9)}$$

^{2,3} Water requirement in $m^3ha^{-1} = 10 * \text{Water requirement in } mm\ m^{-2}; 1\ ha = 10000\ m^2$

Where,

$WDGL_{ji}$ = Total water depleted in m^3 for production of feed dry matter on i^{th} grazing land area per j^{th} household.

ET_{ci} = Total water depleted in mm per growing period on grazing land.

GLA_{ji} = Grazing land area of type i^{th} in m^2 per j^{th} household used by livestock.

GL_{ui} = Feed utilization factor of the i^{th} grazing land.

5. Depleted water for livestock feed: This refers to the total volume of water depleted for livestock feed production from cultivated cropland and grazing land.

$$DWLF_j = \sum_{i=1}^n WDCR_{ji} + \sum_{i=1}^n WDGL_{ji} \dots\dots\dots eq. (10)$$

Where,

$DWLF_j$ = Total depleted water in m^3 per j^{th} household per year for livestock feed.

$WDCR_{ji}$ = Water depleted in m^3 for crop residues per j^{th} household farm of the i^{th} crop type utilized by livestock.

$WDGL_{ji}$ = Total water depleted in m^3 for dry matter from grazing land per j^{th} household farm of the i^{th} grazing land.

3.4.5. Estimation of outputs from livestock (products and services)

Multiple benefits of livestock that include products (milk, offtake, manure) and traction services (ploughing, threshing and transportation) accrued per year at household level were estimated as annual beneficial outputs of livestock. Current market prices of live animals, livestock products and livestock hiring values for different services in the study area were used to quantify the various benefits and services into unity in monetary terms (USD). The annual livestock outputs and services per household were estimated as follows:

1. Milk value: The annual milk value obtained at household level was estimated from the number of lactating cows kept, the average daily milk yield, lactation period of cows and milk price. Records on the amount of fluid milk delivered by sample farmers to MCC was obtained to estimate the daily average milk yield, the total milk production and the value estimated for milk sale per year per farm household.

$$MYV_{ji} = (AMY_{ji} * NLC_{ji} * LL_{ji}) * MV_i \dots\dots\dots \text{eq. (11)}$$

Where,

$AMY_{ji} * NLC_{ji} * LL_{ji}$ = Total milk yield (liters) per year per j^{th} household.

MYV_{ji} = Milk value (USD) per year per j^{th} household.

AMY_{ji} = Average milk yield (liters) per day per i^{th} cow in the j^{th} household.

NLC_{ji} = Number of lactating cow in j^{th} household.

LL_{ji} = Lactation length (days) of i^{th} cow in j^{th} household.

MV_i = Market price of milk (USD per liter).

2. Off-take value: The total amount of benefit obtained from off-take of different types of livestock at household were estimated by considering the number, type and price of the livestock species that a farmer has sold, slaughtered and given out throughout the year. To capture information on the dynamics of each type of livestock kept at household, herd and flock inventory were conducted during the reference year of the study period. Livestock numbers at the beginning and end of the reference study period were used to approximate the average herd size maintained per household per year. Off-take and mortality rates per household were calculated based on the average herd or flock size and the incidences of off-take and deaths over the year. The annual monetary value of offtake was deduced based on the average number of years each livestock types stayed at farm. Mortalities of each type of animals per year at household level and its effect on the output gain and livestock water productivity were taken into account, as these animals used water up until their existence.

$$OTV_{ij} = \sum_{i=1}^n NLOT_{ij} * MV_{ij} - \sum_{i=1}^n ND_{ij} * MV_{ij} \dots\dots\dots \text{eq. (12)}$$

Where,

OTV_{ij} = Total value of net offtake from all types of livestock sold, slaughtered, given out and died per j^{th} household per year.

$NLOT_{ij}$ = Number of livestock offtake (slaughtered, sold and given out) of the i^{th} livestock types per j^{th} household per year.

ND_{ij} = Number of the i^{th} livestock types died per j^{th} household per year.

MV_{ij} = Market value (USD) of the i^{th} livestock type slaughtered, sold, given out and died per j^{th} household.

3. Manure value: In the present study, the methods followed by Haileselassie *et al.* (2006) and Descheemaker *et al.* (2009) whereby each species of livestock converted into TLU and the quantity of manure produced daily per TLU were adopted. Most often estimation of livestock manure production is mentioned as difficult as it varies by livestock age, species, feed types and activities (Haileselassie *et al.*, 2006). The quantity of total manure DM produced per year per household and its nutrient composition were calculated in relation to the size of annual average TLU holdings (Lupwayi *et al.*, 2000; Haileselassie *et al.*, 2005), which was calculated based on the number of animals at the beginning and end of the study period. Manure production was calculated using dry weight productivity of 3.3 kg day⁻¹ per TLU for cattle and 2.4 kg day⁻¹ per TLU for equines and small ruminants (Haileselassie *et al.*, 2005). The amounts of nitrogen (N), phosphorus (P) and potassium (K) nutrients of the manure were estimated based on the average contents of 18.3 g N/kg, 4.5 g P/kg and 21.3 g K/kg on dry weight basis, the compositions determined for livestock manure in the central highlands of Ethiopia (Lupwayi *et al.*, 2000). Monetary equivalence of manure to inorganic fertilizers was extrapolated from the nutrient contents and the local prices of Urea and diammonium phosphate (DAP), during the study period. The average NPK contents (%) of Urea and DAP, the most commonly imported and used inorganic fertilizers in Ethiopia are 46-0-0 and 18-46-0, respectively (Admasu, 2009).

Total manure production per year = TLU * (kg manure per day/TLU * 365 days)

$$TMV_{ji} = \sum_{i=1}^n [(MTLU_{ji} * N_i * MPN) + (MTLU_{ji} * P_i * MPP) + (MTLU_{ji} * K_i * MPK)] \dots\dots\dots\text{eq. (13)}$$

Where,

TMV_{ji} = Total manure value (USD) from all livestock species aggregated into ith TLU per jth household per year.

MTLU_{ji} = Total manure produced on dry weight basis (kg) from the ith livestock species TLU per jth household per year.

N_i = Nitrogen content (kg) per kg of manure on dry weight of ith livestock species.

P_i = Phosphorus content (kg) per kg of manure on dry weight of ith livestock species.

K_i = Potassium content (kg) per kg of manure on dry weight of ith livestock species.

MPN = market price of N per kg (USD) in the area during the study period.

MPP = market price of P per kg (USD) in the area during the study period.

MPK = market price of K per kg (USD) in the area during the study period.

4. Value of traction services: The traction services from livestock considered in this study were ploughing, threshing and transportation. The contribution of different types of livestock to the annual beneficial outputs gained by farm households through traction services were estimated based on the types and amount of the various services delivered on farm and the renting price when animals are hired and additional value has been claimed. Aggregated value for the traction services of livestock was calculated based on the number of oxen used and frequency of cropland cultivation for crop types grown from first ploughing to sowing, the number of animals used for threshing and use of equines for transportation of agricultural produce, human and other commodities. The number of days per year animals utilized for different services (such as ploughing, threshing and transportation and the local price for hiring (converted to USD) of different classes of livestock for the respective services were considered to estimate the value of such services. This was estimated using the following equation:

$$VLS_{ji} = \sum_{i=1}^n (NL_{ji} * TD_{ji} * MV_{ji}) \dots\dots\dots \text{eq. (14)}$$

Where,

VLS_{ji} = The total value of traction services delivered from all livestock types per year per j^{th} household.

NL_{ji} = Number of the i^{th} livestock type performed traction services per year per j^{th} household.

TD_{ji} = Total number of days per year the i^{th} livestock type performed traction services per j^{th} household.

MV_{ji} = Market hiring value per day (USD) of the i^{th} livestock type performed traction services per j^{th} household.

3.4.6. Estimation of water productivity

Water productivities of feed and livestock were estimated based on the water productivity accounting principles (Peden *et al.*, 2003) by taking the volume of water

depleted to produce such different outputs as an input and quantities or values of feeds dry matter yield and livestock outputs and services as an output respectively, *i.e.*

$$\text{Water Productivity} = \frac{\text{Agricultural Outputs}}{\text{Water Use}} \dots \text{eq. (15)}$$

Livestock feed water productivity. The physical water productivity of livestock feed is determined as a ratio of dry matter yield to water depleted to produce feed (van Breugel *et al.*, 2010; Hailelassie *et al.*, 2011). The model is specified as:

$$\text{FWP}_j = \frac{\sum_{j=1}^n \text{DM}_j}{\sum_{j=1}^n \text{WD}_j} \dots \text{eq. (16)}$$

Where, j denotes a unit of observation at the j^{th} household, FWP is livestock feed physical water productivity (kg/m^3), DM_j is quantity of dry matter (kg) of j^{th} feed type (crop residues, grazing, total), WD_j is the amount of water evapotranspired (m^3) to produce the j^{th} livestock feed type.

Depleted water for livestock feed production is computed as:

$$\sum_{j=1}^n \text{WD}_j = \sum_{j=1}^n K_c * \text{ET}_0(G_j) + \sum_{j=1}^n K_c * \text{ET}_0(\beta_j) \dots \text{eq. (17)}$$

Where, j denotes a unit of observation at the j^{th} household, WD_j is the volume of water evapotranspired (m^3) to produce the j^{th} feed type (crop residues and grazing), K_c is coefficients of crop type or grazing land type j , ET_0 is reference evapotranspiration, G_j is area of grazing land type j from where the livestock feed is collected, β_j is area of cropland covered by crop type j from where the livestock feed is sourced.

Livestock water productivity. Livestock water productivity is calculated as an index that relates the net annual livestock beneficial outputs (products and services) to the water depleted for livestock feed production (Peden *et al.*, 2007). The model is specified as:

$$\text{LWP}_j = \frac{\sum_{j=1}^n (\text{O}_j * \text{P}_j + \text{S}_j * \text{P}_j)}{\sum_{j=1}^n \text{WD}_j} \dots \text{eq. (18)}$$

Where, j denotes a unit of observation at the j^{th} household, LWP is livestock water productivity (USD/m^3), O_j is the quantity of j^{th} livestock product (milk, offtake, manure), S_j is service type (ploughing, threshing, transportation), P_j is market price (USD) of the j^{th} product or service type, WD_j is the amount of water evapotranspired (m^3) to produce the j^{th} feed type (crop residues and grazing).

3.5. Statistical Analysis

Means, standard deviations and percentages (frequencies) were used to describe variables observed across farmers stratified into wealth groups. A one-way analysis of variance (ANOVA) was used to determine whether the means of dependent variables observed (such as farm resource holdings, values of livestock outputs and services, volume of depleted water, water productivity indices, harvested grain yields, feed supply, demand and balance) are statistically same or not between wealth groups of farmers. Data complied with the assumptions of ANOVA when checked for normality and homogeneity of variance. The one-way ANOVA model is given by:

$$Y_{ij} = \mu_i + F_i + \epsilon_{ij} \quad \dots\dots\dots \text{eq. (19)}$$

Where, Y_{ij} is the j^{th} observation in the i^{th} wealth group, μ_i is the common effect for the whole wealth group, F_i is the effect of the i^{th} wealth group and ϵ_{ij} is the random error associated with the j^{th} observation in the i^{th} wealth group assumed to be normally and independently distributed, with mean zero and variance $\sigma^2\epsilon$, i designates the wealth group, and j denotes a specific observation. The tests were done at 95% level of confidence ($\alpha = 0.05$). Tukeys' HSD mean comparison procedure was used to test mean differences. Pearson's correlation analysis is employed to evaluate the relationship between the proportion of CR in livestock feed supply and FWP and LWP. The statistical analyses were carried out with SPSS 23.0 (IBM Corp. Released, 2015).

Rank indices were calculated to provide the overall priority of farmers on the purposes of keeping livestock species and production constraints in the mixed crop-livestock system. The purpose or constraint with the highest rank index value corresponds to the highest priority, and the rest follow in order of importance. Formula used by Kosgey *et al.* (2008) was adopted to calculate the indices.

$$\text{Index} = \frac{\sum \left[\begin{array}{l} (r * \text{number of HH in rank first}) + (r-1) * \text{number of HH in rank second} + \\ (r-2) * \text{number of HH in rank third} + \dots + 1 * \text{number of HH in rank last} \end{array} \right]}{\sum \left[\begin{array}{l} (r * \text{number of HH in rank first} + (r-1) * \text{number of HH in rank second} + \\ (r-2) * \text{number of HH in rank third} + \dots + 1 * \text{number of HH in rank last} \end{array} \right]} \quad \dots \text{eq. (20)}$$

Where, HH = respondent households, r = rank value given for the least important factor and 1 is given to the most important factor in the list of enumerated factors.

Furthermore, linear regression models were run using STATA software for windows version 13.1 (StataCorp, 2013) to test the hypothesized relationships of FWP and LWP with the range of explanatory variables defined below. The linear regression model is specified as:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \beta_4 x_{4i} + \beta_5 x_{5i} + \beta_6 x_{6i} + \beta_7 x_{7i} + \beta_8 x_{8i} + \beta_9 x_{9i} + \beta_{10} x_{10i} + \beta_{11} x_{11i} + \beta_{12} x_{12i} + e_i \dots\dots\dots \text{eq. (21)}$$

Where, Y_i is the i^{th} observation of the response variable (feed water productivity or livestock water productivity), β_0 is the intercept, β_1 to β_{12} are regression coefficients of the explanatory variables X_1 to X_{12} : X_1 is farming experience of household head in years, X_2 is education level of household head in completed grade years, X_3 is age dependency ratio (dimensionless), X_4 is family labour force (adult equivalents), X_5 is cultivated cropland (ha), X_6 is aggregated value of crop grains harvested ('000 USD/ha), X_7 is livestock holdings (TLU), X_8 is membership of dairy cooperatives (0 = no; 1 = yes), X_9 is access to credit (0 = no; 1 = yes), X_{10} is access to training (0 = no; 1 = yes), X_{11} and X_{12} are wealth status indicator variables, where $X_{11i} = 1$, if the i^{th} person is in the medium wealth group, 0 otherwise, and $X_{12i} = 1$, if the i^{th} person is in the better-off wealth status group, 0 otherwise; the poor wealth group which takes the value of zero in both dummies is used as reference group and e_i is the random error term $N(0, \sigma^2)$.

3.5.1. Description of explanatory variables and assumptions of their influence on feed and livestock water productivity

Various investigators asserted that farm productivity and resource use efficiency have been influenced by several factors associated with farmers demographic, economic and institutional factors. To select explanatory variables that influence livestock and feed water productivity previous reports and theoretical grounds has been assessed. The demographic factors included were family labour force, age dependency ratio, household head farming experience and formal education level. The economic factors included were the size of cropland cultivated, aggregated value of crop gains harvested, the size of livestock ownership. The institutional factors included were membership of cooperatives, access to credit and of training. Wealth status of farmers were also

included to account for other economic variables which may not be explained by land and livestock holdings and crop produced (Kebebe *et al.*, 2015). The hypothesized influences of explanatory variables included in the present analysis on feed and livestock water productivity are described as follows:

Farming experience (years): Accumulated knowledge and finest skills of farming practices could be achieved through own experiences. While more farming experience is likely to be gained with age, old age may impair the physical strength for application of learned practices on the farming operations, such as labor-intensive rainwater management practices (Kebebe *et al.*, 2015). Up until physical weakness of the farmer with age, gained farming experience is expected to influence the livestock and feed water productivity positively. On the other hand, the farmer simply may become too old without acquaintance of practical farming experiences to improve productivity. These scenarios make unclear the influence farming experience on feed and livestock water productivity.

Education level (grade completed in years): Advances in education level is anticipated to enhance the uptake of new knowledge, improved technologies and best practices (Asfaw and Admassie, 2004; Knowler and Bradshaw, 2007). The higher the level of education of the household head, the more positive influence on the decisions and managements undertaken to increase the productivity of crop, livestock and feed resources and reap the benefits. Likewise, it is believed that water productivity of livestock and their feed would also assume the same trends with increased farm productivity. It is assumed that higher level of grade completed in formal education will have positive influence on livestock and feed water productivity.

Age dependency ratio (dimensionless): This ratio defines the proportion of productively active (15-64 years) to non-active (younger than 15 and older than 64 years) individual members in the household (Barrett *et al.*, 2010). The presence of more dependents in the household is meant the lesser would be the contribution of family members to the farming operations (Sandford *et al.*, 2008). Among other influencing factors, an increase in farm productivity at household is constrained by the availability of sufficient household members in the productive age category (Qasim, 2012;

Sinnathurai *et al.*, 2013). It is assumed that high age dependency ratio, which indicates low proportions of productively active members is negatively associated with the livestock and feed water productivity.

Farm labour force (in adult equivalents): Family size determines the labour force of the households, which are important in all agricultural activities. However, this accounts for the potential contribution of household members to the farm labour force with respect to their age and gender (Hailelassie *et al.*, 2009). Household members of different age and sex group are eligible to contribute labour based on their potential, labour division and the corresponding roles they could play in the farming activities. Whereas lack of sufficient labour potentially compromise the performance of the farm family to increase the agricultural productivity of both livestock and crop. It is assumed that availability of more household members in the productive labour force is positively associated with livestock and feed water productivity (Kebebe *et al.*, 2015).

Land holding (ha): Land holding was among the key resources ownership of farmers that stratify them into different wealth status. Possession of land gives farmers the right and confidence to develop and make it more productive for the intended use. On the other hand, availability of land permits the production of more crop residues from food-feed crop production and other types of feed biomass (Hailelassie *et al.*, 2009; Kebebe *et al.*, 2015). Feed sourced on-farm from larger size of land ownership would enable farmers to supply sufficient amount of feed to meet the requirements of livestock which would eventually improve the productivity, health and offtake of livestock. Large size of cropland cultivated is expected to positively influence both the livestock and feed water productivity as there would be high animal labour contribution for cropland cultivation.

Value for crop grains produced on-farm (in '000 USD): Yield of different crop residues recovered for livestock feeding is strongly related to the food-feed crops grain yields as it is influenced by the harvest index and the water used for crop production (Descheemaeker *et al.*, 2010; van Breugel *et al.*, 2010; Blümmel *et al.*, 2014). Crop residues have a considerable share of livestock feed source in the mixed crop-livestock farming systems. Improved water productivity of a crop has a carryover effect on the

water productivity of its residue and other derived products. Hence greater crop biomass harvest is expected to have a positive influence on livestock and feed water productivity. To accommodate the influence of different crop types and cropping pattern between farmer groups aggregated value of grain yields for all crops types harvested is used in the computation (Kebebe *et al.*, 2015).

Livestock holdings (TLU): In mixed crop-livestock farming system, livestock provide multiple benefits to support livelihoods. They are sources of power and fertilizer for crop production, supply human food, transportation and cash income apart from serving as live-bank and wealth accumulation (Behnke, 2010; Behnke and Fitaweke, 2011). Higher benefits from livestock is achieved from their provisions of manure, traction power, offtake and milk production (Hailelassie *et al.*, 2009; Peden *et al.*, 2009; Amede *et al.*, 2011). Moreover, the role of oxen availability played in the timely adequate cropland preparation could contribute to increase food-feed crop production. Hence, large size of livestock holdings offers the premises to fetch more beneficial outputs for the given feed and water inputs. Thus, livestock holding size is expected to positively influence livestock and feed water productivity.

Membership of dairy cooperatives (indicator variable 0 = no, 1 = yes): Membership of agricultural cooperative has a positive impact on technology adoption (Abebaw and Haile, 2013). Cooperatives are involved in the delivery of different services to their members. These services include, among others, supply of improved farm inputs (e.g. fertilizers, improved seeds, pesticides), provision of loans and marketing of members' farm outputs (Abebaw and Haile, 2013). In the study area, farmers' cooperatives deliver services by facilitating product sale and input supply to their members. Dairy cooperatives for instance, collect, process and sale milk and milk products on behalf of their members, which helped them to ease market problems. Farmers' cooperatives also served to purchase and supply agricultural inputs in bulk and take advantage of the discount for more volume sale and transportation and bring down the cost of inputs for the members. Hence, being a member of dairy cooperatives is expected to positively influence livestock and feed water productivity.

Access to credit (indicator variable 0 = no, 1 = yes): Access to credit encourage farmers to purchase and use improved agricultural technologies (Foltz, 2004; Kassie *et al.*, 2009) such as seeds, fertilizers, pesticides, crossbred animals, artificial inseminations, veterinary services, feeds, and human and animal labour when there is a need. Those are helpful to promote the productivity of both crop and livestock and appreciate the benefits. Getting credit in time of need is expected to influence livestock and feed water productivity positively.

Access to training (indicator variable 0 = no, 1 = yes): Agricultural related training would help to advance the knowhow of farmers and enhance the use of improved farming technologies and inputs to increase the productivity of livestock and their feed resources including crop production. Trained farmers are expected to uptake and implement productive technologies and practices better than their counterparts (Abebaw and Haile, 2013). Eventually it was assumed that farmers with training are more likely to have increase livestock and feed water productivity.

Wealth group: This was included as one of the explanatory variables in the regression to control for the effects which may not be accounted by major farm resources such as land and livestock holdings which determined the wealth status of farmers (Kebebe *et al.*, 2015). Two indicator variables were created as WG_1 and WG_2 , where, $WG_{1i} = 1$, if the i^{th} person is in the medium wealth group, 0 otherwise; and $WG_{2i} = 1$, if the i^{th} person is in the better-off wealth group, 0 otherwise; the poor wealth group, which takes the value of zero in both dummies was used as the reference category.

4. RESULTS

4.1. Household Demographic and Farm Resources Characteristics

Descriptions and comparisons of farm household demographic and socio-economic characteristics including key farm resources holdings across wealth groups of farmers are presented in the following subsections.

4.1.1. *Demographic characteristics*

Descriptions of farm household heads (respondents) characteristics with respect to their wealth groups are summarized in Table 5. Most of the households in the poor and all of in the medium and better-off wealth groups of farmers were headed by males. The highest proportion of respondents in all groups were married, however, relatively higher proportions of divorced and widowed household heads were in the poorer than the wealthier households. Higher proportion of household heads in the poor wealth group was not following formal education. On the other hand, the level of literacy due to both the formal and informal learning was higher in the wealthier than the poorer wealth group of farmers. However, irrespective of farmers' wealth status most of the household heads were in the elementary grade level of formal education. The average years of schooling of the poor household heads were below the overall average, but it was higher for the wealthier group of farmers. Mean age of household heads were almost similar among the poor and medium, but a little higher for better-off wealth groups.

Table 5. Characteristics of household heads across wealth groups of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Household head characteristics	Wealth group			Total (n = 159)
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	
Sex/Gender (%)				
Male	92.0	100	100	97.5
Female	8.0	0.0	0.0	2.5
Marital status (%)				
Not married	0.0	3.4	0.0	1.3
Married	74.0	89.7	100	88.1
Divorced	18.0	3.5	0.0	6.8
Widowed	8.0	3.4	0.0	3.8
Education level (%)				
Illiterate	24.0	6.9	7.8	12.6
Read and Write ¹	12.0	36.2	47.1	32.1
Elementary ²	64.0	48.3	45.1	52.2
Secondary and above ³	0.0	8.6	0.0	3.1
Average years of education (years)	2.3(2.6)	3.0(3.4)	2.8(3.4)	2.7(3.1)
Mean age (years)	45.0(1.6)	45.3(1.4)	48.8(1.4)	46.3(0.9)

n = number of respondents, ¹informal education, ²grade 1-8 completed, ³grade 9 and above, figures in parenthesis are standard deviation.

Comparisons of the household heads farming experience, family size, family labour force and age dependency ratio (ADR) of households are presented in Table 6. The farming experience of household heads was significantly different across wealth status exhibiting higher value for the better-off than other groups. The average family sizes of the better-off and medium wealth group households were somehow comparable, but for both wealth groups it was significantly higher than the poor farmers. The farm family labour force followed the same trend of trajectory as that of the average number of family sizes. Poor farmers had significantly less farm family labour force available to support their farm operations than other groups. However, the age dependency ratio was significantly higher in the poor than both the medium and better-off wealth groups.

Table 6. Means and standard errors of household heads farming experience, family size, family labour force and age dependency ratio across wealth groups of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Characteristics of household head and family members	Wealth group			Total (n = 159)	
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)		
Farming experience (years)	28.02(1.77) ^{ab}	28.38(1.30) ^b	33.82(1.45) ^c	30.01(0.89)	*
Average family size (numbers)	4.86(0.28) ^a	6.22(0.19) ^{bc}	6.41(0.22) ^c	5.86(0.14)	***
Male	2.44(0.17) ^a	3.28(0.18) ^c	3.27(0.15) ^{bc}	3.01(0.10)	**
Female	2.42(0.19) ^a	2.95(0.19) ^{abc}	3.14(0.19) ^c	2.84(0.11)	*
Farm labour force (in adult equivalents)	2.45(0.17) ^a	3.52(0.15) ^{bc}	3.76(0.16) ^c	3.26(0.10)	***
Male	1.37(0.10) ^a	2.06(0.12) ^{bc}	2.17(0.12) ^c	1.88(0.07)	***
Female	1.08(0.09) ^a	1.46(0.11) ^{bc}	1.59(0.11) ^c	1.38(0.06)	**
ADR	0.99(0.09) ^c	0.71(0.07) ^{ab}	0.60(0.07) ^b	0.76(0.05)	**

ADR = age dependency ratio (it is the dependency ratio that relates the number of children (0-14 years old) and older persons (65 years or over) to the working-age population (15 to 64 years old).

n = number of respondents.

Values in parentheses indicate standard errors.

^{a,b,c} Means in a row with different superscripts differ significantly at * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$ probability levels.

The characteristics features of household family members are presented in Table 7. Irrespective of farmers' wealth status, males slightly dominate the overall male to female proportion. In terms of age category, younger people less than 15 years of age were more in the poor family members followed by medium and better-off wealth groups. The productively inactive proportions of the family (members aged under 15 and above 64 years) were more in the poor followed by medium and better-off. Consequently, the observed proportion of productively active family members aged between 15 and 64 years across wealth groups were vice versa. Persons above 65 years of age were the least proportions, even though more of them were observed in the medium followed by poor and better-off wealth group of farmers. Regardless of

farmers' wealth status, male family members contributed more than females to the farm labour force.

Table 7. Proportions of the farm family members characteristics across wealth groups of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Characteristics of family members	Wealth group			Total (n = 159)
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	
Male to female proportion (%)				
Males	50.2	52.7	51.0	51.4
Females	49.8	47.4	49.0	48.5
Age category (%)				
Less than 15 years	43.6	33.2	31.8	35.4
15-64 years	53.9	63.4	67.0	62.2
65 years and above	2.5	3.3	1.2	2.4
Farm family labour force contribution (%)				
Males	55.9	58.5	57.7	57.7
Females	44.1	41.5	42.3	42.3
Education level of family members (%)				
Under school age ⁴	26.0	20.8	16.5	20.6
Illiterate	16.0	12.2	6.7	11.3
Read and write ¹	5.8	10.5	14.1	10.5
Elementary ²	47.3	45.4	48.9	47.2
Secondary ³	4.9	11.1	13.8	10.4

n = number of respondents, ¹informal education, ²grade 1-8 completed, ³grade 9 and above, ⁴ under age to school in formal education (less than 7 years of age).

The proportion of children under age to formal education in school for most of the families (less than 7 years of age was considered) and the level of illiteracy were higher among household members of the poor than the wealthier groups. Besides, the situation showed a declining trend along with improvement in the wealth status of farmers. On the other hand, the proportion of literate household members in the family were more in the wealthier than the poorer farmers, including the informal learning that enabled family members to read and write (such as religious and adult education). However,

among literate categories most of the family members were attending the elementary level of formal education, irrespective of the wealth status of farmers. Moreover, relatively higher proportions of the wealthier family members were in the secondary level of education than the poorer groups.

4.1.2. Land and livestock resource holdings

Comparisons of the key farm resource holdings showed significant differences between farmer wealth groups (Table 8). The magnitude of livestock and land holdings matched the wealth status gradient of farmers, exhibiting a decreasing trend from better-off to poor wealth groups. The total livestock holding aggregated in terms of TLU was significantly different across wealth groups, being higher in the better-off followed by medium and poor farmers, respectively.

Table 8. Means and standard errors of farm resources holding across wealth groups of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Farm resources	Wealth group			Total (n = 159)	
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)		
Livestock holding (TLU)	5.10(0.17) ^a	8.20(0.27) ^b	12.01(0.33) ^c	8.45(0.27)	***
Own cropland holding (ha)	1.07(0.08) ^a	1.30(0.07) ^{ab}	1.77(0.08) ^c	1.38(0.05)	***
Fallow land (ha)	0.06(0.02) ^a	0.09(0.03) ^{ab}	0.29(0.04) ^c	0.15(0.02)	***
Cultivated and grazing lands (ha)	2.32(0.06) ^a	3.22(0.10) ^b	4.10(0.09) ^c	3.22(0.08)	***
Cultivated cropland (ha)	1.60(0.06) ^a	2.19(0.07) ^b	2.51(0.08) ^c	2.10(0.05)	***
Grazing land (ha)	0.72(0.03) ^a	1.03(0.05) ^b	1.59(0.06) ^c	1.11(0.04)	***
Private (ha)	0.37(0.03) ^b	0.46(0.05) ^{ab}	0.75(0.05) ^c	0.52(0.03)	***
Communal (ha)	0.36(0.01) ^a	0.57(0.02) ^b	0.84(0.02) ^c	0.59(0.02)	***

n = number of respondents; values in parenthesis are standard errors.

TLU = tropical livestock unit. 1 TLU = 250 kg live weight.

^{a,b,c} Means in a row with different superscripts differ significantly at *** $P < 0.001$ probability level.

Cropland ownership (righteously entitled) was significantly higher for better-off than both medium and poor farmer groups. With similar variation as cropland ownership, relatively more cropland was left fallowed by wealthier farmers than the poorer during the current cropping season. Area of cultivated cropland and grazing land were significantly different across wealth groups. The size of cultivated cropland that includes cropland righteously entitled and cropland temporarily acquired based on local lease agreements between farmers was falling from better-off to poor wealth status. Area of GL that included privately owned and communal land was found to follow the pattern of wealth status. Eventually, the total land holdings reflected the image of farmers' wealth status consistently being higher for the wealthier.

4.1.3. Access to agricultural training and credit services

The proportion of respondent farmers who were beneficiaries of training and credit services provisions are illustrated in Figure 6. The proportion of farmers who got agricultural trainings related to livestock, forage and crop production within the year were more than from those who received credit services, irrespective of their wealth status. Regarding the service provisions among wealth group of farmers the wealthier were more at advantage than the poorer in terms of the proportion of farmers who received both training and credit service provisions.

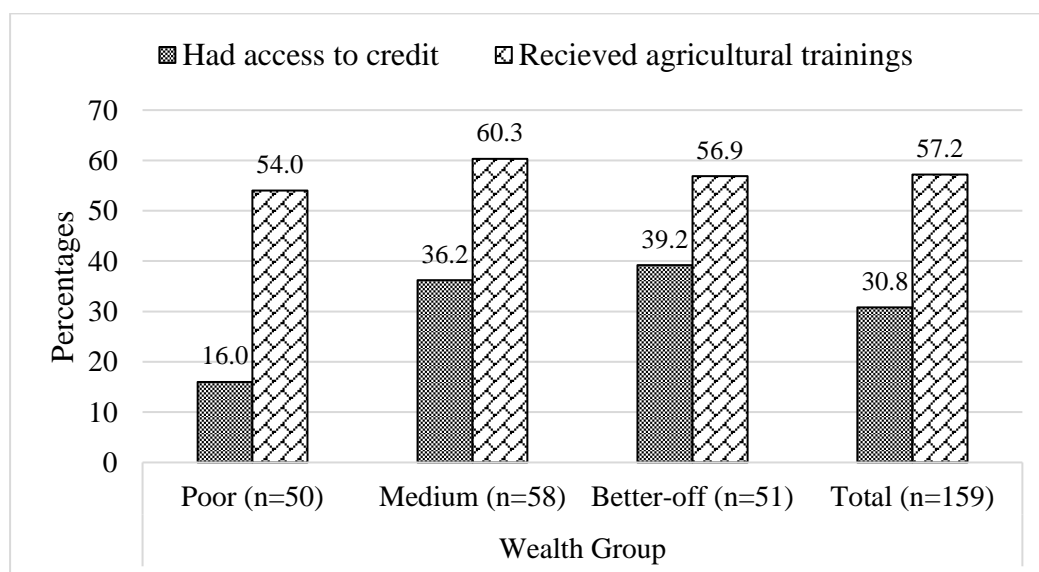


Figure 6. Proportion of farmers who had provisions of agricultural training and credit services among wealth group of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

4.2. Food-Feed Crops Production

4.2.1. Cropland allocation and grain yield

Descriptions on cropland allocation and the proportion of growers who cultivated the main crops which are the staple human food and major sources of CR for feeding livestock are presented in Table 9. The same table also presents the comparisons of mean grain yields (ton) of the major crops cultivated per household between farmer wealth groups. The trends in the size of plot of cropland allocation to grow a particular crop type and proportion of farmers who have grown the crop during the main cropping season were similar irrespective of their wealth status. Currently, barely was the most extensively grown food-feed crop followed by faba bean, wheat and field pea, respectively. This is manifested by the frequent allocation of the largest sized plots of cropland for barley growing than for the other crop types and it was cropped by every farmer regardless of wealth status. The quantity of barley and wheat grain yield harvested per household was significantly higher for better-off than both medium and poor farmer wealth groups. The grain yield of faba bean harvested per household by the better-off and medium wealth groups was significantly higher than the poor. But, no significant difference in field pea grain harvested was observed among the wealth groups. However, the overall volume of grain yield harvested per household from individual crop followed the plots of land allocated for a particular crop type.

Table 9. Area of plots of cropland allocated, proportion of farmers who grow the specific food-feed crop types and grain yields per household in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Crop type, area cultivated, grain yield and proportion of growers	Wealth group			Total (n = 159)
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	
Land allocated (ha)				
Barley	0.86(0.31)	1.11(0.56)	1.17(0.36)	1.05(0.45)
Wheat	0.30(0.21)	0.34(0.18)	0.53(0.25)	0.39(0.23)
Faba bean	0.38(0.17)	0.64(0.31)	0.69(0.42)	0.57(0.34)
Field pea	0.07(0.14)	0.10(0.14)	0.12(0.14)	0.10(0.14)
Farmers who grow (%)				
Barley	100.0	100.0	100.0	100.0
Wheat	78.0	93.1	100.0	90.6
Faba bean	100.0	100.0	92.2	97.5
Field pea	20.0	43.1	49.0	37.7
Grain yield (t/hh)				
Barley	1.71(0.69) ^a	2.08(0.97) ^{ab}	2.51(0.89) ^c	2.10(0.92) ***
Wheat	0.53(0.43) ^a	0.68(0.36) ^{ab}	1.18(0.74) ^c	0.79(0.60) ***
Faba bean	0.60(0.31) ^a	0.88(0.45) ^{bc}	0.97(0.52) ^c	0.82(0.46) ***
Field pea	0.10(0.21)	0.16(0.20)	0.16(0.19)	0.14(0.20) <i>ns</i>

n = number of respondents, ha = hectare, t = ton, hh = household.

Values in parentheses indicate standard deviations in the descriptions of land allocated and standard errors in the mean comparisons of grain yields.

^{a,b,c} Means in a row with different superscripts differ significantly at *** $P < 0.001$ probability level, *ns* = not significant.

The cropland allocation to the currently cultivated crops was proportionally higher for cereals than pulses, exhibiting similar trend across wealth group of farmers. In all farms regardless of wealth status, over 68% of the cropland cultivated during the main cropping season was covered with cereals (Figure 7).

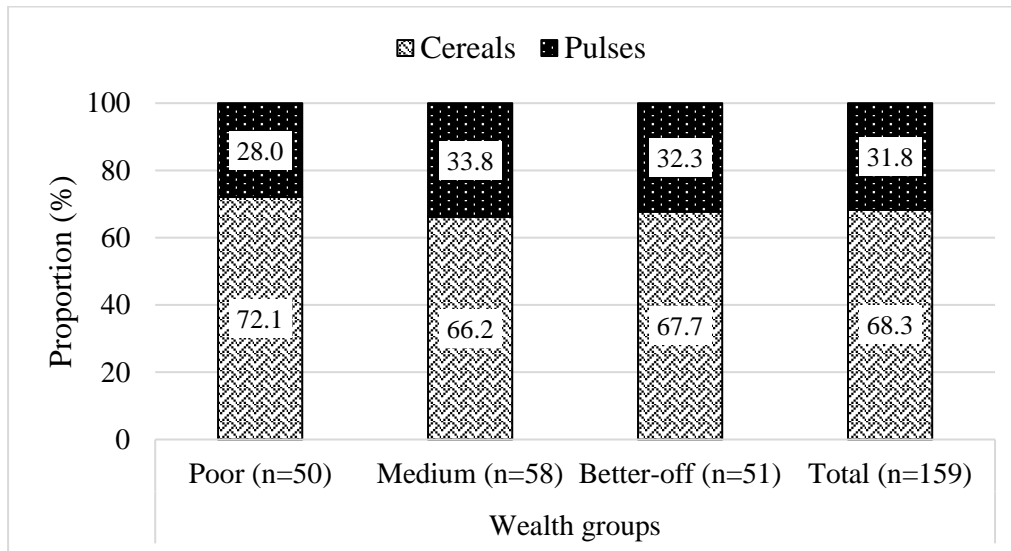


Figure 7. Proportion of cropland plot allocated to cereals and pulses among wealth group of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Significant variations in the productivity of barley and wheat per hectare were observed across wealth group of farmers (Table 10). Barley grain yield per hectare was significantly different between the medium and better-off, but the poor group had no significant variation between the other wealth groups. The poor farmers obtained significantly lower wheat grain yield per hectare than the other wealthier groups. The productivity per hectare of both pulses did not show significantly different variation across wealth group of farmers.

Table 10. Grain productivity of crop types grown across wealth groups of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Grain yield (t/ha)	Wealth group			Total (n = 159)	
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)		
Barley	2.01(0.07) ^{abc}	1.92(0.05) ^a	2.14(0.05) ^c	2.02(0.03)	*
Wheat	1.69(0.06) ^a	2.07(0.08) ^{bc}	2.19(0.09) ^c	2.01(0.05)	***
Faba bean	1.59(0.07)	1.46(0.07)	1.58(0.08)	1.54(0.04)	<i>ns</i>
Field pea	1.54(0.04)	1.65(0.09)	1.42(0.05)	1.54(0.05)	<i>ns</i>

ha = hectare, t = ton.

Values in parentheses indicate standard errors.

^{a,b,c} Means in a row with different superscripts differ significantly at * $P < 0.05$ and *** $P < 0.001$ probability levels, *ns* = not significant.

4.2.2. Cropping calendar

The seasonal crop farming activities performed for the major staple food-feed crops (cereals and pulses) produced in the study area during the main cropping season (*meher*) are illustrated in Figure 8. Generally, cereals (barley and wheat) had long periods of farming operations than pulses (faba bean and field pea). Farmers performed repeated ploughing of the cropland before sowing. In most of the cases the land preparation with repeated ploughing took place between the months of March and June, which include the dry and short rainy period. The number of tillage frequencies and the interval between the ploughings varied depending on the soil type, roughness of the field and the crop type which the farmers propose to plant during the main cropping season. Cropland proposed for cereal crops (barley and wheat) growing ploughed more repeatedly and eventually the length of ploughing period was more extended than for pulses (faba bean and field pea). After preparing the cropland, the sowing period for the main cropping season (*meher*) lasts from end of May to mid-August; weeding lasts from mid-August to mid-October and harvesting and threshing lasts from mid-November to mid-February.

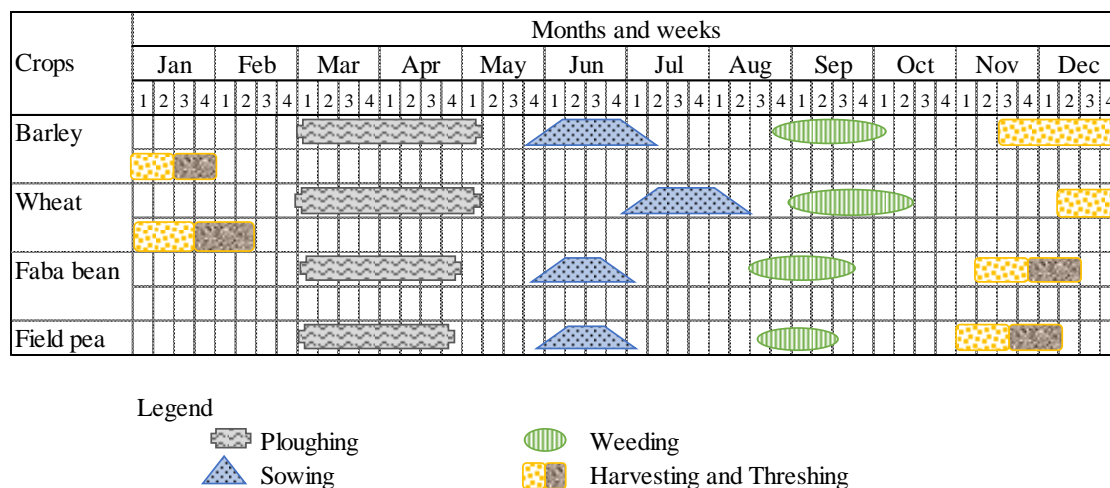


Figure 8. Cropping calendar of major food-feed crops for the main cropping season (*meher*) in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Regarding specific crop types, barley was sown from end of May to early July, weeded from end of August to September and harvested from mid-November to end of January. Wheat was sown from early July to mid-August, weeded from September to early

October and harvested from December to mid-February. Faba bean was sown from end of May to end of June, weeded from mid-August to mid-September and harvested from mid-November to mid-December. Field pea almost follow the pattern of faba bean. The harvesting and threshing periods of the crops sometimes were overlapped, as early sown and/or maturing crops were harvested and threshed for immediate household needs.

4.2.3. Frequency of tillage for cropland preparation

Frequency of cropland cultivation performed for different crop types grown during the main cropping season among wealth group of farmers is presented in Table 11. The number of tillage repeats (plough passes) for the entire period of cropland preparation from first ploughing to sowing for the crop types grown was significantly different across wealth group of farmers. For both cereal crops (barley and wheat), cropland tillage repeats were higher among the wealthier than the poorer farmers. Even though significant variations were observed between farmer wealth groups on the cropland tillage repeats for pulses (faba bean and field pea) the magnitude did not exhibit the trend of farmers wealth status. However, the gaps observed between wealth groups of farmers in the variations of tillage frequency for pulses were narrower than for cereals.

Table 11. Mean number of cropland tillage repeats (number of passes) for crop types grown during the main cropping season (*meher*) in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Crop type grown	Wealth group			Total (n = 159)	
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)		
Barley	2.78(0.06) ^a	3.76(0.07) ^b	4.16(0.06) ^c	3.58(0.06)	***
Wheat	2.78(0.07) ^a	3.43(0.09) ^b	4.25(0.08) ^c	3.49(0.07)	***
Faba bean	2.38(0.07) ^{bc}	2.43(0.07) ^c	2.12(0.05) ^a	2.31(0.04)	**
Field pea	2.60(0.16) ^c	2.20(0.09) ^{ab}	2.00(0.00) ^a	2.20(0.06)	***
Average for cereals	2.78(0.04) ^a	3.59(0.06) ^b	4.21(0.06) ^c	3.53(0.06)	***
Average for pulses	2.38(0.07) ^{bc}	2.38(0.06) ^c	2.10(0.04) ^a	2.29(0.04)	**

n = number of respondents.

Values in parentheses indicate standard errors.

^{a,b,c} Means in a row with different superscripts differ significantly at ** $P < 0.01$ and *** $P < 0.001$ probability levels.

4.2.4. Animal labour use for crop production

The use of animal labour for cropland preparation, crop threshing and transportation of agricultural products and humans during the study period across the wealth group of farmers are presented in Table 12. In this report animal-day refers to one animal average working time for a day. The animal-days calculated for traction services acquired per household per year corresponds to the number of animals used multiplied by the number of days the animals were on a particular duty. According to farmers response, on daily average basis animals worked for 5.50 ± 0.93 (range of 4.00 to 8.00) hours on ploughing, 4.60 ± 0.69 (range of 3.00 to 6.00) hours on threshing and 5.40 ± 1.90 (range of 2.00 to 8.00) hours on transportation. Ploughing was performed by oxen, while threshing was dominantly performed by mixed classes of cattle of different age and sex category except sick, pregnant, calves and lactating animals. Sometimes cattle mixed with equines were used in case when fewer cattle numbers are available on the threshing field. Transportation of agricultural products, human and other commodities were solely the function of equines. The livestock labour use per household computed in terms of animal-days for the different traction duties separately (ploughing, threshing and transportation) and for all traction services in aggregate were significantly different across farmer wealth groups. The wealthier used more animal-days per year than the poorer for ploughing, threshing and transportation services.

Table 12. Mean animal-days (animal labour) use for traction services per household per year in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Activities	Wealth group			Total (n = 159)
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	
Ploughing	67.84(2.67) ^a	117.86(4.84) ^b	143.73(4.9) ^c	110.43(3.5) ***
Threshing	42.50(1.90) ^a	55.62(2.29) ^b	70.12(2.69) ^c	56.14(1.6) ***
Transportation	94.54(15.47) ^a	312.42(23.64) ^b	626.14(27.06) ^c	344.53(21.4) ***
Total	299.4(30.5) ^a	798.3(49.0) ^b	1466.1(57.0) ^c	855.6(46.0) ***

n = number of respondents.

Values in parentheses indicate standard errors.

^{a,b,c} Means in a row with different superscripts differ significantly at *** $P < 0.001$ probability level.

4.3. Livestock Holdings, Structures and Dynamics

Typically, the livestock herds and flocks reared in the study area comprised of cattle, small ruminants (sheep and goats), equines (donkeys, horses and mules) and poultry. The livestock species contribution to the total aggregated livestock ownership (TLU) across wealth group of farmers is demonstrated in Figure 9. Irrespective of farmers wealth status, the contribution of species to the total livestock biomass in all farms was dominated by cattle (56%) followed by equines (23%) and small ruminants (21%). Regarding the wealth groups of farmers, cattle, equines and small ruminants contributed about 59%, 23% and 18% in the poor; 56%, 23% and 21% in the medium; and 53%, 24% and 23% in the better-off aggregated livestock holdings (in terms of TLU) of farmers, respectively.

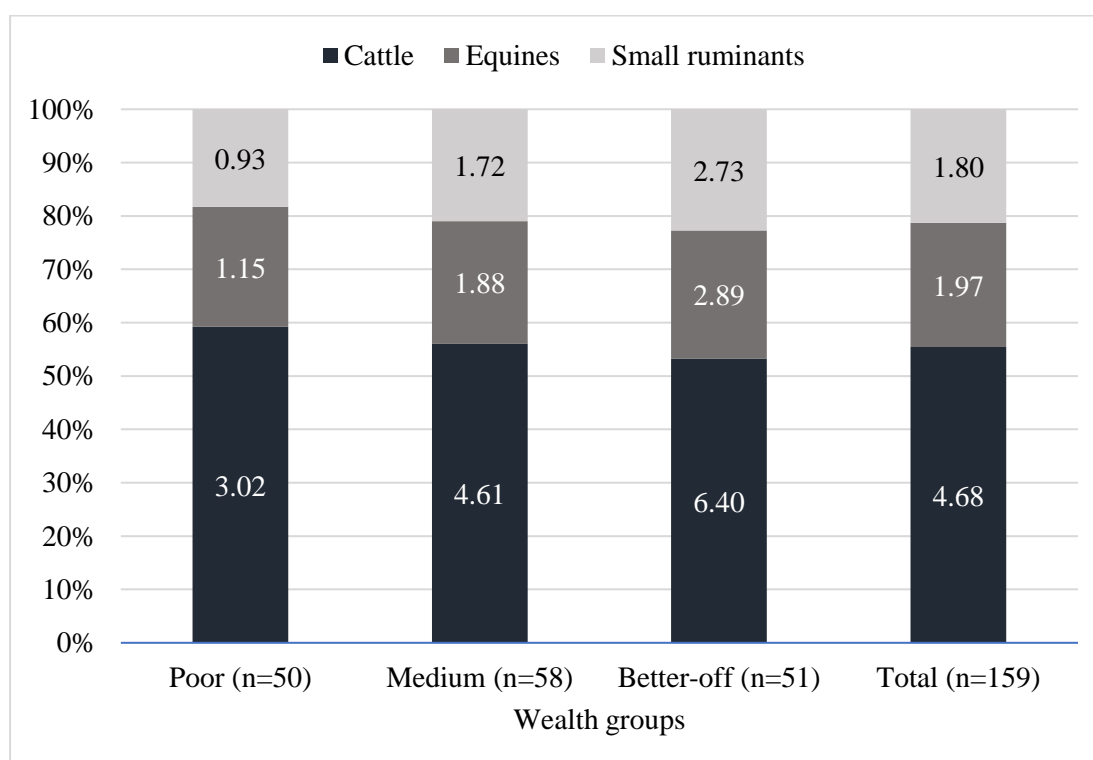


Figure 9. Livestock holdings (TLU, values labelled on the graph) and proportional contribution of species to the total TLU holding among wealth group of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

4.3.1. Livestock holdings and structures

The livestock compositions and herd/flock structures kept across wealth group of farmers are presented in Tables 13 through 15. In terms of numbers the livestock composition kept at household were dominated by small ruminants (64%) followed by cattle (24%) and equines (12%). Even though the actual variations in the number of livestock holdings was evident across wealth group of farmers, the proportion of species composition had almost similar trends. Numerically small ruminants, cattle and equines were mixed at 60%, 28% and 12% in the poor; 64%, 24% and 12% in the medium, and 66%, 22% and 12% in the better-off farmers, respectively.

4.3.1.1. Cattle herd structure

The cattle herd structure across wealth group of farmers is presented in Table 13. Overall the cattle herd structure was dominated by oxen and followed by cows. The trends in the average number of oxen and cows in the cattle herd were similar among wealth group of farmers except in the poor farmers group where the average number of cows was slightly higher than oxen. The third populous class in the cattle herd was calves, which was dominated by male calves regardless of farmers wealth status. Bulls represent the lowest proportion in the better-off and medium wealth status, while it was heifers in the poor farmers group. In the overall cattle herd structure, male animals dominate the females regardless of the farmers' wealth status, which is depicted by the higher male to female ratio across all of the wealth group of farmers. On average for every female there were 1.12 male animals in the cattle herd at all farms regardless of wealth status. However, some variations of male to female ratio in cattle herd structure were observed across wealth groups of farmers. Moreover, when intra-sex ratio of cattle herd, i.e. oxen with other males and cows with other females have been judged at all farms, a shortfall to maintain the current herd structure from home grown replacements were revealed. Overall there were 1.23 oxen for every other male and 1.24 cows for every other female. The shortage of home grown replacements was reflected across wealth group of farmers except the poor, which seemingly had enough young males to replace their oxen, but the poor owned the lowest number of oxen than other wealth groups.

Table 13. Mean number, proportion and ratio of cattle herd structure in the mixed crop-livestock systems of *Debre Berhan* milkshed, central highlands of Ethiopia

Cattle herd structure	Wealth group						Total (n = 159)	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)			
	Mean	%	Mean	%	Mean	%	Mean	%
Total cattle	4.31	100.0	6.59	100.0	9.14	100.0	6.69	100.0
Oxen	0.99	23.0	2.24	34.0	2.57	28.1	1.95	29.2
Cows	1.09	25.3	1.74	26.4	2.40	26.3	1.75	26.1
Heifers	0.51	11.8	0.78	11.9	1.29	14.2	0.86	12.9
Bulls	0.78	18.1	0.63	9.6	0.96	10.5	0.78	11.7
Calves	0.94	21.8	1.19	18.1	1.91	20.9	1.34	20.1
Female	0.31	7.2	0.58	8.8	0.74	8.0	0.54	8.1
Male	0.63	14.6	0.61	9.3	1.18	12.9	0.80	11.9
Total females	1.91	44.3	3.10	47.1	4.43	48.5	3.15	47.2
Total males	2.40	55.7	3.48	52.9	4.71	51.5	3.53	52.8
Male : Female	1.26		1.12		1.06		1.12	
Oxen : Other males	0.70		1.81		1.20		1.23	
Cows : Other females	1.33		1.28		1.18		1.24	

4.3.1.2. *Small ruminants (sheep and goats) flock structure*

Small ruminants flock structure is presented in Table 14. Sheep flock comprised 96% of the small ruminant populations maintained in all the farms, regardless of farmers wealth status. Based on the average numbers of holdings, the proportion of sheep with regards to the wealth group of farmers comprised of 92% in the poor, 95% in the medium and 97% in the better-off farmers. Ewes and does account for the highest proportions of the sheep and goat flocks structure, respectively. The average number of dams in the sheep and goat populations were followed by groups of both sexes in the range of 6-12 months of age. Lambs and kids were the third dominant, while rams, bucks and castrates of both species represent the least proportions. An overall average of breeding male to breeding female ratio of 1 ram for 10.07 ewes (range 1 ram to 8.26 –12.15 ewes) were observed in the sheep flock. In the case of goat flock, the overall average ratio was 1 ram to 9.40 does, ranging up to 16 does per buck.

Table 14. Mean number, proportion and ratio of small ruminants (sheep and goats) flock structure in the mixed crop-livestock systems of *Debre Berhan* milkshed, central highlands of Ethiopia

Flock structure	Wealth group						Total	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		(n = 159)	
	Mean	%	Mean	%	Mean	%	Mean	%
Sheep	8.54	100.0	16.42	100.0	26.55	100.0	17.19	100.0
Ewes	3.55	41.6	7.22	43.9	12.39	46.7	7.72	44.9
Rams	0.43	5.0	0.84	5.1	1.02	3.8	0.77	4.5
Castrates	0.22	2.6	0.44	2.7	0.71	2.7	0.46	2.7
6-12 months	2.64	30.9	4.39	26.7	6.49	24.4	4.51	26.2
Lambs	1.70	19.9	3.54	21.6	5.94	22.4	3.73	21.7
Ram : Ewe	0.12		0.12		0.08		0.10	
Goats	0.76	100.0	0.82	100.0	0.72	100.0	0.77	100.0
Does	0.38	50.0	0.28	33.7	0.24	32.9	0.30	38.5
Bucks	0.00	0.0	0.02	2.1	0.08	11.0	0.03	4.1
Castrates	0.10	13.2	0.02	2.1	0.02	2.7	0.04	5.7
6-12 months	0.18	23.7	0.33	40.0	0.19	26.0	0.24	30.7
Kids	0.10	13.2	0.18	22.1	0.20	27.4	0.16	20.9
Buck : Doe	0.00		0.06		0.33		0.11	
Proportions								
Sheep		91.8		95.2		97.4		95.7
Goats		8.2		4.8		2.6		4.3

4.3.1.3. Equines (donkeys and horses) herd structure

Equines herd structure comprising donkeys and horses is presented in Table 15. Donkeys represent the highest proportion among equines representing more than 68%, irrespective of farmers wealth status. Adult female equines (jennets and mares) represent the largest proportions followed by adult males (jacks and stallions) in both the donkey and horse populations kept across all wealth group of farmers. The average number of foals (the juveniles and young animals less than three years of age) for both equines species represent the minimum proportions in both populations.

Table 15. Mean number, proportion and ratio of equines (donkeys and horses) herd structure in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Herd structure	Wealth group						Total	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		(n = 159)	
	Mean	%	Mean	%	Mean	%	Mean	%
Donkeys	1.43	100.0	2.07	100.0	3.29	100.0	2.26	100.0
Jennets	0.84	58.7	1.09	52.5	1.82	55.4	1.25	55.1
Jacks	0.21	14.7	0.52	25.0	0.88	26.8	0.54	23.8
Foals	0.38	26.6	0.47	22.5	0.59	17.9	0.48	21.1
Horses	0.54	100.0	1.06	100.0	1.55	100.0	1.05	100.0
Mares	0.42	77.8	0.49	46.3	0.76	49.4	0.56	52.8
Stallions	0.10	18.5	0.35	33.3	0.49	31.6	0.32	30.1
Foals	0.02	3.7	0.22	20.3	0.29	19.0	0.18	17.0
Proportions								
Donkeys		72.6		66.1		68.0		68.3
Horses		27.4		33.9		32.0		31.7

4.3.2. Livestock herd and flock dynamics

Various reasons were accountable for the continual incoming and outgoing dynamics of livestock into and away from the herds/flocks. Regardless of the demographic structures of the livestock herds and flocks, the annual inflow and outflow dynamics of respective livestock species across wealth group of farmers are presented in Tables 16 through 20.

4.3.2.1. Cattle herd dynamics

The cattle herd dynamics is presented in Table 16. The change in the mean number of animals in the cattle herds owned across wealth group of farmers between the beginning (opening) and ending stocks of inventory period showed an increased trend except for the better-off farmers, which had a slight decline in the cattle stock balance. The mean

numbers of both incoming and outgoing animals into and away from the cattle herds within the given year had increased corresponding to the wealth status gradient of farmers, whereby more number of animals involved in the inflow and outflow dynamics among the wealthier than the poorer farmers. Moreover, the average number of incoming animals into the cattle herds were more than the outgoing except in the better-off farmers. However, considering all farms in the system regardless of wealth status, the cattle stock buildup was comparatively more than the reduction.

Individual animals joined the cattle herd through births, purchased and received as gift and/or as share farming. Gifts were particularly from relatives, even though the giving in and share farming of cattle was very rare. Generally, irrespective of farmers wealth status, the contribution of calf births at farm were more important than other sources to the cattle stock buildup and as a source of replacements. However, the proportions of incoming animals per year from various sources were different between wealth groups of farmers. Relatively the better-off farmers got more from home grown animals than the other wealth groups to build up their cattle stock and replace the outgoings. Better-off farmers obtained 92% of the annual incoming animals from calving at farm, 8% purchased, but none has been received as gift or share farming. The medium wealth group sourced 76%, 18% and 6% of their incoming animals from births at farm, purchased and received as gift or share farming, respectively. Whereas, the poor wealth group of farmers obtained 49% from calving at farm, 37% purchased and 14% received as gift or share farming of the annual incoming animals. Regardless of wealth status, for the all farms, 74% originated from calving, 20% purchased and the remaining 6% received as gift and/or share farming as the incoming animals for cattle stock buildup and as a source of replacements.

On the other hand, animals left the cattle herd as the results of offtake and catastrophic losses due to diseases and predation and/or theft. Following offtake, which contributed for about 78%, death of animals mainly from diseases was the second important outlet accounting for 22% of reduction in cattle stock numbers. Loss of cattle due to predation and theft were not encountered during the time span of the present inventory period.

Table 16. Cattle herd dynamics across farmer wealth groups in the mixed crop-livestock production system of *Debre Berhan* milkshed, central highlands of Ethiopia

Herd parameter (in numbers and %)	Wealth group						Total (n = 159)	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		Mean	SD
	Mean	SD	Mean	SD	Mean	SD		
Opening stock	4.16	1.40	6.40	1.73	9.20	2.10	6.59	2.67
Ending stock	4.50	1.39	6.71	1.89	9.08	2.23	6.77	2.61
Change in stock	0.34	1.35	0.31	1.22	-0.12	1.46	0.18	1.35
Incoming	1.14	1.11	1.31	1.11	1.53	0.95	1.33	1.06
Born	0.56	0.58	1.00	0.92	1.41	1.02	0.99	0.92
Purchased	0.42	0.57	0.24	0.63	0.12	0.33	0.26	0.54
Given in	0.16	0.37	0.07	0.26	0.00	0.00	0.08	0.26
Outgoing	0.80	0.90	1.00	0.96	1.65	1.21	1.14	1.08
Offtake	0.60	0.64	0.71	0.82	1.40	1.08	0.89	0.92
Sold	0.60	0.64	0.57	0.68	1.14	0.78	0.76	0.74
Slaughtered	0.00	0.00	0.02	0.13	0.10	0.30	0.04	0.19
Given out	0.00	0.00	0.12	0.33	0.16	0.37	0.09	0.29
Died	0.20	0.40	0.29	0.53	0.25	0.44	0.25	0.46
Lost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Offtake rate (%) ¹	13.86		10.84		15.21		13.32	
Death/mortality rate (%) ²	4.62		4.43		2.74		3.74	
Lost (%)	0.00		0.00		0.00		0.00	

n = numbers, SD = standard deviations. Herd dynamics is analysed over one year period.

¹ Offtake rate is calculated as the ratio of the number of cattle (sold, slaughtered and given out) to the average cattle stock.

² Death rate is calculated as the ratio of the number of cattle deaths to the average cattle stock.

Regarding the mean number of cattle outgoings across wealth group of farmers offtake accounted for 75%, 71% and 85%, whereas death accounted for 25%, 29% and 15% in the poor, medium and better-off farmers, respectively. Offtake of cattle occurred in the forms of slaughter, sale for cash income and given out to relatives and/or for share farming. Among these reasons of cattle offtake, live animal sale was the prominent route of outlet for animals from the herd accounting for 67% of the outgoings at all the

farms. Slaughtering of cattle was very rare occurrence in the one-year inventory time frame, representing about 3.5% of the outflow at all the farms. Given out animals as gift and/or share farming represent 8% of the outflow for the overall farms.

Regarding farmers wealth status, for the poor farmers, all of the outgoing takes place as live animal sale, but in cases of the medium and better-off farmers it represents 57% and 69% as live animal sale, 2% and 6% slaughtered and 12% and 10% as given out, respectively. In all the farms irrespective of wealth status of farmers, annual cattle offtake rate of 13% and death rate of 4% were observed. Relatively, the better-off farmers had the highest cattle offtake rate, however, the medium farmers had an offtake rate of cattle which was even lower than the poor farmers (Table 16).

4.3.2.2. Small ruminants (sheep and goats) flock dynamics

Sheep flock dynamics: Sheep represented about 95% of the small ruminants holding averaged for the overall farms. Among wealth group of farmers, the average number of sheep owned represent 92%, 95% and 97% of the small ruminants holding in the poor, medium and better-off farmers, respectively. The annual inflow and outflow dynamics of sheep flock observed across wealth group of farmers is presented in Table 17. Unlike cattle, a reduction in the mean number of sheep flock were observed over the inventory period of time (between opening and ending flock), regardless of the wealth status of farmers. The reduction of sheep flock for all the farms in aggregate was about 11%, but the proportions were relatively higher in the wealthier than the poorer group of farmers.

The cumulative incoming numbers of sheep per year into the flocks for all the farms was 3.87, however it was 1.32 in the poor, 3.81 in the medium and 6.43 in the better-off farmers. The annual incoming number of sheep into flocks of all the farms, comprised 86% born on-farm, 13% purchased and 1% given in /received as gift and/or share farming. However, incoming sheep proportions from various sources which contributed to the sheep flock buildup showed variation between farmers of the different wealth groups. The proportions of incoming sheep due to lambing were more in the wealthier than the poorer group of farmers, representing 89%, 85% and 79% in the better-off, the medium and the poor group of farmers, respectively. The reverse

happened in the case of incoming sheep due to purchase, which accounted for 15%, 15% and 11% in the poor, medium and better-off wealth group of farmers, respectively. Sheep inflow due to gift and/or share farming was only observed in the poor farmers contributing for only about 1% of the incoming sheep within the year.

Offtake, death, loss to predators and/or theft and giving out as gift and/or share farming were the outflow routes of sheep from the flocks, in order of importance. The average number of sheep outgoing from the flock at all the farms within a year was 5.77 animals. The average numbers of outgoing sheep were 2.34 in the poor, 6.12 in the medium and 8.75 in the better-off wealth group of farmers. Regardless of farmers' wealth status, in all the farms offtake which accounted for 76%, was the most outstanding route of sheep exit from the flock followed by death of 23% mainly due to diseases. Sheep sold, slaughtered and given out represented 51%, 24% and 0.2% of the sheep outflow at all the farms, respectively. Overall the number of sheep lost to predators and/or theft was very small, responsible for only 1% of the outflow.

Regarding the wealth group of farmers, the actual number of sheep outgoings through each outlet were more in the wealthier than the poorer farmers. Offtake accounted for 83%, 77% and 73% of sheep outflow in the poor, medium and better-off wealth group of farmers, respectively. Among offtake reasons, sale of live sheep accounted for 60%, 51% and 50%, and slaughter accounted for 23%, 26% and 24% of the sheep outflow in the poor, medium and better-off wealth group of farmers, respectively. Whereas giving out of sheep for relatives and/or share farming accounted for only 0.5% of sheep outflow in the medium but none in other wealth groups of farmers. Sheep mortality in the poor, medium and better-off wealth group of farmers accounted for 17%, 21% and 26% of sheep outflows, respectively. Sheep outflow due to loss to predators and/or theft accounted for 1.1%, in the medium and 1.4% in the better-off, but none has occurred in the poor wealth group of farmers.

The overall averages of sheep offtake rate, death rate and losses for all the farms were about 26%, 7.7% and 0.4%, respectively. Regarding the farmer wealth groups, the highest sheep offtake rate was among the medium (29%) followed by the better-off (24%) and the poor (23%) farmers. The death rate was highest among the better-off

farms (8.4%) followed by the medium (8.0%) and poor (4.7%) farmer wealth groups. The loss of sheep due to theft and/or predators observed was about 0.4% in the medium and 0.5% in the better-off farmers but none has been observed in the poor farmers.

Table 17. Sheep flock dynamics across farmer wealth groups in the mixed crop-livestock production systems of *Debre Berhan* milkshed, central highlands of Ethiopia

Flock parameter (in numbers and %)	Wealth group						Total (n = 159)	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		Mean	SD
	Mean	SD	Mean	SD	Mean	SD		
Opening stock	9.02	4.33	17.60	8.31	27.71	11.95	18.14	11.48
Ending stock	8.00	4.04	15.29	8.15	25.39	12.06	16.24	11.13
Change in stock	-1.02	2.26	-2.31	4.30	-2.31	4.90	-1.91	4.03
Incoming	1.32	1.65	3.81	3.79	6.43	5.81	3.87	4.57
Born	1.04	1.55	3.24	3.05	5.70	5.86	3.34	4.30
Purchased	0.20	0.53	0.57	1.77	0.73	1.40	0.50	1.37
Given in	0.08	0.34	0.00	0.00	0.00	0.00	0.03	0.19
Outgoing	2.34	1.81	6.12	3.41	8.75	5.17	5.77	4.50
Offtake	1.94	1.38	4.74	2.53	6.39	3.27	4.39	3.09
Sold	1.40	0.86	3.12	2.25	4.33	3.04	2.97	2.52
Slaughtered	0.54	0.65	1.59	0.97	2.06	1.08	1.41	1.11
Given out	0.00	0.00	0.03	0.18	0.00	0.00	0.01	0.11
Died	0.40	0.78	1.31	1.39	2.24	2.42	1.32	1.81
Lost	0.00	0.00	0.07	0.37	0.12	0.48	0.06	0.35
Offtake rate (%) ¹	22.80		28.81		24.07		25.54	
Death/mortality rate (%) ²	4.70		7.96		8.44		7.68	
Lost (%)	0.00		0.43		0.45		0.35	

n = numbers, SD = standard deviations. Flock dynamics is analysed over one year period.

¹ Offtake rate is calculated as the ratio of the number of sheep (sold, slaughtered and given out) to the average sheep flock.

² Death rate is calculated as the ratio of the number of sheep deaths to the average sheep flock.

Goats flock dynamics: Regarding the proportions among wealth group of farmers goats comprised of 8% in the poor, 5% in the medium and 3% in the better-off farmers based on the average numbers of small ruminants owned. Averaged over all the farms goats comprised less than 5% of the small ruminants ownership. The inflow and outflow dynamics of goats flock over one-year period across wealth group of farmers is presented in Table 18.

Kids born on farm accounted for 72%, while purchase contributed the remaining 28% of annual inflow of goats on the average of all farms. Poor farmers had all the incoming goats from on-farm births only. The medium and better-off wealth status farmer groups obtained 52% and 67% from on-farm kidding and the remaining 48% and 33% were purchased, respectively. There were no goats received as gift and/or share farming in any of the wealth group of farmers.

In the present inventory the entire outgoing of goats was attributed to offtake, no death and loss to predator and/or theft were reported over the year. For the overall farms, sale of live animals and slaughter accounted for 82% and 18% of the annual offtake of goats, but none were passed as gift or for share farming. Regarding the outflow among the wealth group of farmers, all of the outgoing in the poor farmers was due to sale, while in the medium 75% sold and 25% slaughtered and in the case of better-off farmers 82% sold and 18% slaughtered. None of the goats goes out as gift and/or share farming in any of the wealth group of farmers. An annual offtake rate of 22% were observed at all the farms, irrespective of wealth status. Moreover, an offtake rate of 24%, 14 and 31% were observed in the poor, medium and better-off farmer wealth groups, respectively.

Table 18. Goats flock dynamics across farmer wealth groups in the mixed crop-livestock production systems of *Debre Berhan* milkshed, central highlands of Ethiopia

Flock Parameter (in numbers and %)	Wealth group						Total (n = 159)	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		Mean	SD
	Mean	SD	Mean	SD	Mean	SD		
Opening stock	0.72	1.11	0.79	1.56	0.76	1.67	0.76	1.46
Ending stock	0.76	1.27	0.88	2.05	0.67	1.40	0.77	1.63
Change in stock	0.04	0.45	0.09	0.73	-0.10	0.64	0.01	0.63
Incoming	0.22	0.58	0.21	0.69	0.12	0.43	0.18	0.58
Born	0.22	0.58	0.11	0.31	0.08	0.39	0.13	0.44
Purchased	0.00	0.00	0.10	0.45	0.04	0.20	0.05	0.29
Given in	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outgoing	0.18	0.39	0.12	0.33	0.22	0.50	0.17	0.41
Offtake	0.18	0.39	0.12	0.33	0.22	0.50	0.17	0.41
Sold	0.18	0.39	0.09	0.28	0.18	0.48	0.14	0.39
Slaughtered	0.00	0.00	0.03	0.18	0.04	0.20	0.03	0.16
Given out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Died	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Offtake rate (%) ¹	24.32		14.29		30.56		22.08	
Death/mortality rate (%) ²	0.00		0.00		0.00		0.00	
Lost (%)	0.00		0.00		0.00		0.00	

n = numbers, SD = standard deviations. Flock dynamics is analysed over one year period.

¹ Offtake rate is calculated as the ratio of the number of goats (sold, slaughtered and given out) to the average goats flock.

² Death rate is calculated as the ratio of the number of goats deaths to the average goats flock.

4.3.2.3. Equines (donkeys and horses) herd dynamics

Donkeys herd dynamics: Donkeys represented 68% of the equines average holding for all the farms. Among wealth group of farmers, the average number of donkeys owned represent 72%, 67% and 68% of the equines in the poor, medium and better-off farmers,

respectively. The incoming and outgoing dynamics of donkeys herd over a one-year period of time across wealth group farmers are presented in Table 19. The change in the mean number of donkeys between the beginning and ending stocks within a year were negative for the poor and better-off farmer groups while it had increased for farmers in the medium wealth group. However, at all the farms the balance between the inflow and outflow was positive even though the average increase in the number of donkeys was not substantial.

The contributing factors for donkey herd maintenance and replacement were births at farm and purchases from market, which accounted for 87% and 13% for all the farms, respectively. Considering the wealth group of farmers, the better off obtained all of the incoming donkeys stock from births at own farm, whereas the poor and medium wealth group of farmers sourced 56% and 95% from on farm births and the remaining 44% and 6% were purchased from market, respectively.

Offtake, death and loss to predators or due to theft contributed for about 69%, 24% and 7% of the donkey outgoings at all the farms, respectively. Reasons for donkey outflows showed variation among wealth group of farmers. In the case of poor farmers about 40%, 50% and 10% of donkey outflows were due to offtake, death and losses, respectively. The proportions of offtake, death and losses were 72%, 25 and 6% in the medium and 89%, 7 and 4% in the better-off farmer wealth groups, respectively. Sale of live animals (60%) and giving out as gift and/or share farming (9%) were the main reasons of donkeys' offtake for the overall farms. All of the offtake in poor farmers was due to live animal sale, whereas sale and giving out contributed 61% and 8% in the medium, and 75% and 14% in the better-off farmers, respectively.

The offtake rate, death rate and losses of donkeys for all the farms were 13.7%, 4.9% and 1.3%, respectively. Lower offtake rates and higher rates of death and losses were observed in the poor than the medium and the better-off farmers. The offtake rate, death rate and losses were 11.1%, 13.9% and 2.8%; in the poor farmers 12.6%, 4.4% and 1.0% in the medium; and 15.5%, 1.2% and 0.6% in the better-off farmers, respectively.

Table 19. Donkeys herd dynamics across farmer wealth groups in the mixed crop-livestock production systems of *Debre Berhan* milkshed, central highlands of Ethiopia

Herd parameter (in numbers and %)	Wealth group						Total (n = 159)	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		Mean	SD
	Mean	SD	Mean	SD	Mean	SD		
Opening stock (number)	1.48	0.81	1.97	1.15	3.33	1.26	2.25	1.34
Ending stock (number)	1.40	0.90	2.16	1.12	3.25	1.31	2.27	1.34
Change in stock (number)	-0.08	0.85	0.19	0.66	-0.08	0.69	0.02	0.74
Incoming (number)	0.32	0.74	0.55	0.71	0.49	0.73	0.46	0.73
Born	0.18	0.48	0.52	0.66	0.49	0.73	0.40	0.65
Purchased	0.14	0.45	0.03	0.18	0.00	0.00	0.06	0.28
Given in	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outgoing (number)	0.40	0.99	0.36	0.61	0.57	0.81	0.44	0.81
Offtake	0.16	0.55	0.26	0.48	0.51	0.76	0.31	0.62
Sold	0.16	0.55	0.23	0.42	0.43	0.67	0.27	0.56
Given out	0.00	0.00	0.03	0.18	0.08	0.27	0.04	0.19
Died (number)	0.20	0.40	0.09	0.39	0.04	0.20	0.11	0.35
Lost (number)	0.04	0.20	0.02	0.13	0.02	0.14	0.03	0.16
Offtake rate (%) ¹	11.11		12.62		15.50		13.72	
Death/mortality rate (%) ²	13.89		4.37		1.22		4.87	
Lost (%)	2.78		0.97		0.61		1.33	

n = numbers, SD = standard deviations. Herd dynamics is analysed over one year period.

¹ Offtake rate is calculated as the ratio of the number of donkeys (sold and given out) to the average donkeys herd.

² Death rate is calculated as ratio of the number of donkeys deaths to the average donkeys herd.

Horses herd dynamics: Horses represented 32% of the average equines holding in all the farms. The proportions of horses owned by wealth groups were 28%, 34% and 32% of the average number of equines in the poor, medium and better-off farmers, respectively. The incoming and outgoing dynamics horses in the herd among wealth

group of farmers over a one-year period of time is presented in Table 20. The overall incoming sources of horses comprised of 61% births and 35% purchased. With respect to the wealth status of farmers, on-farm births and market purchase comprised of 62% and 39% of the incoming horses in the poor; 73% and 32% in the medium; and 60% and 40% in the better-off of farmers. No horses were received as gift or for share farming by any of the farmer wealth groups.

About 88% and 12% of the horses were going out from the herd due to offtake and death at all the farms, respectively. However, no loss of horses has been reported due to theft and predators over the one-year period. All of the horses outflow in the poor farmers was due to offtake, while offtake and death accounted for 90% and 10% in the medium; and 75%, and 25% in the better-off farmers, respectively. The offtake of horses for all farms was attributed to sale and given out, each at proportions of 91% and 9%, respectively. At present the going out of horses as gift (23%) were reported among poor farmers only, the remaining 77% as sold, whereas all of the horses' offtake under the medium and better-off farmer groups were due to live animal sale only. The offtake and death rates of horses observed for all farms together were 21% and 2.9%, respectively. No death of horses, but an offtake rate of 46% were observed among the poor farmers. Horses offtake and death rates of 27% and 2.9% in the medium, and 7.7% and 2.6% in the better-off farmers were observed.

Table 20. Horses herd dynamics across farmer wealth groups in the mixed crop-livestock production systems of *Debre Berhan* milkshed, central highlands of Ethiopia

Herd parameter (in numbers and %)	Wealth group						Total (n = 159)	
	Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		Mean	SD
	Mean	SD	Mean	SD	Mean	SD		
Opening stock (number)	0.56	0.50	1.09	0.96	1.53	0.90	1.06	0.90
Ending stock (number)	0.56	0.58	1.00	1.12	1.57	0.85	1.04	0.98
Change in stock (number)	0.00	0.29	-0.09	0.80	0.04	0.34	-0.02	0.55
Incoming (number)	0.26	0.44	0.22	0.42	0.20	0.45	0.23	0.43
Born	0.16	0.37	0.16	0.37	0.12	0.33	0.14	0.35
Purchased	0.10	0.30	0.07	0.26	0.08	0.27	0.08	0.27
Given in	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outgoing (number)	0.26	0.44	0.31	0.63	0.16	0.37	0.25	0.50
Offtake	0.26	0.44	0.28	0.56	0.12	0.33	0.22	0.46
Sold	0.20	0.40	0.28	0.56	0.12	0.33	0.20	0.45
Given out	0.06	0.24	0.00	0.00	0.00	0.00	0.02	0.14
Died (number)	0.00	0.00	0.03	0.18	0.04	0.20	0.03	0.16
Lost (number)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Offtake rate (%) ¹	46.43		26.92		7.74		20.95	
Death/mortality rate (%) ²	0.00		2.88		2.58		2.86	
Lost (%)	0.00		0.00		0.00		0.00	

n = numbers, SD = standard deviations. Flock dynamics is analysed over one year period.

¹ Offtake rate is calculated as the ratio of the number of horses (sold and given out) to the average horses herd.

² Death rate is calculated as the ratio of the number of horses deaths to the average horses herd.

4.4. Farmers Ranking of the Purposes of Keeping Livestock

In the mixed crop-livestock farming system, producers/farmers keep different mixes of livestock for a variety of purposes. Rankings on the major purposes of keeping mixed

livestock types are presented in Table 21. Rankings on the purposes of keeping different types of livestock perceived almost similarly across wealth group of farmers.

4.4.1. Purposes of keeping cattle

Cattle provided multiple benefits in the mixed crop-livestock systems. Among various purposes listed in Table 21, keeping cattle as source of animal power for cropland cultivation has prevailed in the system. Cattle for milk production and as an income source were the second and third ranked purposes of keeping cattle herds. Maintaining cattle as means of live asset accumulation, as sources of manure and meat stood from fourth to sixth ranked functions in order of importance.

4.4.2. Purposes of keeping small ruminants

Keeping small ruminants (dominantly sheep) to generate income for immediate cash needs was the prime purpose followed by as a means of live asset accumulation (saving). The purposes of sheep as a source of meat especially during holiday occasions and as source of manure were ranked as the third and fourth important functions, respectively (Table 21).

4.4.3. Purposes of keeping equines

The primary purpose of keeping equines was for transportation of agricultural commodities and humans. The Second importance was to generate income from live animal sale and hiring. Keeping equines for manure ranked third followed by as an asset for saving. The use of equines as draught power source for cropland preparation is the least ranked purpose (Table 21).

Table 21. Farmers ranking on the purposes of keeping different livestock species in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Livestock species	Purposes	Wealth group						Total	
		Poor (n = 50)		Medium (n = 58)		Better-off (n = 51)		(n = 159)	
		HH	RI	HH	RI	HH	RI	HH	RI
Cattle	Draught power	48	0.28	58	0.30	51	0.27	157	0.28
	Milk	50	0.24	58	0.24	51	0.25	159	0.24
	Income source	50	0.20	58	0.18	51	0.20	159	0.19
	Saving	42	0.13	45	0.13	49	0.14	136	0.13
	Manure	48	0.10	53	0.08	49	0.08	150	0.09
	Meat	38	0.06	35	0.06	41	0.06	114	0.06
Sheep and goats	Income source	50	0.42	54	0.41	49	0.40	153	0.41
	Saving	42	0.24	54	0.26	51	0.26	147	0.25
	Meat	42	0.14	49	0.18	49	0.18	140	0.17
	Manure	38	0.19	33	0.15	33	0.15	104	0.16
Equines	Transport	50	0.39	58	0.43	49	0.38	157	0.40
	Income source	42	0.20	42	0.19	47	0.27	131	0.22
	Saving	42	0.20	41	0.18	43	0.20	126	0.19
	Manure	36	0.18	35	0.18	29	0.12	100	0.16
	Draught power	19	0.03	17	0.03	10	0.03	46	0.03

HH = number of respondents who ranked the purposes, RI = Rank Index.

4.5. Manure Management and Utilization

4.5.1. Manure handling

The proportion of farmers who performed specified manure handling practices across wealth groups are presented in Table 22. Irrespective of wealth status, majority of the farmers had the experience of collecting manure every other day, followed by those who collected daily and every three or more days, respectively. Despite the various

manure storage practices available farmers were using any one or combination of different manure storage methods. The commonest method of manure storage was piling the manure into heap around homestead or barn yard. Secondly, considerable proportion of farmers had prepared pit to accumulate manure for several months. Littering of manure in the barn as a storage method was the least practiced and it was usually common to manure obtained from small ruminants. The proportions of farmers who practiced any one type or combination of the different specified manure storage methods were higher among the wealthier than the poorer group of farmers.

Manure was stored as collected and after made into dung cake. The stored manure was managed by keeping in some form of shade and cover with locally available materials, but not all the farmers had practiced the management. However, these management practices were simultaneously or exclusively applied. Regardless of farmers wealth status, covering manure with locally available protective materials was most commonly applied manure handling practice than keeping in shade. Overall about 40% of farmers keep manure in some form of shade (roof, under tree branches or combined) and about 61% of them used some sort of covering for manure protection (grass/hay/branches, mud/dung plastering or combined). Among farmers who constructed or used natural shade to protect manure, most of them had prepared roofed shade, followed by those who shade the manure under tree branches. Moreover, a considerable proportion of farmers used a combination of manure shading practices. Regarding the wealth status, the proportion of farmers who practiced manure storage in shades was relatively higher in the wealthier group than the poorer.

Grass, hay and tree branches were most commonly used covering materials to protect manure commonly during rainy seasons. The proportion of farmers who used grass, hay and tree branches was higher than those who used other methods to cover manure. Plastering of collected manure with soil-mud and dung were the second common practices in manure protection. Like the experiences of shade utilization for manure, proportionally the wealthier were more involved in the use of cover for stored manure and dung cake than the poorer farmers. Overall about 75% of the respondents used hay, straw or both as organic bedding materials for livestock. However, the practice of using bedding material was limited to the new born (e.g. young calves), dams at the time of

delivery and diseased animals kept isolated for a while. The overall mean storage time of manure was about 7.8 months, regardless of wealth status. However, the wealthier have stored manure for longer period of time than the poorer group of farmers.

Table 22. Livestock manure management and handling practices in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Manure handling practices	Wealth group			Total (n = 159)
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	
Frequency of manure collection (%)				
Daily	22.0	32.8	39.2	31.4
Every other day	56.0	44.8	56.9	52.2
Every three and more days	22.0	22.4	3.9	16.4
Storage methods used (%)				
Do not store manure	0.0	0.0	0.0	0.0
Pit	10.0	24.1	31.4	22.0
Pile/Heap	80.0	60.3	39.2	59.7
Litter	4.0	1.8	3.9	3.2
Combined	6.0	13.8	25.5	15.1
Types of manure shade used (%)				
No shade used	78.0	63.8	37.3	59.7
Roof	10.0	15.5	25.5	17.0
Tree branches	8.0	12.1	17.6	12.6
Combined	4.0	8.6	19.6	10.7
Types of manure cover used (%)				
No cover used	58.0	36.2	23.5	39.0
Grass/hay/branches	20.0	27.6	29.4	25.8
Soil/mud/dung plastering	14.0	20.7	27.5	20.8
Combined	8.0	15.5	19.6	14.5
Do you use bedding material? (yes)	62.0	77.6	84.3	74.8
Manure storage time (months)	5.8(1.8)	7.1(2.8)	10.7(5.8)	7.8(4.3)

n = number of respondents, figures in parenthesis are standard deviations.

4.5.2. *Manure utilization*

The proportion of farmers involved in the different aspects of manure utilization across wealth groups are presented in Table 23. Livestock manure is used as bio-fuel, fertilizer, source of income and plastering of house walls and floors in the study area. Fresh and stored manure were processed into dung cake. Dung cake is made from moistened manure which is flattened into round paste by hand and plastered onto the ground or wall and left in the sun to dry. Then, after it is completely dried used as bio-fuel for home consumption, marketed to the nearby urban areas or stored for later use. The manure obtained from different species of livestock (cattle, goats, sheep and equines) were used to prepare dung cake. However, cattle manure was the most popular and preferred material for dung cake, which is demonstrated by the proportion of respondents who used manure sourced from different livestock species to prepare dung cake. All of the respondents used cattle manure while few of them used manure obtained from small ruminants and equines usually mixed with cattle manure to prepare dung cake. However, manure obtained from equines and small ruminants alone were rarely used for dung cake. Higher proportion of the poorer farmers used manure from small ruminants and equines for dung cake than the wealthier group of farmers. Refused forages and bedding materials, which are hardly available were deliberately mixed with manure during storage and preparation of dung cakes.

Overall sizable proportion of farmers used manure as organic fertilizer at least in their back yard and farm plots near to homestead area, however the increase in the proportion of farmers who used manure as organic fertilizer followed the betterment of their wealth status. Manure was applied on the field by direct spreading as it is collected or stored and after processing into compost. Regardless of wealth status, comparable proportions of farmers applied manure by direct spreading on the field and as composted. However, higher proportion of the poorer farmers applied manure by direct spreading/dumping than the wealthier while it is vice versa in the use of composted manure. Furthermore, higher proportions of the wealthier used both methods of manure application together than the poor farmers. More than 60% of respondents have sold manure in the form of dung cake to generate cash income, but none of the respondents bought manure for any

purpose. Regarding the sale of manure among wealth groups, proportionally the poorer were more involved than the wealthier in manure sale.

Table 23. Livestock manure utilization in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Manure utilization	Wealth group			Total (n = 159)
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	
Do you sale manure (dung cake)? yes	78.0	60.3	56.9	64.8
Do you buy manure (dung cake)? yes	0.0	0.0	0.0	0.0
Do you produce dung cake? yes	100.0	100.0	100.0	100.0
From cattle manure? yes	100.0	100.0	100.0	100.0
From sheep and goats manure? yes	50.0	43.1	21.6	38.4
From equines manure? yes	60.0	48.3	15.7	41.5
Do you use manure as fertilizer? yes	50.0	65.5	70.6	62.3
Direct spreading	26.0	22.4	15.7	21.4
Composted	16.0	24.1	25.5	22.0
Combinations	8.0	19.0	29.4	18.9

n = number of respondents.

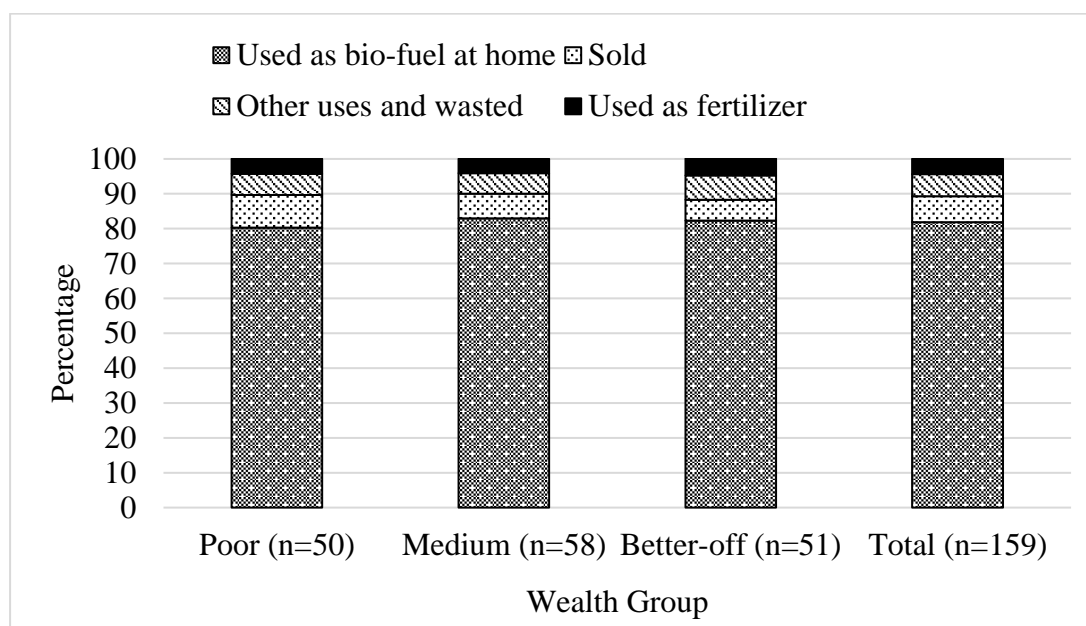


Figure 10. Proportion of manure utilization as perceived by farmers in the mixed crop-livestock system of the *Debre Berhan* milkshed, central highlands of Ethiopia

Farmers perceived that over 80% of manure produced on-farm was used for household bio-fuel consumption, which exhibited similar trend across the wealth group of farmers. The remaining was used for different purposes such as organic fertilizer, income source from sale of dung cake and other uses or wasted (Figure 10).

4.6. Evaluation of Livestock Feed Balance

Farm level feed availability estimated from on-farm produced and procured, the prevailing livestock feed demand and the resulting annual feed balance across wealth group of farmers operating in the mixed crop-livestock production system are presented in Tables 24 and 25.

4.6.1. Feed resources and estimated quantities of dry matter, metabolizable energy and crude protein

Farm level annual feed supply estimated from different sources in terms of DM, ME and DCP is presented in Table 24. On-farm produced feed resources were derived from major food-feed crops grown (barley, wheat, faba bean and field pea), GL (communal and private grazing lands), crop aftermath and fallow land. Corresponding to the amount of grain yield harvested per household per year, the quantity of CR obtained from individual crop types and from all the various crops in aggregate were higher for the wealthier group of farmers. Moreover, the quantities of feed DM, ME and DCP obtained on-farm from sources including GL, fallow land and aftermath grazing were lower compared to the amount attained from total CR; however, the trend and extent of variations seemed to be associated with wealth status. In addition, livestock feeds were sourced from off-farm production, though the quantities procured were dependent on the capability of farmers to afford. The wealthier were relatively more capable to afford considerable amount of additional purchased feeds (hay and some concentrates) from other sources.

Table 24. Feed resource types and estimated quantities of DM, ME and DCP obtained per year per farm household in the mixed crop-livestock system of the *Debre Berhan* milkshed, central highlands of Ethiopia

Feed resource types	Wealth group			Total (n = 159)	
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)		
DM (t/hh)	Crop residues	3.81(1.24)	5.14(1.41)	6.63(1.91)	5.20(1.90)
	Barley straw	2.31(0.94)	2.81(1.32)	3.39(1.20)	2.84(1.24)
	Wheat straw	0.72(0.59)	0.92(0.49)	1.60(1.00)	1.07(0.80)
	Faba bean straw	0.67(0.35)	1.24(0.69)	1.47(1.00)	1.13(0.80)
	Field pea straw	0.11(0.23)	0.17(0.22)	0.18(0.20)	0.15(0.22)
	Grazing land	1.11(0.32)	1.55(0.45)	2.12(0.54)	1.59(0.60)
	Fallow land	0.09(0.18)	0.13(0.32)	0.42(0.41)	0.21(0.35)
	Crop aftermath	0.60(0.16)	0.77(0.22)	0.88(0.21)	0.75(0.23)
	Purchased	0.68(0.53)	1.86(1.69)	2.54(2.03)	1.71(1.73)
ME ('000 MJ/hh)	Crop residues	28.4(9.27)	38.11(10.79)	48.75(14.00)	38.47(14.03)
	Barley straw	18.26(7.40)	22.18(10.38)	26.73(9.46)	22.41(9.78)
	Wheat straw	4.64(3.81)	5.94(3.15)	10.34(6.48)	6.94(5.21)
	Faba bean straw	4.73(2.46)	8.74(4.90)	10.38(7.10)	8.00(5.65)
	Field pea straw	0.78(1.68)	1.24(1.57)	1.29(1.47)	1.11(1.58)
	Grazing land	8.99(2.62)	12.57(3.68)	17.18(4.38)	12.92(4.88)
	Fallow land	0.69(1.47)	1.05(2.61)	3.40(3.37)	1.69(2.85)
	Crop aftermath	4.44(1.18)	5.74(1.75)	6.54(1.56)	5.59(1.74)
	Purchased	4.97(3.90)	13.56(12.31)	18.57(14.81)	12.46(12.61)
DCP (kg/hh)	Crop residues	128.77(42.01)	182.72(51.18)	230(70.82)	180.92(68.69)
	Barley straw	68.26(27.66)	82.95(38.80)	99.95(35.38)	83.78(36.57)
	Wheat straw	18.38(15.08)	23.56(12.48)	41.01(25.69)	27.53(20.65)
	Faba bean straw	35.75(18.62)	66.09(37.05)	78.53(53.68)	60.53(42.72)
	Field pea straw	6.39(13.65)	10.13(12.77)	10.52(11.93)	9.08(12.85)
	Grazing land	70.13(20.41)	98.01(28.69)	133.97(34.17)	100.77(38.09)
	Fallow land	5.41(11.45)	8.17(20.35)	26.54(26.29)	13.19(22.24)
	Crop aftermath	11.40(3.13)	14.96(4.22)	16.89(4.01)	14.46(4.42)
	Purchased	36.41(28.56)	99.29(90.18)	135.99(108.45)	91.29(92.36)

n = number of respondents, DM = dry matter, ME = metabolizable energy, MJ = mega joules, DCP = digestible crude protein, kg = kilogram, t = ton, hh = household; Values in parentheses indicate standard deviations.

4.6.2. Livestock feed supply, demand and balance

Comparisons of the annual feed demand, supply and balance quantified on DM, ME and DCP basis per farm household across wealth groups of farmers are presented in Table 25. The feed demand of livestock estimated based on the expected annual intake of DM, ME and DCP was significantly different across wealth group of farmers, consistently increasing along with the wealth gradient of farmers.

Table 25. Mean annual livestock feed supply, demand and balance per household in the mixed crop-livestock system of the *Debre Berhan* milkshed, central highlands of Ethiopia

Livestock feed supply, demand and balance	Wealth group				
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	Total (n = 159)	
DM(t/hh)	Demand	11.62(0.40) ^a	18.75(0.61) ^b	27.40(0.75) ^c	19.28(0.61) ***
	Supply ¹	5.59(0.20) ^a	7.58(0.24) ^b	10.04(0.30) ^c	7.75(0.20) ***
	Supply ²	6.27(0.22) ^a	9.44(0.36) ^b	12.59(0.44) ^c	9.45(0.29) ***
	Balance ¹	-6.03(0.47) ^c	-11.16(0.67) ^b	-17.35(0.70) ^a	-11.53(0.51) ***
	Balance ²	-5.35(0.47) ^c	-9.31(0.68) ^b	-14.81(0.65) ^a	-9.83(0.47) ***
ME ('000 MJ)	Demand	54.86(1.84) ^a	86.40(2.70) ^b	122.75(2.93) ^c	88.14(2.61) ***
	Supply ¹	42.53(1.52) ^a	57.46(1.90) ^b	75.87(2.19) ^c	58.67(1.52) ***
	Supply ²	47.50(1.67) ^a	71.02(2.75) ^b	94.44(3.30) ^c	71.14(2.14) ***
	Balance ¹	-12.32(2.48) ^c	-28.93(3.42) ^b	-46.88(3.11) ^a	-29.47(2.08) ***
	Balance ²	-7.35(2.56) ^{cb}	-15.38(3.77) ^b	-28.32(3.55) ^a	-17.00(2.06) ***
DCP (kg)	Demand	392.15(14.58) ^a	630.38(23.47) ^b	907.06(21.82) ^c	644.21(20.22) ***
	Supply ¹	215.72(6.79) ^a	303.86(9.27) ^b	407.40(11.83) ^c	309.35(8.19) ***
	Supply ²	252.12(8.27) ^a	403.15(16.3) ^b	543.39(21.94) ^c	400.64(13.26) ***
	Balance ¹	-176.43(15.97) ^c	-326.52(24.72) ^b	-499.67(17.26) ^a	-334.86(15.52) ***
	Balance ²	-140.03(16.90) ^c	-227.24(26.42) ^b	-363.67(20.17) ^a	-243.57(14.57) ***

¹ calculated based on feed sourced on-farm only.

² calculated based on feed sourced on-farm and purchased.

n = number of respondents, DM = dry matter, ME = metabolizable energy, MJ = mega joules, DCP = digestible crude protein, kg = kilogram, t = ton, hh = household;

Values in parentheses indicate standard errors;

^{a,b,c} Means in a row with different superscripts differ significantly at *** $P < 0.001$ probability level.

The on-farm produced annual feed supply from different sources, as well as the total annual feed supply including purchased feeds differ significantly across wealth group of farmers. With similar trend to the livestock demands, the wealthier obtained more quantities of DM, ME and DCP from feeds sourced on-farm and from the total feed supply including the additional purchased feeds. The annual balance of DM, ME and DCP at farm household level assessed based on the on-farm obtained and total feed supply that included purchased feeds was significantly different across wealth groups of farmers, except that the balance in ME was not significantly different between the poor and medium wealth groups. However, in all cases the wealthier encountered more deficit than the poor group of farmers in the quantities of DM, ME and DCP balance attained.

The degree to which the demands for DM, ME and DCP were fulfilled or not with respect to the estimated quantities for maintenance requirement of livestock at farm household level of different wealth status is illustrated in Figure 11a b and c. The magnitude of insufficiency in feed DM, ME and DCP supply for livestock was unlike between the wealth groups of farmers. The better-off group had more severe deficit (inadequate supply) followed by the medium and poor in order of importance. When the supply of DM, ME and DCP was observed regardless of farmers wealth status (at farmer level in a particular wealth group) the DM supply shortage was more pronounced followed by DCP and ME in order of the magnitude of insufficiency, respectively. It was also observed that acquiring additional purchased feeds helped to relief/reduce part of the insufficiencies (deficits) in the DM, ME and DCP supply differently between the poor and wealthier group of farmers. The poor farmer group was able to reduce the shortage in the DM, ME and DCP supply by 6, 9 and 9%, respectively, whereas the medium and better-off wealth groups have reduced the DM and ME shortage equally by 10% and 15%, respectively. But the deficiency in DCP was reduced by 15% among the medium and by 16% among the better-off wealth group of farmers. The overall supply shortage in DM, ME and DCP at all the farms in the farming system was mitigated by 9%, 14% and 14%, respectively due to additional purchased feeds acquired.

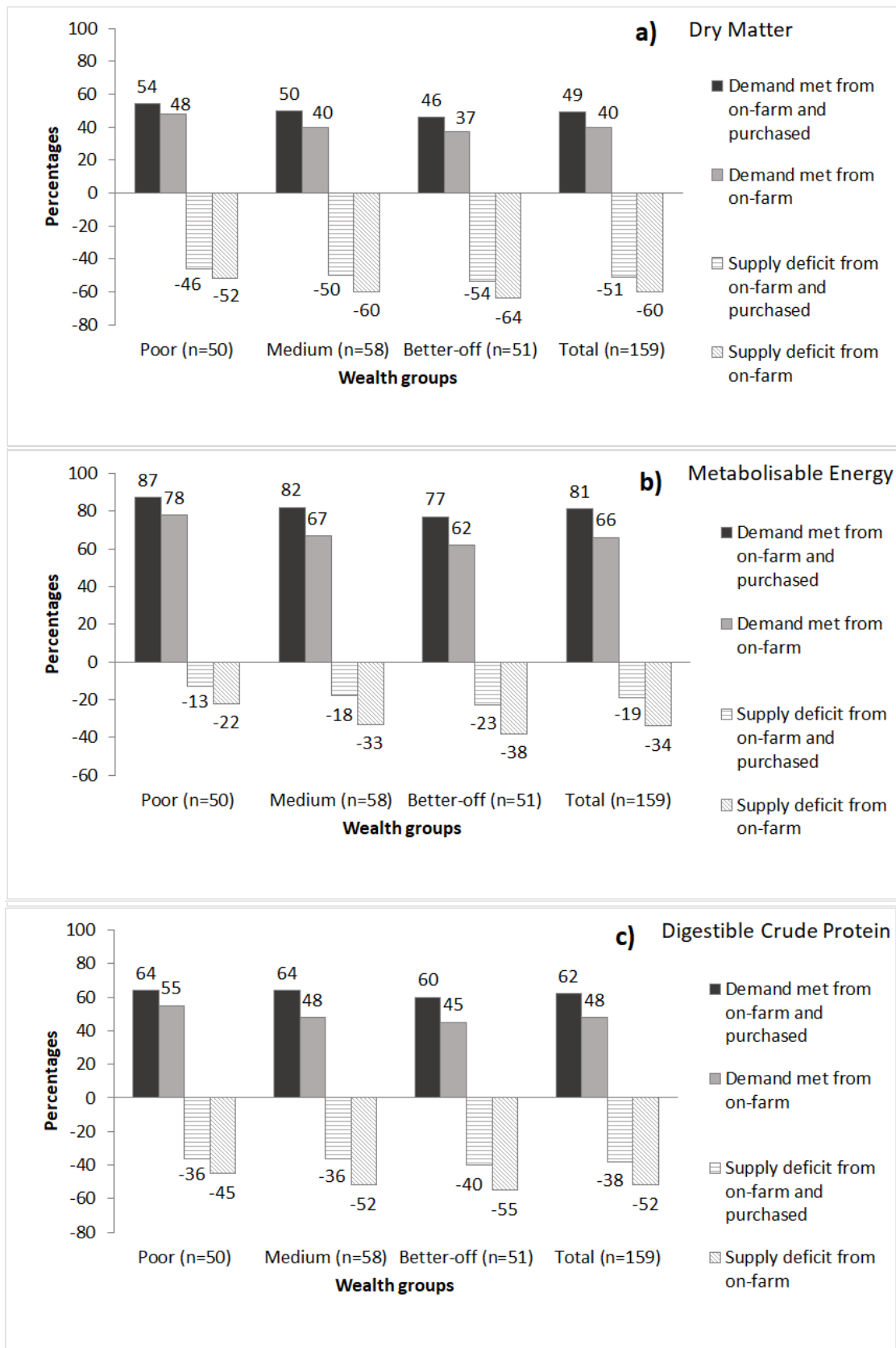


Figure 11. Percentages of dry matter (a), metabolizable energy (b) and digestible crude protein (c) supply and demand balances of farm households categorized into wealth groups in the mixed crop-livestock system of the *Debre Berhan* milkshed, central highlands of Ethiopia

The proportion of farmers under different wealth groups who were in a positive state of annual livestock feed balance are presented in Table 26. Overall very few farmers were able to source sufficient feed to satisfy the maintenance requirements of livestock throughout the year. Relatively more number of farmers from the poor wealth group were in positive state of balance in terms of the feed DM, ME and DCP supply. The situation was better for ME irrespective of farmers wealth status, especially when farmers had acquired additional purchased feeds. Based on the feed supply obtained from on-farm only, none were in a positive DM balance across the wealth group farmers, but less than 2% (all of them from the poor farmers group) when purchased feeds were considered. Generally, the proportion of farmers in a positive livestock feed balance for DM, ME and DCP were contrary to their wealth status, the wealthier suffered more than the poor in livestock feed insufficiency.

Table 26. Numbers and proportions of farmers with positive feed balance in the mixed crop-livestock system of the *Debre Berhan* milkshed, central highlands of Ethiopia

Feed Parameters	Feed sourced from	Wealth group			Total (n = 159)
		Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	
DM	On-farm	0(0.0)	0(0.0)	0(0.0)	0(0.0)
	On-farm and purchased	2(4.0)	0(0.0)	0(0.0)	2(1.3)
ME	On-farm	15(30.0)	3(5.2)	0(0.0)	18(11.3)
	On-farm and purchased	23(46.0)	17(29.3)	7(13.7)	47(29.6)
DCP	On-farm	2(4.0)	0(0.0)	0(0.0)	2(1.3)
	On-farm and purchased	7(14.0)	7(12.1)	0(0.0)	14(8.8)

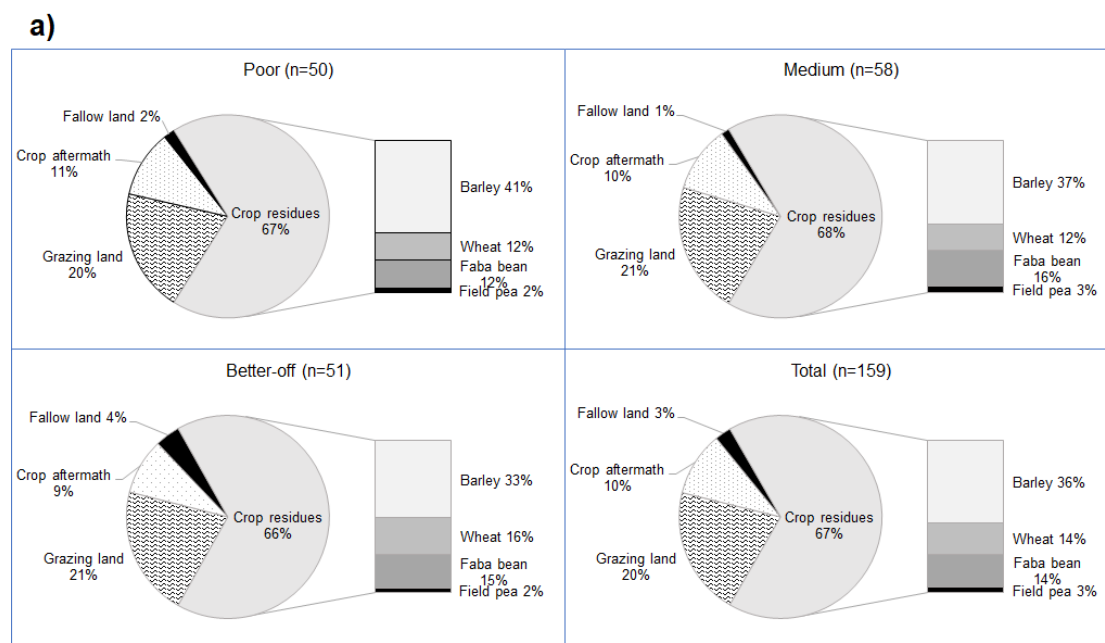
n = number of respondents.

Values inside parentheses indicate percentages (%).

4.6.3. Relative contribution of feed resources to annual livestock feed supply

Proportional contributions of livestock feed resources produced on-farm only (Figure 12a) and combined with purchased feeds sourced off-farm (Figure 12b) to the total feed DM supply obtained per year at farmer level are illustrated among different wealth group of farmers. Regardless of farmers wealth status, the foremost on-farm feed

resource that covered more than half of the annual feed DM supply was CR derived from major food-feed crops (Figure 12a). Even when the contribution of purchased feed resources was considered share of CR prevailed (Figure 12b). Following CR, natural GL, crop aftermath and fallow land contributed to the bulk of on-farm annual feed supply in order of importance (Figure 12a), whereas the proportional contribution of purchased feed resources stood second, except for the poor farmers which was at the fourth level, when the total feed sourced was considered across farmers wealth status (Figure 12b). The contribution of fallow land was very limited as there was scarcity of cropland to set aside of cultivation. Among CR that make up the largest portion of the livestock feed resource base, cereals (barley and wheat) contribute more than legumes (faba bean and field pea). Moreover, the proportional contribution of barley straw was the highest followed by faba bean and wheat, which have comparable contributions, whereas the contribution of field pea was the least, when the share of individual crops was considered irrespective of farmers wealth status (Figure 12a and b).



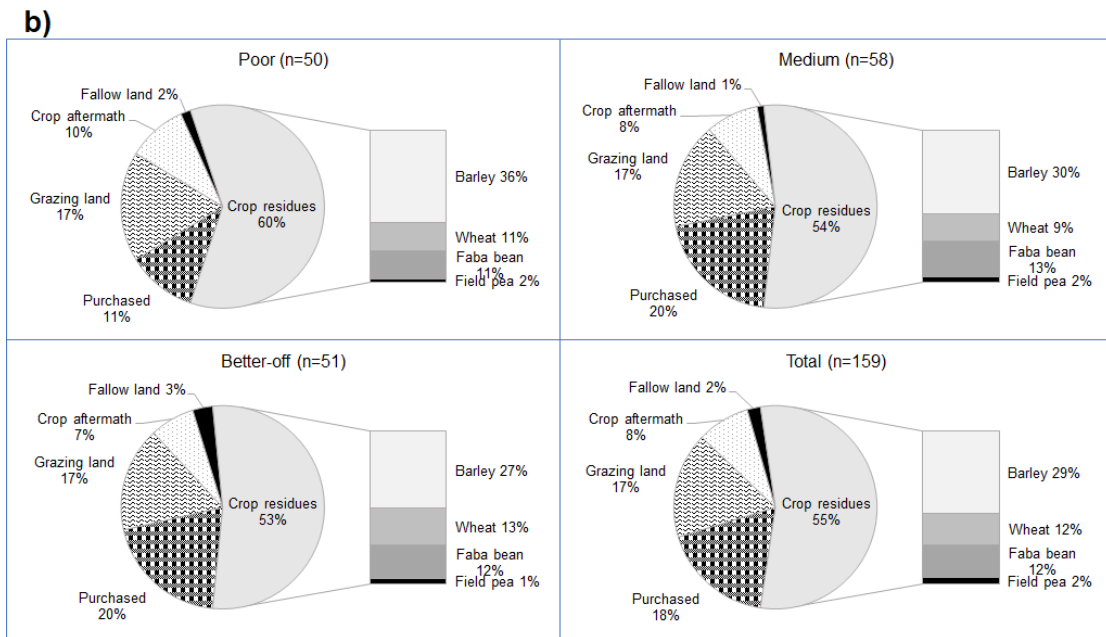


Figure 12. Relative contributions of feed resources obtained on-farm only (a) and on-farm combined with purchased feeds (b) to the total annual livestock feed dry matter supply in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

4.6.4. Seasonal availability of feed resources

The seasonal availability of feed resources throughout the year is illustrated in Figure 13. Crop residues obtained from on-farm crop production were abundantly available during the months of December to March and steadily decline from April to November. Grazing lands even though utilized throughout the year, feed availability was limited to the months of August to December. During the rest of the months, feeds available from grazing lands were meagre. Availability of fallow land grazing coincides with the trend of grazing lands, but with very low contribution from February to August. However, the contribution of fallow land and natural grazing land was increasing from September to November. Availability of crop aftermath grazing follows harvesting periods of crops grown and it was short lived from December to February. Months from April to August were critical periods of feed shortage, during which farmers used most of purchased feed resources. During these critical feed shortage periods, conserved hay and crop residues were also used, preferentially for feeding lactating cows and oxen engaged in cropland preparation.

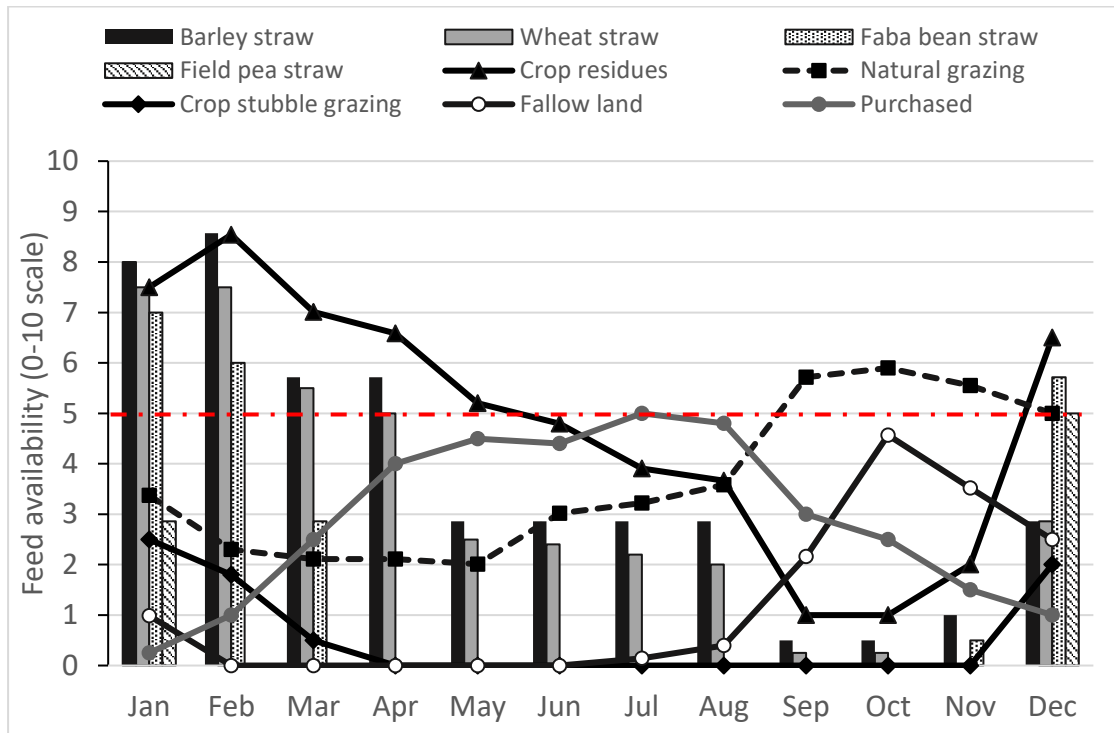


Figure 13. Seasonal availability of feed resources as perceived by farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia. Availability of feed over the year on a scale of 0-10, where 10 = excess feed available, 5 = adequate feed available and 0 = no feed available.

4.6.5. Livestock density on agricultural land use for feed sourcing

Figure 14 illustrates the existing livestock density on agriculture land use types from which livestock feeds were basically sourced. It also showed the livestock density across wealth group of farmers corresponding to the variations in the size of livestock and land ownership. Overall the density of livestock on available grazing land was more intense, which was almost twice more than the density on the cultivated cropland. The situation has been demonstrated with similar trends across the wealth group of farmers. Indeed, livestock density per hectare of the total agricultural land (grazing and cultivated cropland) and cultivated cropland were higher for the better-off than the other wealth groups. However, on the grazing land higher TLU per hectare was observed for the medium followed by the better-of and poor wealth group of farmers, respectively.

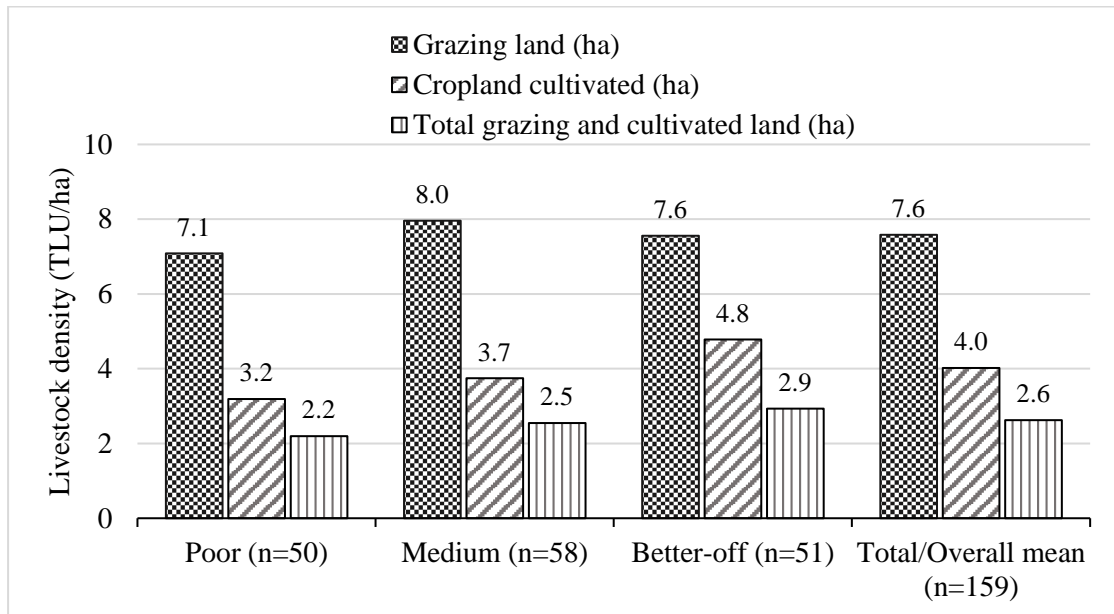


Figure 14. Livestock density per hectare of agricultural land use types used for feed sourcing across wealth group of farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

4.7. Feed and Livestock Water Productivity

Both feed water productivity (FWP) and livestock water productivity (LWP) used the volume of water evapotranspired to produce livestock feed as an input to produce feeds from different sources. Whereas, the annual feed production expressed in terms of total DM available, and the livestock products and services aggregated into monetary terms were considered as outputs in the feed and livestock production processes, respectively.

4.7.1. Feed available, water depleted and feed water productivity

Comparisons of the quantities of livestock feed DM yield and the volume of water depleted (WD) to produce feed from different sources and the resulting physical feed water productivity across farmer wealth groups are presented in Table 27. Livestock feed DM obtained from food-feed crops, GL and the overall were significantly different between wealth groups, being higher for better-off followed by medium and poor farmers, respectively. The volume of WD to obtain different feed resource types and for the overall feed production showed significant variations across wealth groups corresponding to the level of DM production. However, WP of different feed sources showed significantly contrasting variations across wealth groups. In case of feed from

GL, poor farmers gained better WP than medium and better-off. In contrast, better-off farmers gained more WP for CR than medium and poor. However, there was no significant variation on the overall FWP.

Table 27. Means of feed dry matter, water depleted and water productivity of feed and livestock across wealth groups in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Feed, water depleted, livestock output and water productivities	Wealth group			Total (n = 159)	
	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)		
Dry matter of livestock feed available (tons)	5.00(0.18) ^a	6.81(0.22) ^b	9.17(0.28) ^c	7.00(0.19)	***
Grazing land	1.19(0.06) ^a	1.68(0.08) ^b	2.53(0.10) ^c	1.80(0.06)	***
Crop residues	3.81(0.18) ^a	5.14(0.19) ^b	6.63(0.27) ^c	5.20(0.15)	***
Water depleted for total feed production (‘000 m ³)	8.30(0.25) ^a	11.45(0.41) ^b	15.78(0.4) ^c	11.85(0.32)	***
Grazing land	4.65(0.22) ^a	6.65(0.32) ^b	10.25(0.4) ^c	7.18(0.26)	***
Crop residues	3.64(0.14) ^a	4.80(0.17) ^b	5.52(0.18) ^c	4.67(0.11)	***
Feed water productivity (kg m ⁻³)	0.61(0.02)	0.61(0.01)	0.59(0.01)	0.60(0.01)	
Grazing land	0.26(0.00) ^c	0.25(0.00) ^{ab}	0.25(0.00) ^a	0.25(0.00)	***
Crop residues	1.04(0.03) ^a	1.09(0.03) ^{ab}	1.20(0.03) ^c	1.11(0.02)	***
Total livestock outputs (‘000 USD/year)	1.32(0.05) ^a	2.71(0.13) ^b	4.70(0.19) ^c	2.91(0.13)	***
Milk	0.61(0.05) ^a	1.36(0.11) ^b	2.63(0.16) ^c	1.53(0.09)	***
Offtake	0.02(0.00) ^a	0.05(0.01) ^b	0.08(0.01) ^c	0.05(0.00)	***
Traction services	0.48(0.02) ^a	0.97(0.04) ^b	1.50(0.05) ^c	0.99(0.04)	***
Manure	0.21(0.01) ^a	0.34(0.01) ^b	0.49(0.01) ^c	0.35(0.01)	***
Livestock water productivity (USD m ⁻³)	0.16(0.01) ^a	0.24(0.01) ^b	0.30(0.01) ^c	0.23(0.01)	***

n = number of respondents, USD = United States Dollar (1USD = 20.00 Ethiopian Birr)

Values in parentheses indicate standard errors.

^{a,b,c} Means in a row with different superscripts differ significantly at *** $P < 0.001$ probability level.

Figure 15 shows the proportion of feed resources DM derived from agricultural land use types used for feed production and corresponding volume of water depleted on land

use types across wealth group of farmers and overall the farms. The volume of rainwater channelled to livestock production due to feed supply from grazing and cultivated lands showed similar trends across wealth group of farmers. Regardless of wealth status, large volume of rainwater was depleted on grazing lands on which small amount/proportion of feed DM was obtained and vice versa on the cultivated cropland.

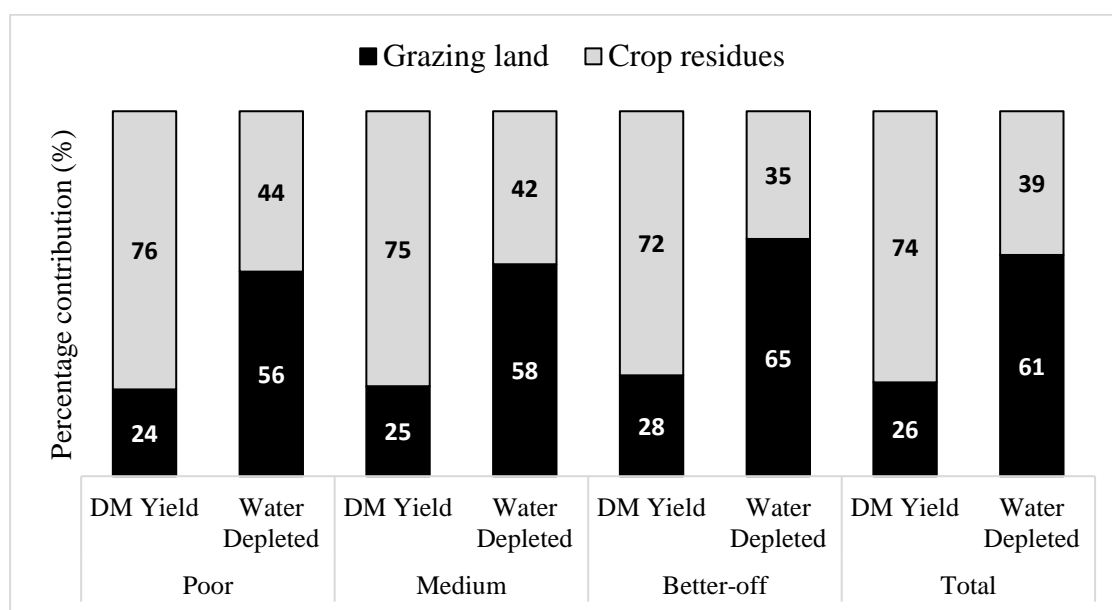


Figure 15. Proportions of feed dry matter yield and water depleted on agricultural land used for livestock feed production in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

4.7.2. Livestock beneficial outputs and livestock water productivity

Comparisons of the mean values of outputs and services quantified on annual basis separately and in aggregate into monetary terms and the resulting LWP between wealth groups are presented in Table 27. Derived monetary values for livestock beneficial outputs (BO) like milk, offtake and manure and traction services exhibited significant variations between wealth groups. The better-off obtained the highest overall benefit as well as various output types and services compared with farmers in other wealth groups. Significant variation in LWP assumed farmers wealth status being highest for better-off and lowest for poor groups. Figure 16a and b illustrates the contribution of output types and species to the total annual BO obtained from livestock. Irrespective of wealth status, milk value generated the highest proportion followed by traction services,

manure and offtake in order of importance. Among species the highest proportion was generated from cattle followed by equines and small ruminants.

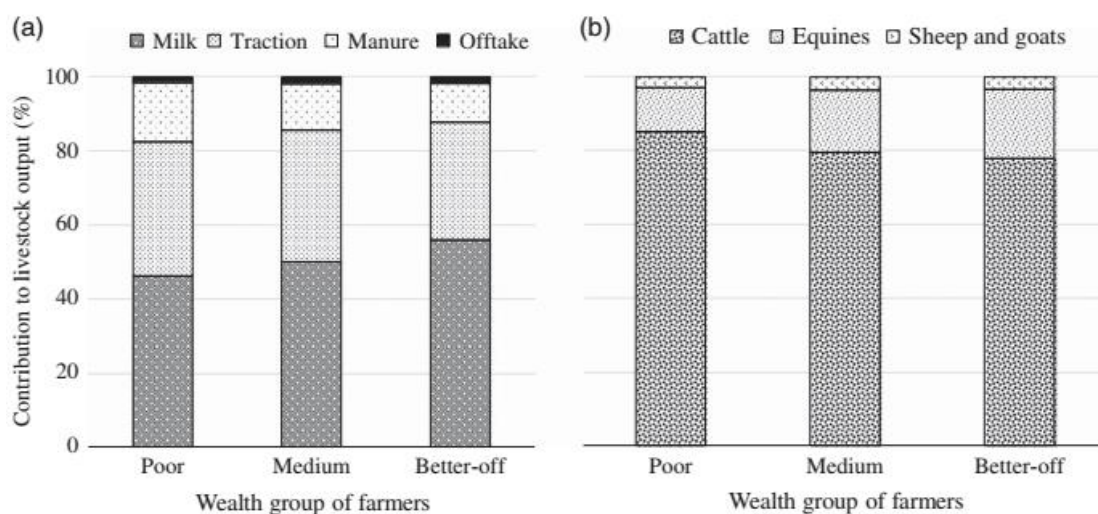


Figure 16. Proportion of estimated annual livestock beneficial output contributed from (a) livestock products and services and (b) livestock species, among farmer wealth groups in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

4.7.3. Relationships of crop residues use with water productivity of feed and livestock

Proportion of CR use in the bulk of livestock feed supply showed strong positive linear relationship ($r(157) = 0.89, P = 0.000$) with FWP. The relationship was linear as illustrated in the scatter plot Figure 17a. But no linear pattern was observed in scatter plot Figure 17b between the level of CR and LWP. It is difficult to suggest the existence of reliable linear association between crop residue use and LWP based on this evidence.

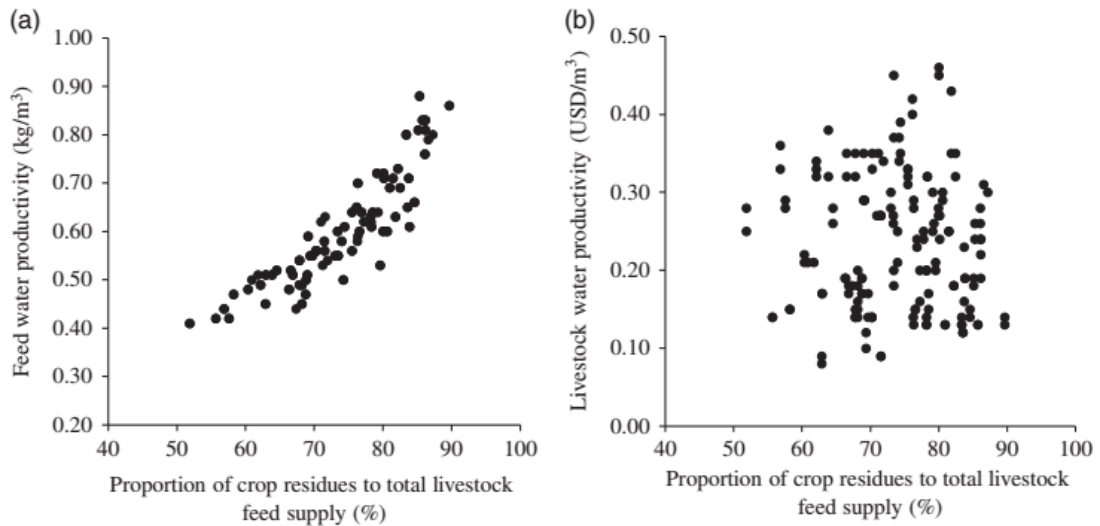


Figure 17. Relationships between the proportion of crop residues in the total livestock feed supply and (a) feed water productivity and (b) livestock water productivity, in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Figure 18 demonstrates the relationship between the observed LWP and FWP. There was no significant relationship detected between LWP and FWP at the presently prevailed performance of livestock and feed production for the amount of freshwater used in the production processes. The quarters in the scatter plot of Figure 18 displayed with respect to the reference lines for the overall mean values of LWP at 0.23 thousand USD/m³ and FWP at 0.60 kg/m³ demonstrate the distribution of LWP and FWP observations, regardless of wealth status. The labels HH and LL in the quarters denotes the number of observations/farmers who simultaneously achieved the LWP and FWP values above and below marked averages, respectively, whereas HL and LH denote contrasting observations of LWP and FWP, where by HL represents above average LWP and below average FWP values, and LH represents the opposite.

The figures in each labeled quarter display the number of farmers with respect to their wealth group. Overall 27% of the observations comprising 4, 36 and 39% of the poor (n = 50), medium (n = 58) and better-off (n = 51) wealth group of farmers, respectively fall in the above average values (HH) for both LWP and FWP indices. Whereas 30% of the observations comprising 44, 34 and 10% of the poor, medium and better-off wealth group of farmers, respectively fall in the below average values (LL) for both LWP and FWP. The remaining 23 and 21% of the observations in HL and LH labeled quarters comprising of 0, 17 and 51%; and 52, 12 and 0% of the poor, medium and

better-off farmers, respectively represent contrasting values falling under the above average for LWP and below average for FWP in HL and vice versa in LH quarter. Generally, the whole picture depicted most of the wealthier attained higher water productivity on livestock production while most of the poorer obtained better on feed water productivity.

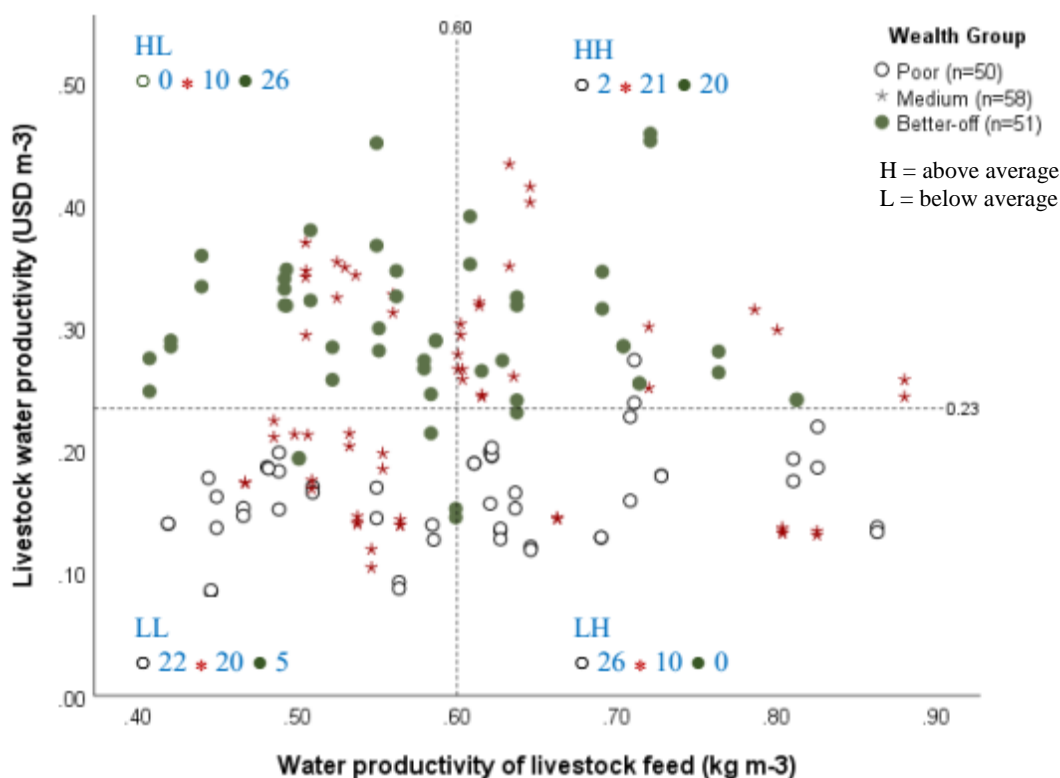


Figure 18. Relationship between livestock water productivity and water productivity of feed in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

4.7.4. Factors explaining feed and livestock water productivity

4.7.4.1. Association of selected variables with feed and livestock water productivity

The bivariate correlations of selected variables expected to associate with feed and livestock water productivity are presented in Table 28. In the present study, the correlations between farming experience and education level of household head with FWP and LWP were not significant. Age dependency ratio was significantly and negatively associated with LWP, but not associated with FWP. Farm labour force, area

of cultivated cropland, total grains value per cultivated land, access to credit for agricultural inputs and access to agricultural trainings had significantly positive association with both FWP and LWP. The association of livestock holding (TLU) was significant for both, but negative with FWP and positive with LWP. There was no significant relation between membership of dairy cooperative and FWP, but the association was significant and positive with LWP.

Table 28. Descriptive statistics and correlation of variables with feed and livestock water productivity in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Variables	Correlations (r)		Descriptive statistics	
	FWP	LWP	Mean	SD
Farming experience (years)	-0.08	0.09	30.01	11.18
Formal education completed (years)	-0.13	0.04	2.70	3.14
Age dependency ratio (dimensionless)	-0.09	-0.17*	0.76	0.59
Farm labour force (adult equivalents)	0.25**	0.21**	3.26	1.26
Cultivated land (ha)	0.35***	0.29***	2.10	0.64
Grains value per cultivated land ('000 USD/ha)	0.32***	0.17*	0.73	0.13
Livestock holding (TLU)	-0.19*	0.60***	8.45	3.38
Membership of cooperative	0.03	0.21**	0.50 [#]	
Access to credit for agricultural inputs	0.49***	0.38***	0.26 [#]	
Access to agricultural trainings	0.47***	0.39***	0.58 [#]	
Number of observations	159	159	159	

Correlation is significant at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ level (2-tailed).

[#] mean proportion, SD = Standard Deviation.

LWP = Livestock water productivity; FWP = Feed water productivity; TLU = Tropical livestock unit; USD = United States Dollar.

4.7.4.2. Factors explaining feed and livestock water productivity

The parameter estimates of the linear regression model for the explanatory variables expected to affect the response variables FWP and LWP at household level are presented in Table 29. The *F*-ratio tests of the regression models for predicting FWP and LWP were statistically significant. The explanatory variables explain 64.4% of the variability in FWP, $F(12,146) = 24.86$, $P = 0.000$, $R^2 = 0.671$ and Adjusted $R^2 = 0.644$.

Whereas 60.9% of the variation in LWP accounted for the explanatory variables in the model, $F(12,146) = 21.48$, $P = 0.000$, $R^2 = 0.638$ and Adjusted $R^2 = 0.609$.

The farming experience of household head, formal school education of highest grade level completed by household head and age dependency ratio have not significantly influenced both FWP and LWP. Family labour force and the area of cultivated cropland had significantly affected both FWP and LWP, but differently in opposite directions. The influence for both explanatory variables were positive on FWP but negative on LWP. The relationship between aggregated value of grains per cultivated cropland and FWP was positive and significant, whereas no significant relationship was observed with LWP. Aggregated livestock holding (TLU) significantly affected FWP and LWP in opposite directions, being positive on LWP and negative on FWP.

Membership of dairy cooperatives had no significant influence on FWP, but on LWP. Being a member of dairy cooperative had resulted an increase in LWP by 2.65 % times than none-member. Access to credit for agricultural inputs supplies and access to agricultural trainings had significantly and positively influenced both the FWP and LWP. Those who had access to credit services for agricultural inputs had increased FWP and LWP by 3.93 and 5.26 % times, respectively than those without access to credit services. Moreover, those who had access to agricultural trainings had increased FWP and LWP by 7.05 and 4.96% times, respectively than those without access to such trainings. Wealth status of farmers had no significant influence on FWP, but the influence on LWP significantly mirrored the wealth status gradient of farmers. The medium and better-off groups had respectively attained 5.98% and 10.34% times higher LWP compare to the poor wealth group of farmers.

Table 29. Linear regression model of parameter estimates for factors explaining the variations in feed water productivity and livestock water productivity in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Predictor variables	Coefficients β (SE)	
	FWP(kg m ⁻³)	LWP(USD m ⁻³)
Farming experience of household head (years)	-0.05(0.06)	-0.01(0.05)
Formal education completed of household head (years)	-0.26(0.19)	0.26(0.15)
Age dependency ratio (dimensionless)	-1.19(1.12)	-0.27(0.90)
Family labour force (adult equivalents)	2.04(0.59)**	-1.00(0.48)*
Cultivated land (ha)	7.30(1.18)***	-2.62(0.95)**
Total value of grains per cultivated land ('000 USD/ha)	36.63(5.01)***	-1.13(4.06)
Livestock holding (TLU)	-1.61(0.30)***	0.76(0.24)**
Membership of dairy cooperatives (0 = no; 1 = yes)	-0.72(1.19)	2.65(0.96)**
Access to credit for agricultural inputs (0 = no; 1 = yes)	3.93(1.58)*	5.26(1.28)***
Access to agricultural trainings (0 = no; 1 = yes)	7.05(1.34)***	4.96(1.09)***
Medium wealth group = 1, otherwise = 0	-2.13(1.78)	5.98(1.44)***
Better-off wealth group = 1, otherwise = 0	-2.83(2.68)	10.34(2.17)***
Constant	24.89(5.22)***	15.35(4.23)***
R-squared	0.67	0.64
Adjusted R-squared	0.64	0.61
F(12, 146)	24.86	21.48
Prob > F	0.000	0.000
Root MSE	0.067	0.054
Number of observations	159	159

Coefficients are significant at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ level.

FWP = Feed water productivity, LWP = Livestock water productivity, TLU = Tropical livestock unit, USD = United States Dollar, SE = Standard errors (in parentheses).

Coefficients of FWP and LWP were multiplied by a constant number (100) to improve presentation. Poor wealth group used as reference category.

4.8. Farmers' Perceived Rankings of Constraints of the Mixed Crop-Livestock Production

Rankings on the major production constraints of the farm components in the mixed crop-livestock system are presented in Tables 30 through 33. After enumeration of the major felt problems to increase the livestock, forage and crop productions, rank indices for the perceived constraints were derived based on the response frequencies of sampled

farmers. The magnitude of the rank index value shows the severity of the problem relative to other constraints in the rank orders, the higher the index value the severe the problem was perceived.

4.8.1. Livestock production constraints

Cattle and sheep are the dominant livestock species reared in the study area. The constraints which were restraining increased/improved livestock production (cattle and sheep) are presented in Table 30 and 31. Shortages of land and feed ranked as the most important limiting constraints, even though the rankings were prioritized vice versa for cattle and sheep production. Diseases prevalence and inadequate veterinary coverage were ranked as the third and fourth important constraints for cattle production (Table 30), while they were ranked at par as the third important constraints for sheep production (Table 31).

Table 30. Constraints limiting cattle production as ranked by sampled respondent farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Constraints of cattle production	Wealth group						Total	
	Poor		Medium		Better-off		HH	RI
	HH	RI	HH	RI	HH	RI		
Feed shortage	50	0.19	58	0.16	51	0.21	159	0.18
Shortage of land (grazing land)	47	0.17	58	0.16	48	0.19	153	0.17
Diseases prevalence	36	0.14	53	0.14	35	0.12	124	0.14
Inadequate veterinary service coverage	36	0.08	54	0.10	35	0.11	125	0.10
Lack of access to credit	36	0.12	45	0.11	24	0.08	105	0.10
Human labor shortage	37	0.07	53	0.08	33	0.11	123	0.08
Lack of improved genotype stock	33	0.09	43	0.08	21	0.04	97	0.07
Lack of AI service	30	0.05	43	0.06	16	0.04	89	0.05
Inadequate extension support services	30	0.05	41	0.05	16	0.02	87	0.04
Market inaccessibility	31	0.03	44	0.04	18	0.05	93	0.04
Drinking water scarcity	23	0.01	35	0.02	15	0.03	73	0.02

HH = number of respondents who ranked the constraints, RI = Rank Index.

Lack of access to credit, human labor shortage, lack of improved genotype stock, lack of AI services, inadequate extension support services, market inaccessibility, and drinking water scarcity were ranked from 4th to 9th as limiting constraints for cattle production, in order of importance. Among the constraints of cattle production, inadequate veterinary service coverage and lack of access to credit ranked 4th with similar index value; whereas inadequate extension support services and market inaccessibility ranked 8th with same rank index value (Table 30).

Regarding sheep production constraints, lack of access to credit, inadequate extension support services, market inaccessibility, lack of improved genotype stock, human labor shortage, and drinking water scarcity stood from the 4th to 8th rankings. Same rank indices were observed for diseases prevalence and inadequate veterinary service coverage both ranked as the 3rd important, whereas market inaccessibility and lack of improved genotype stock ranked as the 6th important constraints limiting sheep production (Table 31).

Table 31. Constraints limiting sheep production as ranked by sampled respondent farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Constraints of sheep production	Wealth group						Total	
	Poor		Medium		Better-off		HH	RI
	HH	RI	HH	RI	HH	RI		
Shortage of land (grazing land)	50	0.22	56	0.20	49	0.28	155	0.23
Feed shortage	46	0.19	51	0.17	39	0.20	136	0.18
Diseases prevalence	36	0.12	46	0.12	26	0.11	108	0.12
Inadequate veterinary service coverage	36	0.09	51	0.12	32	0.16	119	0.12
Lack of access to credit	36	0.13	42	0.12	20	0.08	98	0.11
Inadequate extension support services	31	0.09	39	0.09	14	0.04	84	0.08
Market inaccessibility	30	0.05	39	0.06	12	0.04	81	0.05
Lack of improved genotype stock	29	0.06	37	0.06	12	0.03	78	0.05
Human labor shortage	30	0.03	40	0.04	13	0.04	83	0.04
Drinking water scarcity	22	0.01	31	0.02	10	0.03	63	0.02

HH = number of respondents who ranked the constraints, RI = Rank Index.

4.8.1.1. Forage production constraints

Problems complained as limiting constraints for improved forage production and utilization by sampled respondent farmers are presented in Table 32. Shortage of land on which to graze livestock or grow forage and lack of locally adaptable improved forage seeds/seedling were the two most limiting constraints of forage production with the higher rank indices in order of importance. Inadequate extension support service provisions and shortage of human labor targeted in the production and use of improved forages were the third and fourth ranked constraints limiting forage production and utilization. Lack of access to credit and prevalence of forage pests were the fifth ranked problems with same rank index value. Other forage production constraints complained by farmers were weeds infestations, shortage of fertilizers, shortage of animal labor and forages plant diseases, which were ranked from 6th to 9th in order of importance.

Table 32. Constraints limiting forage production as ranked by sampled respondent farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Constraints of forage production	Wealth group						Total	
	Poor		Medium		Better-off		HH	RI
	HH	RI	HH	RI	HH	RI		
Shortage of land	50	0.20	58	0.19	51	0.23	159	0.20
Shortage of locally adaptable improved seeds/seedlings	49	0.18	55	0.16	47	0.19	151	0.18
Inadequate extension support services	39	0.14	56	0.16	37	0.14	132	0.15
Shortage of human labor	40	0.11	46	0.11	27	0.10	113	0.11
Lack of access to credit	49	0.09	46	0.06	38	0.11	133	0.08
Pests	31	0.08	43	0.09	19	0.06	93	0.08
Weeds	34	0.08	44	0.08	22	0.05	100	0.07
Shortage of fertilizers	35	0.06	43	0.06	21	0.05	99	0.06
Shortage of animal labor	18	0.01	31	0.05	23	0.07	72	0.04
Diseases	30	0.05	35	0.04	7	0.01	72	0.03

HH = number of respondents who ranked the constraints, RI = Rank Index.

4.8.2. Food-feed crop production constraints

Major constraints limiting food-feed crop production and severity of the enumerated problems as depicted by the magnitude of rank index values are summarized in Table 33. Shortage of cropland were the limiting constraint complained by most of the farmers as the prime constraint to increase food-feed crop production. Shortage of inorganic fertilizers stood as the second most important problem, whereas shortage of locally adaptable improved seeds and lack of access to credit were at par with similar rank index value and ranked as the third important constraints of food-feed crop production. Shortage of animal and human labour, and inadequate extension support services were ranked from fourth to sixth influencing constraints to increase the food-feed crop production in order of importance. Weeds and crop pest infestations ranked seventh with same rank index value, whereas diseases prevalence/occurrence was the least ranked constraint of food-feed crop production.

Table 33. Constraints limiting food-feed crop production as ranked by sampled respondent farmers in the mixed crop-livestock system of *Debre Berhan* milkshed, central highlands of Ethiopia

Constraints of crop production	Wealth group						Total	
	Poor		Medium		Better-off		HH	RI
	HH	RI	HH	RI	HH	RI		
Shortage of land	49	0.20	56	0.18	50	0.20	155	0.19
Shortage of fertilizers	44	0.16	55	0.15	46	0.15	145	0.15
Shortage of locally adaptable improved seeds	47	0.10	58	0.11	48	0.16	153	0.12
Lack of access to credit	41	0.14	56	0.13	38	0.10	135	0.12
Shortage of animal labor	38	0.10	54	0.10	36	0.08	128	0.09
Shortage of human labor	45	0.07	53	0.07	41	0.10	139	0.08
Inadequate extension support services	37	0.07	52	0.07	33	0.07	122	0.07
Weeds	35	0.06	50	0.06	29	0.05	114	0.06
Pests	31	0.07	45	0.08	20	0.04	96	0.06
Diseases	36	0.04	49	0.05	28	0.06	113	0.05

HH = number of respondents who ranked the constraints, RI = Rank Index.

5. DISCUSSION

5.1. Household Demographic and Farm Resources Characteristics

The household heads (respondents), household demographic characteristics and key farm resources holdings across wealth group of farmers are discussed in the following sub-sections.

5.1.1. Household demographic characteristics

The gender of household head being male dominated in the present study is similar with the observations of several studies as reported by Hussen *et al.* (2016) in *Jimma* Zone, Geleti *et al.* (2014) in *Bako* and *Nekemte* areas and Wondatir *et al.* (2011) in *Debre Berhan*, *Jimma* and *Sebeta* areas. It is also similar with CSA and World Bank (2013) report, which generally reflects the national profile.

The proportions of married (81.1%) and not married (1.3%) household heads are comparable with livestock (sheep) keepers in *Debre Berhan* peri-urban areas (Tsega *et al.*, 2014). These figures are found to be higher than those married and lower than the unmarried proportions reported for marital status of the household members aged 10 years and above revealing 50.5% married (49.9% monogamous and 0.6% polygamous) and 37.8% never married in the *Amhara* Region (CSA and World Bank, 2013). The overall proportion of divorced in the study area (6.8%) is comparable with the *Amhara* Region (6.3%), but higher than the national average (2.6%) documented by CSA and World Bank (2013). Compared with the values reported by same source, the widowed proportion (3.8%) is lower than the *Amhara* Region of 4.5% but similar with the national average of 3.8%. The proportions of widowed and divorced household heads were considerably higher in the poor farmers and rarely in the medium. However, those proportions were not apparent in the better-off farmers. These may indicate that wealth may have contributed to the maintenance of family health and marriage stability.

The mean age of household heads (46 years) is comparable with a report on the average age for *Nekemte* and *Bako* which was 47 years (Geleti *et al.*, 2014). The average farming

experience of respondents of about 30 years in the study area indicates that individuals started engagement in the farming activities at around 16 years of age. However, under Ethiopian context boys and girls start earlier in life helping their families with certain agricultural activities such as herding, feeding and watering of livestock and performing agronomic activities such as ploughing, weeding, harvesting and threshing in the crop production. Regardless of their wealth status, the vast majority of household heads were enrolled in elementary level of formal education (grade 1-8), moreover, considerable proportion of household heads were able to read and write from informal learning. The average formal education level of 2.7 years for all farmers (ranged from 2.3 to 3.0 years) in the study area is comparable with the education level of household heads reported by Melesse *et al.* (2008) for Wulinchity (2.5 years) and Melkawoba (3.1 years) areas located in the central rift valley of Ethiopia. The education level of household heads is often believed to have an influence on the decisions of improved technology adoption (Knowler and Bradshaw, 2007) and the predisposition of household heads to let their family members attend formal schooling.

The overall average family size of 5.86 in the present study is higher than the national average of 5.14 reported by CSA (2016), which is closer to the family size of the poor but lower than the wealthier group of farmers in the study area. It is still much higher compared to the average family size for both the *Amhara* Region (4.62) and the North *Shewa* Zone (4.45), where the study site is located (CSA, 2016). The lower family labour force availability among the poor farming families than the other wealth groups could be explained by the observed small family size coupled with the higher age dependency ratio attributed to the presence of more inactive dependent family members, especially children under 15 years of age. The age distribution of family members and the consequent state of age dependency ratio, particularly among poor farming families, are in agreement with the national demographic characteristics (CSA, 2015) which explains that about 45% of the population are under 15 years of age, reflecting the dominance of the young section of the population with less contribution to the farming labour force requirement. The higher illiteracy and lower elementary and secondary school enrolment rates of family members observed more among the poor than the wealthier households may imply that the capability and willingness of farmers

to invest in learning themselves and their families successfully is influenced by wealth status.

5.1.2. Farm resource holdings

Land and livestock are key farm resources in the mixed crop-livestock system of the central highlands of Ethiopia. The situations in relation to the wealth status of farmers in the study areas are discussed hereunder.

5.1.2.1. Land holding

The overall average of cropland entitled per household (1.38 ha) for sampled farmers is higher than the average holding for the national, *Amhara* Region and the north *Shewa* Zone at 0.95, 1.08 and 1.20 ha per household, respectively (CSA, 2016). However, the cropland entitlement for the poor group of sampled households is lower than the CSA (2016) report for the *Amhara* Region and the north *Shewa* Zone. The difference may be partly attributed to the weighted average influenced by the higher cropland holding of the wealthier groups and the relatively similar proportion of sampled farmers from each wealth category in the present study, which may not reflect the proportion of farmers in the national⁴, regional⁵ and zonal⁶ profile of wealth status stratifications. Moreover, the larger size of cultivated cropland among sampled farmers at all levels may be attributed to the size of additional cultivated cropland acquired through temporary lease agreements in the study area. Regardless of farmers wealth status, the size of grazing land per household in the present study was higher than 0.12, 0.07 and 0.14 ha for the national, *Amhara* Region and north *Shewa* Zone, respectively (CSA, 2016). The average private grazing land (0.52 ha) observed in the present study was somehow higher than 0.46 ha of the average size of private grazing land per household reported by Hassen *et al.* (2010) for the high altitude Zone in the *Basona Worana* district in the central highlands of Ethiopia. Nonetheless, the use of feed and the water associated with feed production from communal grazing land for livestock feeding is directly linked to the livestock herd size (Haileslassie *et al.*, 2009; Kebebe *et al.*, 2015; Bekele

⁴ Country level (Ethiopia)

⁵ *Amhara* National Regional State in Ethiopia

⁶ North *Shewa* Zone in *Amhara* National Regional State

et al., 2017). Hence, the discrepancy in the grazing land use per household between wealth groups of farmers is mainly a reflection of the herd size and the dividend from communal grazing land, which is consistently higher for the wealthier than the poorer.

5.1.2.2. *Livestock holding*

The aggregated livestock holding per household averaged for all farmers (8.45 TLU) in the present study is higher than the value reported by Hassen *et al.* (2010) for *Basona Worana* district (6.15 TLU), but lower than that reported by Wondatir *et al.* (2011) for *Debre Berhan* (20.1 TLU) area in the Central Highlands of Ethiopia. These differences were also consistently apparent for the different species of livestock. In contrast to the present report of 4.68, 1.80 and 1.97; Hassen *et al.* (2010) reported 4.45, 0.76 and 0.94 whereas Wondatir *et al.* (2011) reported 14.6, 2.5 and 3.0 average TLU per household for cattle, sheep and goats, and equines holdings, respectively. These differences could be attributed to the sampling area and study population coverage, where by the former author considered the entire *Basona Worana* district while the later author considered the population around *Debre Berehan* urban district.

5.1.2.3. *Livestock density on agricultural land use for feed sourcing*

The density of livestock per land use type reflects the relative share of agricultural land use types from which the bulk of feed biomass is sourced in support of livestock. The variation in the prevailing livestock density across wealth groups depended on the land and livestock ownership. The grazing pressure was more intense among the wealthier because of the larger size of livestock ownership relative to the land holding. However regardless of wealth status, overall the stocking rate is too high even when the total agricultural land (grazing and cultivated land combined) is considered. In the present study, the overall livestock density exhibited on grazing land (7.6 TLU/ha) and on agricultural lands used for feed sourcing comprising of grazing land and cultivated cropland (2.6 TLU/ha) were higher than the livestock density of 2.4 TLU/ha on the whole area of the region and 0.6 TLU/ha on the rangelands of the *Amhara* Region in Ethiopia (WBISPP, 2002). The present observation reflected high pressure of livestock on agricultural land, which is in agreement with the report of Descheemaeker *et al.* (2010) on the livestock density on grazing land of the *Lenche Dima* watershed in North

Wollo Zone of Amhara Region (7.1 TLU/ha), which explained an alarming state of degradation of the rangelands due to overstocking.

The livestock density on grazing land is almost two-fold the density on cultivated cropland (4.0 TLU/ha), which shows the importance of crop production for livestock feed sourcing. The relative difference in livestock density on agricultural land use types could be partly an indication of the alienation of livestock from relatively fertile grazing lands due to conversion into croplands. This state of affair ultimately affected the size and productivity of grazing lands. In agreement with this, WBISPP (2002) reported that expansion of cultivation occurs at the expense of communal grazing lands, woodlands and forests. In doing so relatively better lands in soil fertility and with gentle slopes are usually allocated for crop cultivation while the less fertile are left for livestock grazing. The decreasing trend in the area of grazing land further intensify the livestock density and increases the pressure on the grazing land resulting in aggravated land degradation, declining soil fertility and eventually decreases in feed biomass yields. The insufficiency and decreasing feed biomass from grazing lands in turn lead to an increasing reliance on crop residues for livestock feed supply, which signifies that grazing lands converted to croplands are not a total loss to the livestock. However, the amount and quality of crop residues obtained from extended croplands may not compensate the feed biomass from converted grazing lands.

5.2. Existing Farming Practices in the Study Area

Crop-livestock production systems are land-use systems in which livestock husbandry and cropping are practiced in association (Sumberg, 2003). The mixed crop-livestock farming, which is principally rainfed is the typical production system in the study area. Similarly, several authors documented that the highland farmers in Ethiopia are highly dependent on rainfed agriculture (Peden *et al.*, 2006; Hailelassie *et al.*, 2008; Erkossa *et al.*, 2014). The commonest forms of integrations between crop and livestock production where livestock provide traction services (ploughing, threshing and transportation) and manure for crop production and in turn the use of crop residues for livestock feeding are well established in the study area. In agreement with these forms of integrations, Descheemaeker *et al.*, (2010) explained that the mixed crop-livestock

systems provide farmers with several assets that emerge both from the separate crop and livestock production components, and from the interactions between the two.

5.2.1. Crop production

Crop production in the mixed crop-livestock system has multiple objectives. In line with farmers objectives in the study area, cereals and pulses are grown in a certain cropping pattern, primarily to provide food for the household. The aim for crop residues production to provide feed for livestock is secondary as a byproduct of grains. Surplus crop production for market to accumulation wealth is of seldom occurrence, but it is potentially relevant among the wealthier group of farmers. However, when the household has immediate cash needs but deprived of other means such as livestock for sale or credit to acquire cash, small amount of crop is sold or exchanged to attain the urgent needs, even when no surplus crop yield is available. It could also be selling one type of crop to get the other(s) needed. In that case the household, especially the poor group will be forced to purchase or rely upon food aid for the staple food crops in the later remaining period of the year or until the next harvest.

5.2.1.1. Food-feed crop types and cropping pattern

The major food-feed crops grown by farmers in the main growing season are multiple combinations of cereals (mainly barley and wheat) and pulses (mainly faba bean and field pea). Eventually, the types and amounts of food grain and crop-residues harvested in the season depends on the cropping pattern. Cropping pattern in the present context is related to the proportion of the plot area covered under different crops in the growing season. According to several observations, apart from the natural features such as soil type, rainfall, and other factors like price and input, the farm size holding and land tenure system affect the spatial and temporal arrangement of crops to be grown in a parcel of land (Singh, 2012; Mandal and Bezbaruah, 2013; Nugroho and Nuraini, 2016; Ying-bin and Wei-min, 2016). Hence the prevailing cropping pattern at farm level determines the quantity and quality of livestock feed sourced from crop production among wealth group of farmers. The present observation is also in agreement with several reports which documented that crop residues of cereals and pulses provide an important contribution to the basis of ruminant animals diets in a wide range of agro-

ecologies and farming systems (Wright *et al.*, 2012; Duncan *et al.*, 2013; Duncan *et al.*, 2016). Moreover, farmers tend to grow more than one crop type in the season to lessen or avoid the risk of crop failure in addition to the need to supply a variety of crop types to the household needs. In line with this, FAO (2011) suggested that options adapted to rise the opportunities of crop diversification reduce the risk and lessens the need for periodic liquidation of capital (e.g. livestock sale) in times of crisis due to climate variability.

The cropping pattern of specified major food-feed crops grown have variable intensity between wealth groups of farmers. However, among the cereals barley is identified as the most important crop of the area grown by majority of the farmers, which according to Hailelassie *et al.* (2007) is also considered as a suitable crop to the soil and climate of the highland areas. Barley and wheat (the second important cereal) are grown in rotation with pulses like faba bean and field pea, aiming the maintenance of soil fertility due to nitrogen fixation by the legumes (pulses). In agreement, Amsalu and de Graaff (2006) reported that crop rotation along with other erosion control measures is a widespread practice undertaken by local farmers for soil fertility maintenance. Moreover, Hailelassie *et al.* (2007) explained that crop rotations arranged depending on soil fertility and nutrient requirements would help to avoid the threats for the long-term sustainability of the system and enhance profit gain from nutrients enrichment processes. In addition, Rockström *et al.* (2009) also suggested appropriate crop rotation combined with good farm management would help to reduce the use of pesticides. Hence, farmers choice of the cropping pattern and crop management practices have an influence on the nutrients fluxes in the system and would have implications to the food-feed crops productivity and ultimately to feed supply for livestock production.

5.2.1.2. *Land allocation and tillage*

Farmers may have different reasons for making the choices of crops grown. Of course, the choices of crop combinations and subsequent land allocation depends on the size of land ownership, the land fertility, the precursor crop and what the farmers want to grow for their own home use, to obtain livestock feed or to sale grains. The larger plots of cropland allocation to cereals mainly to barley growing irrespective of farmers wealth status might be because cereals constitute the major portion of the staple food crops for

the community. Once the decisions on the crop type combinations and land allocation have been made tillage operation will follow based upon the chosen crop types. Priority for thorough land preparation is given for cereals than pulses, which is illustrated by the more frequent tillage passes on plot of land allotted for cereals. The trend is similar among wealth group of farmers except that the poorer farmers are halted to perform tillage frequency as they would like to do so, because of the limited animal and human labour resources supply available or they could afford. Similarly, Temesgen (2007) reported that among farmers within a specified area, the number of tillage operations in any production system to be influenced by the skill of the farmer (years of farming experience and educational level), by the availability of production resources (family labor, oxen and land), and by the farmer's perception about the purpose of tillage (such as moisture conservation and weed control).

In the study area soil tillage for cropland preparation is entirely performed with draught animals, particularly oxen. In line with this, Gebregziabher *et al.* (2006) described oxen drawn traditional tillage implement called ard plow, (*Maresha* in local Amharic language) is a tool that most of Ethiopian farmer used to till the land. In addition, Temesgen (2007) explained that traditional tillage systems practiced by farmers in Ethiopia are characterized by repeated and cross plowing with an indigenous plow (*Maresha*). Moreover, according to the study report of Temesgen *et al.* (2008), farmers perform repeated tillage for the purposes of weed control, initiate weed germination, moisture conservation, manure incorporation and finally for seed covering.

The contribution of livestock labour to cropland preparation is among the key attributes which demonstrated the crop-livestock integration. Frequent tillage operation increases livestock labour contribution in the farming system, which may have also influence on food-feed crops yields, which may eventually contribute to improved feed and livestock water productivity. In this regard several studies demonstrated that traction service for cropland preparation has a positive influence on increased livestock feed sourcing and livestock and feed water productivity (Hailelassie *et al.*, 2009; Descheemaeker *et al.*, 2010; Kebebe *et al.*, 2015). However, Temesgen (2007) and Temesgen *et al.* (2008) reported that highly repeated and cross plowing may lead to land degradation and needs a study why farmers undertake repeated plowing and the promotion of conservation

tillage systems that advocate minimum soil disturbance to alleviate land degradation problems has to depend on the soil type and slope of the cultivated land.

5.2.1.3. Crop yield

The explanations to be pointed out for the justifications of the differences in the yield attained from different crops grown by wealth group of farmers may follow the reasons attributed to the variations in cropland allocation and land preparations. Concomitantly, the differences in the crops grain yield per household and per hectare across wealth group of farmers mainly attributed to the plot size, soil fertility status and agronomic practices and level of farm input utilization including animal and human labour uses. The wider gap observed in the variation of yield of cereal crops than pulses between the wealth groups may be due to the usual practice of farmers to apply inorganic fertilizers for cereals crops than pulses whenever afforded. Owing the linkage between grain and crop residues yield related to harvest index the difference in grain yields among wealth group of farmers can be directly translated into the varied amount of crop residues yield acquired for livestock feed supply. Several researches explained that farmers wealth status realized by the availability of land, livestock and labour which is also evidenced in the present study has permitted farmers to channel relatively more input to increase agricultural productivity (Hailelassie *et al.*, 2006; Zingore *et al.*, 2007; Abebe, 2013). For instance, Tittonell *et al.* (2005) noticed different patterns of resource flow at farm scale, nutrients accumulation on farm and the input utilization intensity difference due to the wealth status of farmers. The researches further reflected that richer farmers purchase and use larger amounts of mineral fertilizers and able to apply even in their furthest crop fields. Moreover, the wealthier also have organic resources which they mainly used near the homestead. Consequently, resource endowment and the dynamics of input utilization at farm level may result in soil fertility status variations of the different farms which potentially leads to difference in crop biomass productivity between wealth groups of farmers.

5.2.2. Livestock production

Keeping a blend of livestock species in the mixed farming systems is a norm. The livestock composition in the mix comprised of cattle, small ruminants (sheep and

goats), equines (donkeys, horses and mules) and poultry. The commonest variation across wealth group of farmers in the study area is the size of each species in the mix rather than the species composition.

5.2.2.1. *Holding size and herd structure*

The numerical contribution of each species in the herd/flock is found to be unanimously linked with the wealth status gradient of farmers. Similar observation was reported by Descheemaeker *et al.* (2010) in *Lenche Dima* watershed of *Amhara* Region where the holding size of each livestock types/species is strongly dependent on the farmer's wealth status. Moreover, irrespective of farmers wealth status the relative proportions of cattle and small ruminants (sheep) in the species mix are the dominant, which is in concordance with reports of Gryseels (1988) and Wondatir *et al.* (2011) in the central highlands of Ethiopia.

Cattle holding and herd structure: The existing cattle structure scenario justify the critical importance of breeding animals to produce replacements for oxen besides to milk production as oxen are decisive for the traction (ploughing and threshing) requirements of crop production in the mixed system. This is ascertained by the dominance of males with highest contribution of oxen and followed by the dominance of cows from the female category in the overall cattle herd structure, regardless of farmers' wealth status. This situation has been demonstrated by various reports in the mixed crop-livestock farming systems of Ethiopia where cattle keeping is central to support crop production due to provisions of animal power for ploughing and threshing, and manure for soil fertility maintenance (Amede *et al.*, 2009; Fuller and Aye, 2012; Descheemaeker *et al.*, 2013; Herrero *et al.*, 2013; Jaleta *et al.*, 2013).

The shortage of home grown replacements for oxen and cows could be attributed to a number of interrelated reasons. Many of the farmers may prefer to sale and or given out young animals, which may prolong the retention of old animals in the herd before natural replacement, resulting in a limited culling rates of older animals. Death of young stock may play its share to reduce their proportion in the herd structure. In addition, the low reproductive performances of cattle, which are evidenced by the age at first calving

and calving interval reports of 50.6 and 22.2 months in the central Ethiopia (Duguma *et al.*, 2012), and 41.8 and 15.9 months in the *Debre Berhan* area for crossbred cows (Wondatir *et al.*, 2011), respectively may also contribute to the shortage of home grown replacements to maintain the existing herd. Moreover, the retention of trained older oxen that are required for adequate ploughing of cropland until the young bulls are trained well and recruited to deliver the most needed cattle service in the mixed farming systems, may also implicate the current herd structure.

Small ruminants holding and flock structure: Though the numbers of small ruminant holdings are aligned with the betterment of farmers wealth status, small ruminants particularly sheep are kept in large numbers compared to cattle and equines in any of the household whether poor or rich. In agreement with Tibbo (2006), the possible reasons could be their initial investment to start with, the shorter production cycle and faster growth rate to get their benefits relatively in short periods of time, and greater environmental adaptability. They are also easier to restock even after loss due to adverse calamities such as death. Among small ruminants, sheep production is a domain of interest in the central highlands of Ethiopia. In the sampled farms of the present study sheep constituted the highest proportion (96%) of small ruminants, irrespective of wealth status. Lack of adaptable goats to the area and limited availability of browsing plants may be cited among the challenges for goat production and the minimum holdings per household.

In the present observation, the average holding size of sheep flock (17.2 heads ranging from 8.5 to 26.6 among farmers wealth status) was higher than 13.2 heads of sheep in *Gumuz* sheep (Abegaz, 2011) but lower than *Menz* with an average holding of 32 animals (Getachew *et al.*, 2010). Ewes constituted about 45% while does represent 39% of the sheep and goats flock, respectively which is comparable to the proportion of breeding ewes (47%) reported for *Menz* sheep in north *Shewa* (Getachew *et al.*, 2010) but lower than 50% reported for *Gumuz* sheep in north Gonder (Abegaz, 2011). Does in the study area are slightly lower than 44% reported by Tolera, (1998) for Kochore district in the Southern Nations, Nationalities and Peoples Regional State of Ethiopia.

Moreover, varied proportions of other age groups of sheep were observed with other study results reported in different parts of the country. For instance the proportion of ram and ewe lambs of 6-12 months of age which accounted for 26% of the flock in the present study is higher than 16.% reported for *Gumuz* sheep (Abegaz, 2011). The proportion of lambs (>6 months) 22% in the present study is lower than 27% reported by Abegaz (2011) for *Gumuz* sheep and 34% reported by Getachew *et al.* (2010) for *Menz* sheep. The proportion of rams and castrates of sheep although small, some variations observed between the present 4.5% and 2.7% with the proportions reported by Getachew *et al.* (2010) at 5.7% and 3.9% for rams and castrates, respectively. Even more higher proportion of rams (7.2%) was reported by Abegaz (2011) for *Gumuz* sheep. These variations may be attributed to the versatility of these classes of sheep in the flock dynamics. For instance, higher offtake usually happens with castrates, ram and ewe lambs than ewes. On the other hand, the mortality rate among the lambs is usually higher than adults.

The ram to ewe (1 ram to 10 ewes) and buck to doe (1 buck to 9.4 does) ratios observed for all farms in the present study are higher than the 1 ram to 8.3 breeding ewes ratio reported for *Menz* sheep by Getachew *et al.* (2010) in the mixed farming system of central highlands and the 1 ram to 7 ewes ratio for *Gumuz* sheep in Metema district of the *Amhara* National Regional State reported by Abegaz (2011), but lower than the recommended ratio of fertile sires and dams (one ram/buck to 20–25 ewes/does or 3 per 100 ewes/does in a year-round mating) documented by ESGPIP (2008). However, the age of the breeding ram/buck, the length of the mating season and the environment in which the animals are kept may influence the ratio (ESGPIP, 2008). The present ram to ewe and buck to does ratio shows the presence of too much sires for the dams which indicated the possibility to increase an offtake or enter into fattening of rams and bucks, provided the existence of more sires for flock mating in the individual farms. The possibility of taking aside extra rams/bucks from breeding service could also be justified by installing breeding programs in the community which promote sharing of selected/superior sires among neighboring farmers.

Equines holding and herd structure: The dominance of donkeys (68%) than horses (32%) in the equine population observed in the current study is in line with donkey and

horses proportions of 79% and 21% at the national, 86% and 14% at the regional, and 90% and 10% at the zonal levels, respectively (CSA, 2015). However, the proportions of horses in the present study is higher than the CSA (2015) report.

The average holdings per household of 2.26 donkeys and 1.05 horses in the present report is higher than reported values of 0.48 and 0.13 for the national, 0.61 and 0.10 for the regional, and 0.83 and 0.09 for the zonal average holdings of donkeys and horses, respectively (CSA, 2015). Moreover, the herd structure is dominated by adults in both equines, where proportion of jennets (55%) and mares (53%) takes the lead, followed by jacks (24%) and stallions (30%). The proportions of young equines (<3 years) representing 21% in donkeys and 17% in horses, which are not frequently active in delivering transportation services are the least in both equines. Even though the proportions in the present study and CSA (2015) report showed variation, the general trends in the age and sex distributions of donkeys and horses herds replicate similar pattern, where the adult females dominate the males followed by juveniles. For instance, in agreement with the patterns of the age and sex distributions in the study area, (CSA, 2015) reported the donkeys age and sex distribution of 42%, 34%, 24% at the national 45%, 28%, 27% at the regional, and 42%, 37%, 21% at the zonal levels of jennets, jacks and foals (<3 years), respectively. The same report showed the age and sex distribution of horses as 41%, 40%, 19% at the national, 53%, 31%, 16% at the regional, and 62%, 17%, 21% at the zonal for the mares, stallions and foals (<3 years) in the horses' herd structure, respectively.

The proportion of equines and their age structure dominated by adults shows the relative importance of equines for transportation service, whereby donkeys are more frequently required for most of the transportation services delivered in the study area. The dominance of the adult females depicts their numerical importance in reproduction to maintain the replacements for the herds and also to take advantage of the combined benefits from females for breeding and transport services.

5.2.2.2. *Livestock population dynamics*

The livestock herd dynamics indicates the periodical management of owners and natural events occurred in the herd. It involves the incoming, outgoing and retained individual animals in the livestock herd/flock in a specified period of time. The outgoing could occur in the form of offtake (sale, slaughtered, given out) and death of the animals for various reasons. While individual animals could join the herd due to the natural reproduction (births), purchased, received as a gift or share farming/rearing. Owners managed incoming and outgoing events in the livestock herds/flocks is attributed to the utility and life cycle of species in the prevailing production system. For instance, in the mixed crop-livestock systems these dynamics are not frequent and neither occurred in large numbers for large animals, but relatively could happen in the case of small ruminants.

Cattle herd dynamics: The incoming and outgoing annual events in the cattle herds of the mixed production system were not noticeable even among the wealthier farmers. Even if holdings vary between wealth status of farmers the overall possessions are very small compared to the pastoral systems where the cattle offtake, death and calving rates played a prominent role in the cattle dynamics among pastoralists as illustrated by Desta and Coppock (2002) in southern Ethiopian rangelands and by Mwanyumba *et al.* (2015) in Garissa County of Kenya. Besides to the low annual reproduction rate of cattle compared to small ruminants, the maturity age for cattle disposal through sale or slaughter is prolonged resulting in a very small to none annual events of incoming and outgoing of animals in normal situation, unless catastrophic event due to abrupt death (disease outbreak) had occurred during the year.

The calving rate (50% ranging from 45 to 53%) in the present study is similar to the national (51%) but higher than both the regional (45%) and zonal (41%) calving rates reported by CSA (2015). The incoming cattle due to births in the present study contributed for 74% of the annual inflow for all farms considered in the present study. Whereas the contribution of calving to the cattle stock buildup at the national, regional and zonal levels were 68, 62 and 55%, respectively (CSA, 2015), which are lower than the present observation. Moreover, according to same CSA document cattle purchase

contributed about 7.4% at the national, 8.5% at regional and 7.9% at zonal farmers levels of the cattle stock buildup, which is lower than the present report of 20% (ranging from 7.8 to 36.8%). Other means by which cattle are acquired (received as gift) is in small proportion accounting for only 6% (ranging from 0 to 14%) in the present study but these options were far lower at the national (1.3%), regional (0.7%) and zonal (1.2%) levels.

In the present study, an annual cattle offtake rate of 13.3% (range of 13.9-15.2% among wealth groups) had contributed to about 78% (ranging from 71 to 85% among wealth groups) of the annual cattle outflow. This proportion was higher than the contribution of offtake to the annual cattle outflow attained due to 12%, 13% and 11% annual cattle offtake rates which contributed to 68%, 74% and 69% of the outflows at the national, regional and zonal levels, respectively (Negassa and Jabbar, 2008). But the present offtake is lower than the annual gross commercial off-take rates of cattle (16%) including the highland areas of *Amhara*, *Oromia* and *Tigray* regions (Negassa and Jabbar, 2008). Sale of cattle represented 67% (ranging from 57 to 75%) of the annual offtake in the present study, whereas CSA (2015) reported the contribution of sale to offtake rate at proportions of 58%, 65% and 58% for the national, regional and zonal levels, respectively, which are lower than the present observation. Moreover, the present result indicated that slaughtering influenced cattle outgoing at a lower rate (3.5% ranging from 0 to 6%) than offering to others (8% ranging from 0 to 12%), which is in agreement with same CSA report which documented that, slaughtering accounted for 3.9, 4.5 and 5%; and whereas offerings accounted for 6.2, 4.5 and 6.1%. of the annual cattle outgoing at the national, regional and zonal levels, respectively.

According to the CSA (2015) report, death was responsible to reduce the annual cattle buildup by 32, 26 and 32% at the national, regional and zonal levels, respectively, which were higher than the contribution of death for cattle outgoing at 22% (ranging from 15 to 29%) observed in present study. However, the cattle death rate (3.7% ranging from 2.7-4.6%) in the present study is lower than the national (5.7%), regional (4.4%) and zonal (4.8%) cattle death rates CSA (2015).

The cattle herd dynamics portrays farmers efforts to obtain benefit from offtake, restocking the herd and retention of valuable categories of animals for the intended main purposes along with the inevitable natural events occurring in the herd. The numerical dynamics of cattle in the one-year period of time is not that much evident to show conceivable influence on the herd balance mainly because of herd size and short period of time, which necessitates longer period of inventory time to capture tangible picture on cattle dynamics in the mixed crop-livestock production system. However, at present the overall outflow and inflow dynamics of cattle in the prevailing mixed farming system, offtake and calving played the most obvious roles in regulating the annual herd balance.

Small ruminants flock dynamics: Because of their numerical dominance the annual dynamics in sheep flock is more important than goats in the present study area. The reduction (-11%) in the numbers of sheep at all farms maintained over the year exhibited a negative sheep flock buildup. This is in agreement with Negassa (2017), who reported a negative annual growth rates at national level in all livestock species except goats in female-headed households in Oromia Region (growth rate = ending stock/beginning stock - 1). The annual population growth trends in sheep and goat flocks were affected by the inflow (births, purchases, and gifts received) and outflow (sells, deaths, gifts, thefts) events occurring over the year (Negassa and Jabbar, 2008). Despite being the most common incoming routes than other events, lambing and kidding contributed 86% and 72% for the buildup and maintenance of sheep and goats flock balance, respectively. This is supported by the report of Negassa and Jabbar (2008) where sheep and goats birth accounted for 72-73% of the sheep and 79-83% of the goats inflows to population in the smallholder farmers. In the present study, purchasing was the second most important avenue of incoming sheep (13%) and goats (28%) into the flocks to sustain the reproduction and production of small ruminants. Likewise, Negassa and Jabbar (2008) reported purchase as the second contributor of the inflows of sheep and goats, but the magnitude under smallholder farmers was higher for sheep (25-27%) and lower for goats (17-18%) than the present observation. Inflows for sheep and goats due to received animals as gifts were reported at similar proportions of 3% by Negass and Jabbar (2008), which are higher than the present observations of incoming sheep and goats due to gift and share farming, which is less than 1% for both.

The present annual offtake rates of sheep (26%) and goats (24%) contributed largely to the outgoings at 76% (ranging from 73 to 83% among wealth groups) for sheep and 100% (range of 75 to 100% among wealth groups) for goats outflows. These offtakes are lower than the annual gross commercial off-take rates of 34% for sheep and 30% for goats reported by Negassa and Jabbar (2008) including the highland areas of *Amhara*, *Oromia* and *Tigray* regions. However, comparatively the contribution of offtake rates to the outflows were 66-70% for sheep and 59-74% for goats (Negassa and Jabbar, 2008), which were lower than the present observation. Moreover, the magnitude of sale and slaughter in the present result contributed about 68% and 32% in sheep and 82% and 18% in goats offtake, respectively. These contributions are higher than the incidences of offtake elements reported for sale and slaughter which accounted for 40% and 27% in sheep and 49% and 22% in goats offtake, respectively (Negassa and Jabbar, 2008). In addition, CSA (2015) documented that sales contributed 46, 45 and 41% of sheep and 40, 38 and 26% of goats; and slaughtering contributed 22, 31 and 22% of sheep and 19, 27 and 21% of goats at the national, regional and zonal level, respectively, which ascertained the importance of sheep and goats marketing and slaughtering on the annual outflow due to offtake routes. In the present study, offering as a way of sheep and goats outgoings from their flocks was encountered in a very small proportion for sheep (0.5%) but not in goats, however, though small, CSA (2015) reported an annual practices of offering at rates of 2.3, 1.9 and 2.3% for sheep and 2.8, 1.8 and 3.4% for goats at the national, regional and zonal level, respectively.

Mortality of sheep (7.7% for all farms) was another outlet that considerably affected sheep outgoing in the present study accounting for 23%, but which was not observed over the year in goats owned by few sampled farmers in small numbers. Moreover, the number of sheep lost to predators and/or theft was very small (1%). Whereas according to Negassa and Jabbar (2008), death rates of 17-32% of sheep and 13-19% of goats accounted for 29-34% of sheep and 23-41% of goats outflows, which were higher than the present observations. The influence of mortality is further substantiated by the survey result documented for sheep death rates of 15, 15 and 16% contributing for 29, 22 and 35% of the outflows; and goats death rates of 17, 22 and 26% contributing for

38, 33 and 49% of the outflows at the national, regional and zonal level, respectively (CSA, 2015).

Unlike cattle, the flock dynamics of small ruminants particularly sheep (comprising 96% of the small ruminants in the study area) was more recurrent, i.e. the inflow and outflow cycle occurred more frequently in sheep flocks than cattle herds. Even though the number of small ruminants (sheep) kept at household was more than cattle, their populations were not as stable as other livestock types during the time span of the inventory period. The overall reduction in the mean number of sheep flock size was evident regardless of farmers wealth group. However, in absolute number the offtake of sheep followed the wealth gradient, the highest being among the better-off followed by medium and poor farmers.

Small ruminants in the mixed farming system are probably the most versatile animals used to fulfill the immediate cash needs of farmers irrespective of their wealth status. They can be destocked and restocked relatively in less expenditure with reasonable period of time than large animals. In the inflows and outflow dynamics of small ruminants birth contributed most for the buildup and maintenance of the flocks, however, is was counterbalanced by high mortality. Similarly, according to Negassa and Jabbar (2008) farmers in the mixed farming system relied less on market to maintain and buildup flocks. On the other hand, it was observed that offtake (sale, slaughter) and death are the major avenues of sheep and goats outflows. These counteracting incidences have an effect on the benefit gain from the production of small ruminants, particularly sheep in the study area. Generally, the offtake rates are considered as low and the death rates as high under the current state of small ruminants production compared to the national average rates, which do not show improvements through years as it has been explained by Negassa and Jabbar (2008) and CSA (2015). Given the prevailing conditions; improvement in productivity, increase in reproduction, reducing mortalities will bring an opportunity for increasing offtake are necessary to ensure sustained benefit from small ruminants (sheep) production to increase livestock water productivity.

Equines herd dynamics: The dominance of donkeys (68%) than horses in the study area is supported by the CSA (2015) report, even though, higher proportion of donkeys is documented constituting 79, 86 and 90% of the two equine populations in the national, regional and zonal levels, respectively (CSA, 2015). The variation could be associated with the more frequent and versatile use of donkeys as pack animals for transportation of agriculture inputs and outputs and beyond, like transportation of construction materials, firewood, water, which the horses are seldom used. Horses are usually used for human transport. Moreover, relatively the lower investment to own and maintain, and the ease of management even among the poor farmer may also contribute for dominance of donkeys over other equines. For instance, a case study conducted in different areas of the country; the west (Eastern *Harerge*), the north (Central *Tigray*) and central (Eastern *Shewa*) that made comparisons of draft animals (oxen, donkeys, horses and mules) rated donkeys higher, especially in the ease of management and feeding requirements than other animals (Marshall and Ali, 2000). Even in terms of economics donkeys were rated comparable to oxen, considering the purchasing price, daily expenses and returns to the household from using the animal (Marshall and Ali, 2000). Same study witnessed that, in *Shewa Zone* and *Tigray* about 85% and 49% of the household own donkeys with an average of 2.7 and 1.5 heads per household, respectively.

On-farm birth and purchase were the major sources of equines stock buildup and source of replacement at all the farms representing 87% and 13% of the incoming donkeys and 61% and 35% of the incoming horses into the herds, respectively. The contributions of other means to acquire equines over the year were very rare. The relative proportions of incoming sources of equines were in agreement with the CSA (2015) report, where births of donkeys represent 47, 49 and 55% and that of horses represent 46, 35 and 53% of incoming equines over the year at the national, regional and zonal level, respectively. Same report documented the contribution of purchase for the incoming donkeys at the proportions of 50, 49 and 45% and for horses at the proportions of 50, 59 and 47% at the national, regional and zonal levels, respectively. Moreover, minimum contributions of other incoming means (such as gift) to the herds buildup and maintenance of donkeys at 2.5 and 2.1%, and horses at 3.8 and 5.9% at the national and regional levels, respectively were documented (CSA, 2015).

On the other hand, in the study area the outgoing of equines from the herds mainly due to offtake (most of sale) and death contributing at respective proportions of 69 and 24% in donkeys and 88% and 12% in horses showed variations with CSA report. The CSA (2015), documented the contribution of offtake to the outflows at 52, 57 and 36% for donkeys and at 45, 52 and 54% for horses at the national, regional and zonal level, respectively. Whereas, death as one of the devastating outlet for equines from the herds represented 48, 43 and 64% for donkeys and at 55, 48 and 46% for horses at the national, regional and zonal level, respectively (CSA, 2015), which evidenced the substantially higher death rates than the present observations. Moreover, in the same document the contribution of sale for equines outgoings were reported at 49, 54 and 36% for donkeys and 42, 52 and 54% for horses at the national, regional and zonal level, respectively. Offerings as an offtake and loss of equines due to predation and theft were rare occurrence contributing the least to the dynamics of equines herds over the year. This is in agreement with CSA (2015) report for an offering of 3.2% for donkeys and 3.7% for horses at the national level, and 2.8% of donkeys at the regional level as an outlet of equines from herds.

As discussed above the major events in the dynamics of equines herds over the year were births and purchase for the incomings; and sale and death for outgoings. The seemingly inflated proportions of incoming and outgoing events in the dynamics of equines were merely due to the size of average holdings, which were few in numbers regardless of farmers wealth status. Usually equines are kept in bachelor or in a very few numbers relative to other livestock species, whereby the incoming and exit of an animal over the year may result a dramatic shift in the balance of equines herd in the farm. A farmer who does not possess any may get one, or who has only one may lose it for certain reason, which resulted in a 100% scenario of incoming in the former and outgoing in the latter case. However, losing them to farmers may mean a deprivation of their irreplaceable services in the system which may compromise the livelihoods of farmers in the mixed farming and their contribution to livestock water productivity. Helping farmers to maintain or get one, especially to the poor and promote sound husbandry of equines (health and feeding management) are promising practices to deal with improvement of farm productivity, water use and support of farmers livelihoods.

5.2.2.3. *Farmers ranking of the purpose of keeping livestock*

Farmers ranking of the purposes of keeping livestock species across wealth groups were almost similar. The prime importance of keeping cattle in the mixed farming systems as a source of draught power for cropland preparation and traction was testified by the overwhelming opinion of farmers, irrespective of their wealth status. In agreement, this purpose of cattle has been persistently reported from several observations in the mixed farming systems (Gryseels, 1988; Swanepoel *et al.*, 2010; Wondatir, 2010; Behnke & Fitaweke, 2011). Oxen ploughing for crop production has been used in Ethiopia for millennia (Astatke and Jabbar, 2001). Limited past attempts to promote the modified traditional ard-plough '*maresha*' with broad bed maker (BBM) especially designed for vertisols cultivation and animal drawn mouldboard ploughs had not been successfully adopted and used by the majority of smallholders in the country (Astatke and Jabbar, 2001; Rockström *et al.*, 2009; Temesgen *et al.*, 2009). Moreover, other mechanization innovations like use of tractors to modernize the crop cultivation has not been widespread among smallholders attributed to a number of constraints, such as the affordability and skill of farmers, fragmented land holdings and lack of supply and dissemination of the technology appropriate to local conditions (Gryseels, 1988; Mengistu *et al.*, 2005; Headey *et al.*, 2014). These circumstances in the mixed farming system made draught oxen as a matchless option up until present to supply power to support crop production, hence maintenance and replenishment of oxen remained as the most important case to keep cattle.

Milk production, even though ranked as the second important function of rearing cattle should not be underestimated as farmers claimed to gain continuous nourishment and cash income from sale of milk. Moreover, in the central highlands of Ethiopia improvement of local cows through crossbreeding with high milk yielding exotic breeds (Holstein Friesian) has been promoted and practiced for long (Ketema, 1998; Desta, 2002; Yilma *et al.*, 2011). Today it is not uncommon to encounter a crossbred animal in any farm in the study area, irrespective of farmers wealth status. For instance, Wondatir (2010) in his study reported over 90% of respondent farmers in *Debre Berhan* own crossbred animals in their cattle herds. However, unfortunately due to absence of

record keeping, it is hard to tell the level of exotic inheritance in most of the crosses kept under the mixed system in the study area, as the result of which indiscriminate and uncontrolled crossbreeding is going on unabated. Failing to know the existing blood level compromised the attempt to gain the expected benefit from crossbreeding strategy in the system. Under smallholder farmers with optimal management level, genetic improvement through crossbreeding of the indigenous cattle around 50% of exotic inheritance of Holstein Friesian breed has been the major recommendation proposed as a quick way of increasing milk production to meet the ever-increasing demand for milk and milk products in Ethiopia (Haile *et al.*, 2009). Same authors explained, a strategy for higher exotic inheritance levels (for example, 87.5% Holstein) could be justified under intensive production systems, provided the level of management needed could be achievable. However, the crossbreeding practiced in the smallholders mixed farming system did not respect the recommended strategy to adhere around 50% Holstein inheritance (Haile *et al.*, 2009). Despite milk production is ranked as the second important purpose of keeping cattle, failing to successfully manage the crossbreeding strategy coupled with suboptimal management in feeding and health might influence the benefit from milk production, Therefore, following the breeding strategy to maintain the exotic inheritance to the recommended level for the prevailing system requires installing farm level recordkeeping mechanism along with input supply, feeding, health, marketing and improvement of the farmers management skills the training and sharing of good practices.

Other purposes ranked after draught power and milk production for keeping cattle are subsidiary to the two major functions. Farmers gain income in the meantime from sales of live animals or their products like milk. On the other hand, they envisioned to keep more and productive animals as long as they could afford than saving money in financial institutions, making animals as a live saving asset. Manure is also a precious resource used as fuel for household use and also as an income source from selling of dung cake. However, its use as an organic fertilizer is seldom exploited. Moreover, rearing cattle as meat source was not considered as the priority for cattle were seldom slaughtered at family level for meat except in certain occasions like wedding, in large families during holidays and in ad hoc coalition groups formed for sharing the meat.

Small ruminants are considered as an asset which can be easily liquidated whenever the need arises, probably next to poultry. Small ruminants were the most frequently sold animals to purchase other goods for home consumption and agricultural inputs required by the household, and to cover for school expenditures of the families. Owing to this fact, keeping small ruminants as an income source and saving prevailed as the first and second importance of keeping small ruminants, specifically sheep in the study area which are suited to the production system and relatively kept in numerous numbers. The importance of small ruminants for meat was also appreciated, because of their small size and lower price, it is convenient for most farmers to sacrifice them for meat usually during occasion of holidays. In agreement with the present result, Andargachew and Brokken (1993) explained that apart from being considered as more reliable form of wealth accumulation, sheep are a readily convertible source of cash at time of need as well as an important source of meat. In addition, Ketema (2007) reported that sale of sheep and goats to generate cash constitute the primary purpose, followed by slaughter of sheep and goats for family consumption in *Alaba* district of Southern Ethiopia. Moreover, a study in smallholder farming systems in Kenya by Kosgey *et al.* (2008) indicated the importance of sheep farming to the farmers for tangible benefits (e.g., regular cash income, meat, manure and, in the case of goats, milk) versus intangible benefits (e.g., the role of small ruminants as an insurance against emergencies).

Keeping equines for transportation services could not be overemphasized as farmers unequivocally stated transportation of agricultural products and humans as the sole most important function of equines in the system. This is in agreement with Gebrewold *et al.* (2003) and Gebreab *et al.* (2004), who described the main role of donkeys as a beast of burden due to their use in transporting harvested crops from fields to homesteads, grain and cash crops from agricultural areas to the various markets, agricultural inputs from distribution centers to farmsteads, fuel-wood, charcoal and animal dung to markets and for home use, water for home consumption, crop residues for animal feeding and construction, and building materials such as sand, gravel, wood and stones. Moreover, the services of equines delivered to transport traded commodities like agricultural products is usually associate with the purpose of keeping equines as an income source. Other benefits acquired due to maintenance of equines such as a live saving assets and sources of manure were not appreciated much as qualified purposes

for the motivation of keeping equines. Horses on the other hand were mainly kept for human transportation, which is in agreement with Admassu & Shiferaw (2011) study report in *Hadiya* and *Gurage* zones of southern Ethiopia, where the main purpose of keeping horses are gharry services, ridding and packing services which are associated with transportation of human and other commodities.

5.3. Manure management and utilization

5.3.1. Manure handling

Regardless of farmers wealth status about 84% of sampled farmers experienced manure collection in less than three days. Manure removed from the barn at the prescribed frequency was continuously added onto the heap or in the manure pit. Such frequent collection of manure by the vast majority of smallholder farmers in the mixed system mainly attributed to the importance of manure for the daily needs of household fuel consumption and the necessity of processing the manure into dung cake before it is used as bio-fuel or sold. Another reason could be to minimize the loss of manure due to trampling. Moreover, farmers need to conserve and store manure for later use either in the form of dung cake or composted to use as organic fertilizer in the backyard or near farm lands. In concordance with the observed frequency of manure collection in the study area, Lupindu (2017) reported a manure collection practices among urban and peri-urban cattle keepers in developing countries (in *Morogoro* the eastern part of Tanzania) once a day, more than once a day and weekly at proportions of 61, 16 and 24%, respectively. However, contrastingly Rufino *et al.* (2007) documented, in the less intensively managed systems, such as semi-grazing or free grazing, manure is collected from the corral once or twice a year just before application to the croplands, but in intensive dairy systems manure may be removed daily from the stall. Same authors further explained that the frequency of manure removal from the stall had a large influence on the amount that may be further recycled and in the case of less intensive system stated above, the overall losses from collection and storage can be significant.

Even though all sampled farmers in the study area practiced some form of manure storage mechanism, the majority (60% ranging from 37 to 78% among wealth groups;

the lowest proportion being in the poor wealth group) do not use shade of any type to protect the stored manure from deterioration due to exposure to sunlight, wind and rain. Comparable to this, Lekasi *et al.* (2003) reported most of the farmers (67%) in *Maragua* district of central Kenya preferred to store their manure in a heap or pit and 46% of them kept it under some sort of shade. But those who store manure by deep littering (33%) are more than the present result (Lekasi *et al.*, 2003). In addition, Kumsa *et al.* (2004) reported the existing variation in manure storage system in *Hollela* area of central Ethiopia, but with higher proportion (over 70%) of the surveyed farmers pile manure under open sun for about eight months while relatively lower proportion (11%) stored it in a pit. In the present result, overall about 40% (ranging from 24 to 58%) of the farmers did not use any form of cover to protect collected manure. Moreover, the proportion who did not use cover for stored manure was highest among the poorer than the wealthier group of farmers. Contrastingly more farmers (90%) that did not cover manure are reported in *Maragua* district of central Kenya (Lekasi *et al.*, 2003). However, proper storage of manure in shade with cover prevents the loss of nutrients in manure through leaching, run-off and volatilization; and environmental pollution and other nuisances like bad odor and flies (Teenstra *et al.*, 2015).

In the study area, most of the care taken in collecting and storing manure was focused on reducing the wastage of dung cake to be used as bio-fuel, which usually did not regard the aspects of nutrients loss and the pollution effects on the environment (air and water resources), and on the human and animal health due to mishandled manure. Various reports had explained the importance of proper handling of manure in storage, such as the use of protective shade and cover to minimize the nutrients losses and negative effects of manure. For instance, according to Teenstra *et al.* (2015), the nutrient losses can be reduced by limiting the contact surface between manure and air by stacking and compressing the heap and by protecting the manure against the influence from wind, water and sunlight. In addition, according to Rufino *et al.* (2006) and Rufino *et al.* (2007) heaping manure reduces its surface area and so decreases leaching compared with uncollected manure. However, when manure heaps are uncovered, as is often the case in Africa, leaching losses will be of greater importance (Rufino *et al.*, 2006). Moreover, a study by Lekasi *et al.* (2003) confirmed the beneficial effects of roofing on manure nutrient concentrations by offering protection from the

leaching effect of rain and from high temperatures. In addition, Kumsa *et al.* (2004) claimed that the storage of manure under open sun to affect its quality negatively. For example, the results of an experiment involving covering manure heaps with a plastic film showed that the uncovered heaps underwent aerobic decomposition and lost about 55% of the initial dry mass and 50% of the initial N, whereas those that were covered and roofed lost about 30% of their mass and about 20% of their N during the 7 months of storage (Rufino *et al.*, 2007).

Researchers suggested covering manure for reducing mass and nutrient losses can be achieved through simple and low-cost management interventions. According to Rufino *et al.* (2007), bedding helps to reduce N losses, because urine is absorbed and N is immobilized in the bedding materials (straw or hay). However, the practice of bedding in the study area was limited to stalled animals because of sickness or they are new born (e.g. calves, lambs). The chance of collecting dung mixed with forage refusals was also a rare opportunity and if so, it was in small amount, because only selected animals were stallfed with seasonally conserved hay and straw due to feed scarcity. Moreover, in the mixed farming systems most of the time animals stayed on grazing lands and stallfed occasionally. Whenever the opportunities allow farmers used to collect manure mixed with bedding materials and feed refusals but adding other organic residues to the manure during collection or storage (to the heap or in the pit) to deliberately preserve nutrients losses was not a common practice.

5.3.2. *Manure utilization*

Like any other rural areas of Ethiopia, farmers in the study area principally use manure as a source of fuel for household energy needs complemented with firewood. Farmers prepare dung cake from different livestock species, however, they prefer cattle dung for convenience of dung cake preparation than any other livestock species which is in agreement with the practice around *Holetta* in the central Ethiopia (Kumsa *et al.*, 2004). Manure was also used as a source of income and organic fertilizer. The amount of manure used for other purposes like plastering of house floor and walls were of minor importance. Manure was sold by considerable proportion of farmers (64.8%) regardless of their wealth status, totally in the form of dung cake which might be because of the

ease of transportation and the need of the current buyers to use manure as a source of bio-fuel energy in the same form. But the relatively higher proportion of the poorer group of farmers who sold indicates the role of manure sale to support of their livelihoods compared to the wealthier. None had bought manure for energy source as well as to use it as organic fertilizer which is not widely adopted. Instead they tend to collect dried manure dispersed on the open field where any once livestock (cattle) stayed on grazing and additionally gather firewood to complement the manure as an energy source.

Regarding the use of manure to fertilize soil, even though limited in quantity and proportion of users, a variety of application methods were used. Considerably higher proportion of the poorer group (52%) applied it by directly dumping/spreading onto the field around homestead, whereas relatively higher proportions of the wealthier groups (37% of the medium and 36% of the better-off) prepared it into compost before application. These might be due to the variations in the availability of family labour, amount of daily collected manure and the level of awareness in manure application to fertilize the land. The direct spreading practice of manure application on the surface of the land without covering it with soil could further aggravate the loss of its nutrients. The recommended application of solid manure is to apply onto arable land and immediately incorporate into the soil by harrowing (Teenstra *et al.*, 2015) and apply manure in furrows and cover it with soil (Onduru *et al.*, 2008). Several findings recommended composting manure as an essential strategy in enhancing the quality and stability of manure (Lekasi *et al.*, 2003; Jackson & Mtengeti, 2005; Rufino *et al.*, 2006). Composting manure in deep pits or under anaerobic conditions minimizes ammonia losses (Teenstra *et al.*, 2015). In this study, however, the proportion of sampled farmers 35% (range of 32 to 36%) who deliberately composted manure to use as organic fertilizer was low, but comparatively higher proportions in the wealthier group of farmers. However, it should be noted that whether it is used as fertilizer or not, stored manure as heap or in pit obviously undergoes some processes of composting due to microbial action, however, the fate of nutrients in manure (i.e. reduction in nutrient losses) may not certainly be guaranteed.

The way the manure is handled determines the rate of nutrients losses and pollution risks. In concordance, Rufino *et al.* (2007) noted that making the most efficient use of animal manures depends critically on improving manure handling and storage. In this respect, various researchers investigated the management and handling of manure and indicated that methods of collection, storage and application have an influence on its nutrient utilization and perceived effects of the manure on the environment (Lekasi *et al.*, 2003; Rufino *et al.*, 2006; Rufino *et al.*, 2007; Teenstra *et al.*, 2015). In the present study area, however, invariably inappropriate practices of manure management to preserve nutrients and reduce the detrimental effects of pollution due to livestock excreta were observed, irrespective of farmers wealth status. For instance, the use of bedding materials to retain urine mixed with dung and composting larger amount of animal manure for soil fertilization were not common. But according to (Rufino *et al.*, 2007), the use of roofing, shade, cover, organic beddings and frequent collection are suggested to delay and reduce nutrients losses (e.g. increase the efficiency of N retention) before application on farm lands. The long period of manure accumulation and exposure of manure to the vagaries of weather potentially predisposes it to nutrients losses through volatilization and leaching (mostly N). In this regard, Teenstra *et al.* (2015) demonstrated that the amount of nitrogen in the manure tends to decrease over time, because NH_3 , N_2 or N_2O are emitted or because soluble N is leached by rainwater. Likewise, the P_2O_5 and K_2O can also be lost by leaching from rainfall, further reducing the value of the manure.

Manure is among the beneficial outputs regularly contributed by livestock throughout their entire life. For instance, in estimating the LWP, manure valuation as one of livestock output quantified in terms of inorganic fertilizers equivalent had contributed considerably to the total value of livestock beneficial outputs obtained per farm daily (Hailelassie *et al.*, 2009; Mekonnen *et al.*, 2011; Kebebe *et al.*, 2015). The use of animal manure as fertilizer for crop production and the crop residues for animal feeding played a role in nutrient recycling which is among the basis for the complementarity and integration of the crop and livestock production in the mixed farming system. On the other hand, manure is among the factors on which livestock production is frequently challenged as a detrimental cause of air and water pollution due to its mismanagement. In view of water use balance, consumptive use of water by livestock occurs both

directly through stock watering/drinking or making the water non-utilizable through pollution and indirectly through the production of feed. So, water pollution caused by livestock manure increases the volume of water allocation to livestock production which may result in reduced LWP, due to water degraded as a result of pollution. According to Hoekstra *et al.* (2011) the volume of water depleted due to pollutants (e.g. N in manure) is equivalent to the volume of water required to assimilate the waste, quantified as the volume of water needed to dilute pollutants to such an extent that the quality of the ambient water remains above agreed water quality standards.

As evidenced from investigations described above, losses of manure nutrients have both economic and environmental implications, which could compromise resource use efficiency and system productivity. This entails for the collection, storage, preservation and application methods of manure to aim at preventing the losses of nutrients and reduce the detrimental effects. In this prospect, interventions like frequent manure collection, sheltering manure in roofed shade and cover, composting, covering with soil after field application, complementing manure and inorganic fertilizers are among others recommended by several investigators (Kumsa *et al.*, 2004; Rufino *et al.*, 2007; Teenstra *et al.*, 2015). Alternatively, manures could be used for biogas production to ease the energy problem, and the sludge is still a valuable fertilizer without much change in the nutrient content of the manure which could be applied to the farms (Lupwayi *et al.*, 2000; Teenstra *et al.*, 2015). Thus, evaluating the existing manure management and utilization systems, designing of affordable strategies relevant to the prevailing production system to measurement and reduce the nutrient losses and undesirable effects would be important in bridging nutrient gaps and enhancing crop and livestock productivity. These eventually would have expected to bring in improvements of livestock and feed water productivity.

5.4. Evaluation of Livestock Feed Balance

5.4.1. Types and availability of feed resources

The types and amount of feed obtained per household depend on land use, size of land ownership and cropping pattern during the production season. Irrespective of wealth

status, large proportion of land was allocated for crop cultivation than other land use types including grazing, which is in agreement with reports of Amsalu *et al.* (2007) and Assefa *et al.* (2013). The increasing expansion of land cultivation for crop production at the expense of GL has resulted in shrinkage of the area and productivity of GL (Amsalu *et al.*, 2007). Consequently, CR generated from production of food-feed crops comprised the largest proportion of livestock feed resources. In agreement, Bogale *et al.* (2008) reported the progressive decline of GL and the use of CR as the major source of livestock feed particularly during the dry season in the mixed farming system of the *Bale* highlands of Ethiopia. In addition, Wondatir *et al.* (2011) observed the heavy reliance of farmers at the *Debre Berhan* area in the central highlands of Ethiopia on CR for feeding their livestock.

Besides the suitability of the local agro-climate for barley growing (Amsalu *et al.*, 2007; Hassen *et al.*, 2010), the higher quantity of barley straw collected was associated with the preference of farmers and the consequent allocation of larger plots of cropland for the barley crop cultivation. Apparently, the remaining smaller plots of cropland were shared for other crop types, which correspondingly leads to lesser quantity of straw obtained from crop types such as wheat, faba bean and field pea. In line with the present study, Bogale *et al.* (2008) explained the variation in the quantity and quality of CR produced could be due to the cropping intensity besides the variations in altitude, soil type and rainfall patterns where the crop has been grown and its productivity.

In relation to the size of cropland ownership and parcel allocated to a specific crop type, higher volume of biomass was harvested by better-off and medium wealth groups than poor farmers. This crop biomass productivity is accordingly translated into the higher amount of CR harvest which reflected the gradient of farmers' wealth status. In addition to the plot of cropland allocation, the availability of family labour force, size of livestock owned particularly oxen, natural fertility of the cropland and other variable factors associated with the capacity of farmers to afford various inputs and manage timely agronomic practices influence the volume of CR produce per household. Moreover, the amount of feed derived from the crop field in the form of crop aftermath grazing is intrinsically influenced by the cropping pattern and plot of cropland allocation, as part of the feed recovered, is the remainder of the parent crop obtained

after harvest in addition to the different weeds and other herbaceous plants grown on the crop field. In line with this, Tolera (2007) reported the quantity and quality of stubble left varies considerably depending on the harvesting techniques applied for the various crops and the grass weeds grown underneath the main crop. Therefore, it is predictable that the wealthier could be able to benefit more than the poor farmer groups from crop aftermath grazing which is attributed to the larger size of cropland and livestock ownerships.

The size of available GL in the study area is small irrespective of wealth status, though the wealthier are more favoured to exploit available feed resource from freely grazing the communal land due to ownership of relatively larger livestock herd size. Moreover, fallow lands as livestock feed source were very rare, as there is critical land shortage for crop cultivation as well. In agreement, Tolera (2007) reported that it was in the past that GL, hay and fallow land grazing were the main sources of feed; however, at present the situation has changed due to the rapidly increasing of human population and expansion of crop production into the grazing areas. Same author asserted that there is very little that livestock can forage from the limited communal grazing due to continuous grazing and the mismatch between the feed supply potential of the land and the number of animals kept. Consequently, crop residues are increasingly becoming the main sources of livestock feed resources in the MCL systems (Tolera, 2007; Bogale *et al.*, 2008; Duncan *et al.*, 2016). Other several studies have also disclosed that, in recent years, GL in the MCL systems are devastatingly overstocked and that the herbage biomass productivity is declining both in quantity and quality (Hailelassie *et al.*, 2009; Asfaw, 2013; Amsalu & Addisu, 2014; Hassen *et al.*, 2010; Tschopp *et al.*, 2010; Hussen *et al.*, 2016). Therefore, expansion of GL to increase feed availability is not a practical option as the increasing trends of both the human and livestock population are going to claim more additional land further for crop production, settlement and feed sourcing.

Hence, options to improve the availability of CR and looking for other alternative to avail additional feed resources should be intervened. From evidences captured in the present study which are supported by several other findings, most of smallholder farms in the MCL systems are dependent on CR as the main source of feed for livestock.

Moreover, nowadays straws have also become an important source of revenue (Tolera, 2007) and used for other purposes that compete livestock feed supply. To intervene the problem, Sharma *et al.* (2010) and Tolera (2007) suggested close collaboration of crop and livestock scientists aimed at multidimensional crop improvement to increasing the quantity and feeding value of CR without negatively affecting the grain yield and quality. In addition, Tolera (2007) further suggested the introduction of cover crops that could be grazed after short rainy season, high yielding forage crops with possibility of multiple harvests per year and multipurpose leguminous trees used as supplemental green fodder could be explored to alleviate the feed shortage pertaining to the existing situation. Furthermore, interventions to increase feed biomass per unit area of GL, proper grazing management and purchase of supplemental feeds whenever possible would be among the options that help to reduce the influence of feed shortage on livestock health and productivity.

The fluctuations in the seasonal availability of major feed resources are mainly associated with the rainfall distribution and cropping pattern of food-feed crops. Crop residues are plenty during the dry season, which is the period of threshing for harvested crops. Availability and utilization of crop aftermath grazing is aligned with harvesting periods of crops in the dry season. Crop residues and hay are also conserved for mitigating feed shortage, especially during peak periods of cropland ploughing in the wet season. Forages from grazing lands and fallow lands are available following the main/long and short rainy seasons, when the moisture is sufficient enough to support plant growth.

5.4.2. Livestock feed supply, demand and balance

In the present study, livestock feed balance evaluated is generally found to be negative irrespective of farmers wealth status, indicating the critical feed shortage in the system to fulfil the DM, ME and DCP requirements for the prevailing livestock. Overall, only about 49%, 81% and 62% of DM, ME and DCP requirements are fulfilled, respectively, with the current amount of feed supply from on-farm production and purchased feeds. Several previous study findings support the present report in that in the mixed-crop livestock system where land is limited, the contribution of CR is prominent and GL are

deteriorating in size and productivity, and the livestock production is performed under annual feed deficit. For instance, Wondatir *et al.* (2011) reported that around *Debre Berhan* the annual feed supply only satisfies 64% of the maintenance DM, 81% of the ME and 66% of the DCP requirements of the animals per farm. In addition, a study in *Gummara-Rib* watershed of the Lake *Tana* sub basin in *Amhara* Region by Amsalu and Addisu (2014) showed that the available feed sources address only 72% of the annual DM requirement per household. These studies confirmed the long-standing impediments for increasing livestock productivity consistently claimed by smallholder farmers and development practitioners in the MCL systems, where seasonal feed shortage both in quantity and quality coupled with inadequate successful interventions, which are remained unabated.

The present study and others mentioned here used same amount of average daily DMI for a standard TLU of 250 kg at 2.5% of live body weight suggested by Jahnke (1982), which is 6.25 kg/day, to arrive at an aggregated demand for feed DM at household level per year. However, the daily DM feed intake is affected by various animal and feed related factors. For instance, FAO (2012) described where there is good access to feed, and health and welfare are optimum, the DM intake for young ruminant animals is likely to be 4% of body weight and decline to 2–2.5% as animals are getting mature. Moreover, where feeds of low digestibility are the main or only sources, voluntary intake will be significantly influenced due to the longer time it takes to progress through the digestive tract, and as a result low digestibility is reflected in lower intakes.

Livestock feed balance reported under smallholders in the mixed-crop livestock system is frequently negative (Kassa *et al.*, 2003; Wondatir and Mekasha, 2014; Yisehak and Janssens, 2014) and even so many times declared as below the maintenance requirements (Assefa *et al.*, 2013; Wondatir *et al.*, 2011; Amsalu and Addisu, 2014); however, in fact livestock continued to survive, reproduce, provide and perform their vital functions, whereas the different products and services obtained cannot be imagined at maintenance requirement level let alone when an overwhelming annual feed deficit below maintenance is revealed. Hence, series of critical questions could arise on the assumptions, methods and validations of livestock feed balance estimations, which were also iterated by Kassa *et al.* (2003). For instance, whether the

suggested daily DMI amount estimated at 2.5% of live body weight is limited to only satisfy the maintenance requirement or not?, as described in various livestock feed balance studies. To what extent the suggested daily allowance fulfils the animal requirement? Do feed types of any quality and form can be ingested at the suggested rate by any type and/or class of livestock throughout all seasons of the production year? Is that amount of feed could be affordable daily by smallholders in the MCL system consistently throughout the production year?

Hence, the feed balance results should be cautiously interpreted, in that the livestock production system is running in an annual feed deficit does not mean that the livestock are currently without any benefit to offer. It is not unimportant either, since it quantitatively unveils the picture of what farmers and experts claim to be the most important determining factors of livestock production, which are feed shortage and the increasing trend of land scarcity on which to produce livestock feed. First of all, the suggested rate for the DMI of feed does not indicate the quality of the feed supplied but the average quantity that the animals could potentially consume daily. In addition, it does not mean that whatever is ingested is equally available to all types of animals. This is because the nutritional requirement of an animal depends on several factors: species, size, age, weight, physiological status (pregnancy, lactation), level of production (rate of gain, amount of milk produced), general health, amount of work, weather condition and season (Tolera and Said, 1992; Moore *et al.*, 2009; FAO, 2012).

Secondly, there is a need to closely observe the dynamics of farm elements and make situation analysis throughout the production year. Actually, the feed balance estimate showed the situations aggregated on annual basis, as if the feed availability and livestock DM, ME and DCP requirements per day are distributed evenly throughout the production year. However, a lot of dynamics can happen in the seasonal feed resources availability, nutritional composition and quality, and in the individual animal body (physiological state) and in the livestock herd in the course of the annual production process. It is an established fact that quantity and quality of feed available from natural pasture are affected by season (Kassa *et al.*, 2003; Abegaz *et al.*, 2007; Bogale *et al.*, 2008; Moore *et al.*, 2009; Wondatir and Mekasha, 2014; Yisehak and Janssens, 2014). Feed sourced from crop production is also affected by type of crop, cropping pattern,

amount of input used like fertilizers and agronomic practices applied (Lenne *et al.*, 2003; Valbuena *et al.*, 2015; Duncan *et al.*, 2016). Different feed resources of varied quantity and quality may be available to livestock across different seasons, which could be produced on-farm or purchased depending on the capability of producers to afford. The animals may undergo the phenomenon of compensatory growth, i.e. lose weight during periods of feed scarcity and put on weight (gain) during times of good feed availability. In the meantime, livestock could deliver any forms of products and services during periods of feed availability and/or mobilize what is deposited during good times of the year. At herd level, an inflow from natural reproduction and purchase of animals, and an outflow due to death, sale and slaughter, and share rearing of animals in either case could all happen within the year following the scarcity and availability of feed at household level. In the present study, generalization of the livestock feed balance on annual basis without assessing the seasonal pattern of feedstuffs in terms of availability and utilization could be seen as limitations and therefore it is good to see it on seasonal basis as there are times for plenty and deficit. Hence, the seasonal feed availability coupled with farmers feeding practice and coping mechanism of feed shortage, the productivity gain or lose and the inflow and outflow dynamics of livestock at household level should be considered, while interpreting the livestock feed balance.

5.5. Livestock and Feed Water Productivity

5.5.1. Water use for feed production and feed water productivity

The major livestock feed supplies in the study area are byproducts of crop cultivation and natural grazing lands. Choices of the major crop types for food-feed production were comparable in the system irrespective of farmers' wealth group. Barley, wheat, faba bean and field pea were the major cultivated crops in order of importance. Besides to the local climatic variables which are common denominators, the differences in the amount of crop residues yield, rainwater evapotranspiration and the resulting crop residue water productivity are attributed to many factors including the crop type, the area of land allocated per crop, frequency of land preparation, the land fertility, application of fertilizer and pesticides, and labour input managed by farmers of different wealth group. Allocation of a plot of land pieces for a particular crop type in the

cropping season was determined mainly by the size of cropland owned and capability of the farmer to acquire additional land through local lease agreements. Apparently, the decreasing gradient in the size of cropped land from better-off to poor wealth groups dictates the relative difference in type and quantity of CR production, volume of WD and FWP in the same direction. In conformity with the present circumstances, Blümmel *et al.* (2009) and Hailelassie *et al.* (2009) reported that the size of cropped land and crop diversity are major contributing factors for disparities in the type and amount of CR that farmers can afford to supply and the associated volume of rainwater evapotranspiration per year for production of livestock feed in MCL system.

As a matter of fact, the DM harvested and water evapotranspired to produce CR is intrinsically dependent on crop attributes from which it is derived. The effects manifested on the crops are carried over to CR in the process, although the share of WD for grain and CR depends on each product fraction from the total biomass (Descheemaeker *et al.*, 2011; Hailelassie *et al.*, 2011). Variations in crop biomass yields among wealth groups contributed to the difference in the volume of water evapotranspired for part of feed production. In line with the present study, Hailelassie *et al.* (2009) and Kebebe *et al.* (2015) investigated similar pattern of variation among wealth groups, whereby better-off farmers gained higher feed production from CR with improved WP. Fortunately, productivity improvements in grain and residues of food-feed crops can be made all along the line of technologies and management practices such as plant breeding, selection, tillage, fertilization, weed and pest control, harvesting, water use and other agronomic practices (Borlaug, 2000). However, low technology uptake and access to resources are the challenges that restrain the capacity of poor farmers. Given the positive relationship of these factors with increased yield of crop biomass and associated WP, interventions targeted to improve provision of inputs, credit, extension and training support to the poor would potentially help to improve CR yield and part of water use for feed production. Hence, farming practices aimed to improve water use efficiency, biomass productivity and improving nutrient contents (feed quality) of crops would potentially help to improve the crop residues yield and part of the water use for livestock feed production.

Another major path to water depletion for livestock feed production is GL (Hailelassie *et al.*, 2011; Kebebe *et al.*, 2015), which has two types of ownership; private and communal. Generally, the low FWP on GL irrespective of wealth status indicates the need of interventions at all levels. However, the difference in FWP on GL observed among poor and other wealth groups was prominently the reflection of communal GL use intensity attributed to livestock density and ownership pattern. Poor farmers do share small portion of communal GL than other wealth groups, which was appropriated relative to the size of livestock ownership, yet they own comparable size of private GL, which were relatively in good condition. Relatively wealthy farmers with more TLU exploited more feed and water and gain less FWP on GL than poor farmers, as their herd were responsible for the removal of more biomass from communal GL, which is not properly managed.

The low FWP on GL is an indicator of inefficiency in water use for feed production, which can be partly explained by poor GL management and overgrazing. Overgrazing cause land degradation (Peden *et al.*, 2007), has adverse impact on the biomass productivity and nutritive value of pastures by negatively affecting the soil properties (Bossio *et al.*, 2010), which increase the unproductive water lose through water evaporation from the soil surface (Passioura and Angus, 2010) and resulted reduced FWP on GL. Every member of the local community, even though has the right to use communal GL, do not feel secured. They noticed that communal lands are the once easily available for redistribution and land grant to the landless youth, investors or other public sector needs. Farmers did not pay attention for better GL management, proper use and adopt sustained interventions to improve the biomass productivity and condition of the communal land resources. This is supported by Lawry *et al.* (2014) who reported that secured land tenure enables farmers to invest in long-term improvements without fear in the expectation that they will reap the benefits from their farms. Therefore, mechanisms that ensure land security is expected to promote better land management, which could positively impact land productivity and increase FWP. Proper grazing management and pasture improvement is essential for increased feed biomass production and FWP from GL. The supply of improved forage seeds and application of soil and water conservation practices would enhance the improvement in FWP.

5.5.2. *Beneficial outputs from livestock and livestock water productivity*

Farmers explore the advantaged of keeping blend of livestock species to generate distinctive outputs and services through allocation of farm resources available at their disposal. The present work considered outputs like milk, offtake, manure and traction services to estimate the annual livestock BO. However, Behnke (2010) underscores that livestock under smallholder MCL systems in developing countries like Ethiopia perform other social and economic functions as savings and insurance which are difficult to evaluate annually in monetary terms.

Unlike the findings of Hailelassie *et al.* (2009), Kebebe *et al.* (2015) and Alemayehu *et al.* (2017), where manure and traction services accounted for the prime share of annual benefits, in order of importance, in this study higher proportions of benefits were captured from cattle milk production followed by traction services, whereas manure value was the third largest contributor regardless of farmers' wealth status. Contrary to the present result, Alemayehu *et al.* (2017) reported lowest monetary contribution from milk production in the *Gumara* watershed of Blue Nile Basin. The potential of dairy farming in the study area is evidenced due to market accessibility for the products and inputs in *Debre Berhan* town and *Addis Ababa* city and conduciveness of the temperate type climate that could easily be acclimatized by crossbred dairy animals of the locals with exotic blood of temperate origin (Holstein Friesian). Various studies emphasized the desirability of the area for intensive dairy farming with crossbred animals (Wondatir *et al.*, 2011; Ayalew and Asefa, 2013). The variation in milk value between farmer groups was mainly attributed to the number and productivity of milking cows particularly crossbreds kept in wealthier than poor farmers. Variation in the value of traction services has displayed the pattern of disparity in the cropped land area, frequency of cultivation, and volume of production reflecting the state of wealth among farmers. The pattern of variations in manure production and estimated value among wealth groups was unequivocally associated with the types and size of livestock holdings, and the type and level of feeding. In support of the above explanations, Hailelassie *et al.* (2009, 2011) and Kebebe *et al.* (2015) reported that variations in the different outputs and services of livestock are mainly attributed to the size and type of

livestock holdings, area of cropland cultivated and the capacity of farmers to afford and use required production inputs in their farm operations. Even though there was variation in livestock offtake among wealth groups, its contribution to the total annual livestock output is the least. This observation reflects the general situation of the country reported by Behnke (2010) and Shapiro *et al.* (2015), where animal offtake rate is low especially in the mixed system. In MCL system the primary purpose of keeping livestock is to complement the crop production and maintain continuity of livestock herds. However, dairying with crossbred animals could not be undermined in the study area, as it is potentially good-looking endeavour provided good husbandry and management interventions are in place.

Generally, in the present context the variations in LWP can be explained by cumulative spill-over effects of the contrasting ownership of assets, outputs gained and inputs used at farm level between wealth groups. These circumstances reinforced the previous findings on the magnitude of LWP and the effect of farmers wealth status on LWP by Hailelassie *et al.* (2009), Kebebe *et al.* (2015) and Alemayehu *et al.* (2017), that households in better-off and medium wealth categories registered higher values of total BO and LWP. Access to resources and relevant technologies are expected to substantiate the relationship between yield and WP. Considering the potential of the area for MCL system, interventions that complement each other can be suggested to increase WP in smallholders, particularly for the poor groups. Promotion of livestock production focused on milk through crossbreeding, supplementation and sound healthcare; and crop production through provision of suitable varieties, oxen and fertilizers complemented with training will boost the capacity of poor farmers to achieve increased LWP.

5.5.3. Contributions of crop residues to feed and livestock water productivity

Crop residues are considered relatively as cheap sources of livestock feed supply in the MCL systems. However, the use of CR is transcending beyond livestock feed and their price is tremendously increasing. It can be used as construction material, fuel and in conservation agriculture for soil fertility enrichment and water conservation management. If not used as livestock feed, the water embedded in crop residue could

be diverted to other benefits. This justifies that the water cost due to feeding CR to livestock could not be entirely considered as free source. What makes it cheap source is that no extra land and water inputs are demanded beyond the requirement for the principal product of crop cultivation i.e. grains and pods (Blümmel *et al.*, 2014). Owing the opportunity cost of using CR to other benefits other than livestock feed, it is rational to share the cost of water used for crop biomass production. This partitioning of water evapotranspired for crop biomass production and the use of CR as livestock feed explains the strong and positive relationship with FWP due to production of part of the feed biomass with less volume of water.

Obviously, higher feed DM yield per unit volume of WD reduces the water input for livestock production and ultimately will increase LWP. This has been reported by various authors (Hailelassie *et al.*, 2009; Peden *et al.*, 2009; van Breugel *et al.*, 2010; Descheemaeker *et al.*, 2013; Michael *et al.*, 2014; Kebebe *et al.*, 2015). However, the unclear but more likely nonlinear relationship pattern between the level of CR supply and LWP in the present scenario may reflect the other dimensions of CR. Crop residues are obtained as byproducts after full maturity of the plant where less utilizable structural components of the plant tissue are high. Plant maturity has a counteracting effect on digestibility and nutrient availability to the animal. This makes CR as a sub-optimal feed resources to meet the nutrient requirement and thus are not enough to bring livestock productivity to their potential. This is an established fact from numerous studies (Blümmel *et al.*, 2009; Blümmel *et al.*, 2014; Duncan *et al.*, 2016). In the production systems where share of CR in the ration of livestock is considerable and other interventions like supplementation, alternative feed resources and feed treatments are limited the productivity potential of livestock will be impaired. The limitations imposed by high proportion of CR result in decreased output from livestock and consequently to low LWP. Mechanisms that help to enhance the feed value of CR will have an immense potential to increase LWP. Achieving synchronized improvement in FWP and LWP is expected to increase water use efficiency at the farm level in the MCL system. Furthermore, it should be born in mind that results that indicate the association of FWP and LWP requires considerable scrutiny at any scale of consideration (such as at national, regional, farm or animal scale).

5.5.4. Contributions of farm resource to farm productivity and livestock feed sourcing

The availability of farm resources such as family labour, land and livestock are the pillars of farm productivity. These resources have an influence on the level of crop biomass production, which in turn affect the availability of grain and crop residues for human and livestock feeding. The present study is in agreement with previous reports of Hailelassie *et al.* (2009) and Kebebe *et al.* (2015) which revealed the significant effect of resources endowment of farm households on the productivity of food-feed crops, livestock and the WP of both livestock and feed under the smallholder MCL system.

Relatively smaller size of cropland area and fewer oxen for cultivation deprived poor farmers from generating enough food and feed supply. Farming families with small size of cropland ownership were hardly able to diversify their harvest of food-feed crops and increase the crop grain yield and associated CR biomass production due to limitation of available cropland and subsequent allocation of smaller plots for the intended crop types. In addition, the small number of livestock ownership, especially oxen among poor farming families, has a limiting influence on the use of needed animal labour for traction services, such as timely cultivation of cropland with optimum tillage frequency required for the crop types grown. Moreover, the limited availability of family labour force in the poor family group may have restrained their capacity to intensify human labour use in the farming operation, which may negatively contribute to the cause for lower farm productivity. It influences farmers to apply adequate labour input for optimum agronomic activities like tillage frequency, timely land cultivation and weeding that are required to increase crop biomass productivity.

On the other hand, wealthier (medium and better-off) farming families with relatively more ownership of livestock (ploughing oxen), cropland and farm labour force were able to cultivate their cropland adequately in time allowing for more annual benefit gain from own cropland and livestock. Having better farm resources endowment capacitate the wealthier to acquire additional cropland from other farmers through local lease agreement and cultivate for share cropping in addition to the land they rightfully owned. Then the cultivators may attain share of the CR in part or as a whole depending

on the agreement with the cropland owners. Two ways of local lease agreements for cropland are practiced: share the product or pay the rent in cash for the land. When they do share agreement, the cultivator is entitled to use whole CR while only share half of the grain yield to land owner. When they do rent the land in cash agreement, the land cultivator pays a certain amount of money to the land owner for a given period of time (usually a year) based on land size, fertility, water access for irrigation and length of period of agreement and takes whole crop biomass yield. Eventually, the wealthier were enabled to avail additional CR from diversified food-feed crops harvest on wider cropped area to offer for their livestock, which in the meantime support to improve livestock productivity.

Comparable observations were reported by Kebebe *et al.* (2015) and Molla (2013) that farmers with more ownership of livestock numbers particularly oxen and farm labour force are able to cultivate cropland on the right time of the season with required frequency of tillage to prepare the land better and depress the influence of weeds on yield of the main food-feed crops. In support of the present study, several other studies (Blümmel *et al.*, 2009; Haileslassie *et al.*, 2009; Kebebe *et al.*, 2015; McDermott *et al.*, 2010), reported that inadequate cropland preparation due to limited access to production factors such as land, human and animal labour affect the food-feed crop biomass production. Proper agronomic practices are duly done when sufficient family labour is available or farmers are able to afford hired labour, which was amenable for better-off farmers and in rare cases for medium but not for the poor groups. The wealthier were also relatively more efficient in collecting hay from private GL and store for later use in times of scarcity or practice strategic feeding by providing for the more productive animals such as milking cows and working oxen (Hassen *et al.*, 2010; Wondatir *et al.*, 2011). Moreover, labour availability is compulsory to carryout sound livestock management and improve their productivity (McDermott *et al.*, 2010).

5.5.5. *Factors affecting/explaining feed and livestock water productivity*

At the present state of agricultural rainwater use and farm productivity in the study area, a unit increase in family labour force in terms of an adult equivalent is estimated to result in an increase of FWP by 2.04% but a reduction of LWP by 1% provided other

influencing variables held constant. The contrasting influence of farm labour force, which is positive on FWP and negative on LWP could be an indication of variation in the labour productivity of feed and livestock production relative to the amount of water used. The available family labour was motivating for increasing the FWP but may not be efficient for the currently observed level of aggregated livestock beneficial outputs attained, i.e. human labour productivity was better in crop production (from which most of feed was derived) than livestock production. The positively associated relationship of family labour force to FWP may be ascribed to the level of labour allocated for crop production and soil moisture conservation practices to obtain crop residues. Corroborating with the present result, Hailelassie *et al.* (2009) demonstrated that farmers with relatively higher labour force were able to ensure timely weeding and tillage, and invest in conservation works that induced reduced soil moisture depletion on cropland due to lowering transpiration from weeds resulting to less amount of water depleted for crop production from which considerable quantities of livestock feed is generated. However, the present result revealed negative relationship contrary to the expectation and findings of Kebebe *et al.* (2015) who reported positive influence of family labour on LWP. Hence, the family labour force should be complemented with productivity enhancing mechanisms to increase the labour productivity of livestock production and subsequent LWP.

Area of cultivated cropland and value of harvested grains exhibited positive relationship with FWP. For an increase in the area of cultivated cropland by a hectare the FWP estimated to increase by 7.30%, when all other independent variables are held constant. With same assumption, for a thousand USD obtained from aggregated value of grains produced on-farm, FWP is expected to increase by 36.63%. An increase in the size of cropland cultivated potentially allow crop diversification, increased amount of crop biomass and aggregated of value grains harvested at household which may contribute to increased FWP. The positive influence on FWP may be associated with the partitioning of water evapotranspired to produce crop biomass between grains and crop-residues obtained for feeding livestock. This is apparently linked to the relationship of harvested grain yield and derived crop residues for livestock feeding, which is in agreement with the reports of Hailelassie *et al.* (2009) and Kebebe *et al.* (2015), who explained that more crop biomass yield per a given area with less water

evapotranspiration could be translated into efficient water use of food-feed crop production.

On the contrary, given other explaining variables held fixed, an increase in the area of cropland cultivated by a hectare causes a 2.62% reduction of LWP, but an increase in the aggregated value obtained from grains produced on-farm do not cause a significant influence on LWP. It is obvious that the larger the area of cropland cultivated in the mixed system the higher the requirement for traction services (ploughing, threshing and transportation) which will eventually add to the amount of annual livestock beneficial output obtained per household due to more animal labour contribution. However, this expected relationship of increase in LWP with the size of cultivated cropland is not positively explained in the present scenario. This could be attributed to the low level of other livestock outputs to bring efficient water use and increased LWP. For instance, Hailelassie *et al.* (2009), Descheemaeker *et al.* (2010) and Kebebe *et al.* (2015) reported apart from traction services, the limited annual offtake rates and livestock productivity such as milk in the mixed crop-livestock production systems are among the critical determining factors limiting improvements in LWP.

Aggregated livestock holding (TLU) had contrastingly significant influence on LWP and FWP. The coefficients are positive for LWP but negative for FWP. A unit increase in the livestock holding size resulted in an increase of LWP by 0.76%, but a decrease of FWP by 1.61%, provided other variables held constant. Similarly, Kebebe *et al.* (2015) reported significantly positive effect of livestock ownership on LWP due to the high volumes of livestock outputs such as manure equated in to inorganic fertilizer equivalents and the traction services provided for the timely cropland preparation, threshing and transportation, which are attainable from ownership of large livestock numbers. The negative relationship of FWP with increasing livestock holdings may be attributed to use of grazing lands most of which are degraded and not well managed from which small quantities of livestock feed biomass is obtained but much water evapotranspired for livestock feed production. In this regard, Amede *et al.* (2011) explained that, in the Nile basin highland areas where the livestock are kept in the upper slopes at high densities thought to affect its hydrology profoundly, causing erosion of varying intensity, widespread degradation of the vegetative cover and other damage.

Moreover, Peden *et al.* (2009) underscores that conserving agricultural water and maintaining high levels of vegetative ground cover is a challenge in grazing areas. These circumstances may elucidate the negative influence of increased livestock numbers per a given area on FWP, contributing to low feed biomass availability for the water used to produce feed from grazing lands. Hence looking for interventions, such as rehabilitation of degraded landscapes to allow high rates of infiltration and water holding capacity of the soil to increase feed biomass production from grazing lands, improving grazing management and livestock stocking rate could be suggested to increase the opportunities for improving the current level of FWP.

Farmers who are members of dairy cooperatives attained 2.65% times higher LWP than their non-members counterparts, however, the relationship had no significant influence on FWP, other explaining factors held constant. This may be associated with the services provided by the dairy cooperatives which are working mainly on milk collection and marketing activities. However, it should be borne in mind that the MCC received fluid milk from farmers irrespective of membership to dairy cooperatives. The dairy cooperatives collect, process and sale milk and milk products. Moreover, other services like provision of inputs such as concentrate feeds supplies were limited only to the dairy cooperative members, even though there was no regular supply as demanded by them. In agreement, Negassa (2009) pointed out that the formation of marketing cooperatives that deliver economies of scale may be an effective strategy for linking smallholders with major market outlets. In addition, Abebaw and Haile (2013) reported the positive impact of agricultural cooperatives membership to technology adoption for improving agricultural productivity due to the expected important roles the cooperatives could play in achieving better growth in the sector. Nonetheless, according to Bitew *et al.* (2011) the involvement of dairy cooperatives as part of the rural development process in Ethiopia are mainly limited in milk collection, processing and marketing, yet, the supply of feeds and appropriate livestock breeds are major constraints to enhanced milk production in Ethiopia. These constraints are compounded by inefficiencies in the operation of milk and input markets in the country (Bitew *et al.*, 2011). Therefore, promotion of dairy cooperatives to increase the milk collection, processing and marketing capacities through supply of milk chilling, processing and transportation facilities, promotion of the management and inputs delivery capacity

such as concentrate feeds would help to improve the performance of cooperatives which could eventually contribute to improvement of livestock and feed water productivity.

As expected access to credit services and trainings had positive and significant influence on both FWP and LWP. Those who had access to credit services for agricultural inputs had increased FWP and LWP by 3.93 and 5.26 % times, respectively than those without access to credit services. Moreover, those who had access to agricultural trainings had increased FWP and LWP by 7.05 and 4.96% times, respectively than those without access to such trainings. Farmers who have access to credit and/or training are more likely to use inputs and apply improved practices that enhance the productivity of both crop and livestock which might eventually contributed to increased FWP and LWP than who are disadvantaged for these services. Lack of finance constrain access to inputs and lack of awareness may impair the use of improved practices (technologies). For instance, Negassa (2009) reported access to credit and extension services are often mentioned as an important condition to increase smallholder dairy farm operation and sale raw milk. In addition, Kassie *et al.* (2011) explained that lack of sufficient credit and information inhibited farmers to make decisions for necessary investments to acquire inputs and use of technologies. Based on the results, it seems possible to accelerate the adoption of improved technologies for livestock water use by providing training and improving access to credit. The apparently observed results suggest access to credit with non-exploitative terms of re/payment plan and technical assistance through targeted/relevant trainings would motivate famers to improve their farm productivity through use of technologies and application of best practices for efficient resource use including water for livestock and food-feed crop production.

5.6. Agricultural Production Constraints as Perceived by Farmers

5.6.1. Livestock production constraints

Land is a commonly shared resource for the production of crop, feed, forest, livestock, and used for other non-agricultural enterprises. In ranking of constraints by farmers land shortage came to the forefront as the most limiting factor to increase livestock

production in the mixed systems. Such analysis among farmers is not only about the limited size of land which is shared among different sectors but coined with the low productivity level of livestock per unit of land. This could be explained by the level of land fragmentation, degradation and low productivity of feed and food crops coupled with limited use of technologies to enhance productivity, which ultimately resulted in insufficient feed resource supply for livestock production. These circumstances were unanimously supported by several reports in different parts of the of Ethiopia (Peden *et al.*, 2008; Hailelassie *et al.*, 2009; Wondatir *et al.*, 2011; Yilma *et al.*, 2011; Mohammed *et al.*, 2014; Zereu and Lijalem, 2016). The limited availability of land for feed production in conjunction with its low feed biomass productivity, and the existing low opportunity of obtaining feed from other alternative sources make feed shortage an inseparable constraint from land shortage for increasing livestock production. This is in conformity with the findings of Wondatir *et al.* (2011) and Hassen *et al.* (2010), where feed scarcity posed a serious threat for livestock production and productivity improvements in the central highlands of Ethiopia. In addition, Mengistu (2010) reported feed shortage as the most important rated problem for livestock production in Ethiopia.

Farmers claim for livestock diseases as an impeding constraint to increase livestock productivity is attributed to the prevalence of rampant livestock diseases coupled with the inadequate interventions for prompt prevention and sound control mechanisms. These claims have been ascertained from previous study results documented. For instance, regarding cattle production Desta (2002), explained that a number of parasitic, bacterial, fungal and viral diseases and nutritional deficiencies which are prevalent in the country affect the productivity and reproductive efficiency of dairy cattle production specially using cows with exotic blood. Corroborating the present claim, a study conducted in different production systems of Ethiopia by a team of researchers reported that in *Amhara* Region animal disease was the major problem accounting for 50-75% of the total young stock mortality (including calves, lambs and kids) followed by malnutrition and poor mothering ability (Fentie *et al.*, 2016). Same report revealed among the diseases, diarrhea was the most frequently reported disease that caused newborn mortality ranging from 32.4% in calves to 61% in kids, especially in the first month of age, and respiratory disorders caused 15-26% of young stock mortality. In

addition, various diseases and parasites (Gizaw *et al.*, 2010) and respiratory diseases (Tibbo, 2006) affected sheep production by lowering the growth and reproductive performances and offtake rate, besides to the high morbidity and mortality rates. Therefore, farmers claim and the evidences from various investigations calls for prompt delivery of interventions targeted to improve both nutrition and health status of livestock in the study area. By doing so an improvement in livestock productivity and increasing of animal offtakes will be achieved which would potentially contribute to increased livestock water productivity. Otherwise, the sickness and death of animals and the cost of treatments associated would be a debit for improving livestock water productivity.

The rating of lack of access to credit for livestock production among the top constraints indicates the limited accessibility of financial institutions and systems to support livestock production. Farmers need credit mainly to purchase animals and inputs such as feed, medication. However, access to credit as required by the sector is a critical challenge, which is more severe among the poor group of farmers. Likewise, Alemayehu & Tassew (2017) reported that livestock development enterprise needs higher level of investment and long-term loan, however, the lending requirements and the loan size provided for example by the *Amhara* Credit and Saving Institution (ACSI) is small and hardly fit the requirements for livestock development, such as sheep and cattle production and fattening.

Human labour shortage as ranked by producers is comparatively more sever for cattle than for sheep production. Though both species have a common requirement for labour such as attending on grazing, watering, housing, the relatively higher labour requirement of cattle production may be associated with the extra labour required for milking and milk product processing. Other reasons could be associated with the collection of crop residues, hay and purchased feeds on which cattle are mostly fed on than other livestock species. The labour allocated to these tasks is mostly related to cattle than sheep production. Moreover, most of the stated tasks for sheep production are taken over by children, while adults are involved in most of the tasks related to cattle production.

Among other constraints lack of improved genotype preceded inadequate extension support services in cattle production while it is vice versa in sheep production. Lack of artificial insemination service (AI) which is related to improving the genetic resource for milk production is only ranked for cattle production as there is no practice in case of sheep production. The low rating for lack of improved genotype and AI may be related to the inaccessibility and incapability of most of the farmers to maintain the required exotic blood level in the crosses due to lack of breeding plan and uncontrolled mating.

Market accessibility as a constraint is relatively ranked higher in sheep than cattle production may be due to the presence of MCC near villages which received fluid milk daily and transport it to milk processing plants and catering units, and the infrequent marketing of cattle than sheep in the study area. However, accessibility of market for purchase of inputs such as supplementary feeds is remote in both cases.

Drinking water scarcity is the least ranked constraint for both cattle and sheep production, because of the non-seasonal availability of water sources for livestock drinking such as “*Beressa River*” and nearness of most of the grazing areas to the watering sources.

5.6.1.1. *Forage production constraints*

Besides shortage of improved forage planting materials, shortage of land is the most critical problem for forage production in the study area. Same problems were reported in different areas of the country as most limiting factors to promote forage production. For instance, in *Nekemte* and *Bako* areas Geleti *et al.* (2014) observed low improved forage production attributed mainly to the limited land allocation; whereas land shortage and lack of planting materials associated with high cost in *Wolaita Zone* southern Ethiopia (Zereu and Lijalem, 2016) are impediments for forage production. The limitation of land allocation for forage production may be due to the small size of land ownership and the priority given for staple food crop production. The unavailability of reliable forage seeds/seedlings production and supply system may have also potentially contributed to the shortage of planting materials. In agreement,

Mengistu (2010) noted that inadequate technical support and lack of appropriate and sufficient input supply particularly forage seed are the major causes for the failure of forage technologies adoption in the country at a wider scale. In addition, limited area specific studies conducted on the return on investment of forage production may have also influenced the motivation of farmers to allocated land and invest on required inputs to produce feed. Moreover, according to Gebremedhin *et al.* (2003) household resource endowment, especially land and labour were important encouraging factors for the adoption of an oats-vetch forage technology in the Ethiopian highlands mixed crop-livestock farming systems.

Apart from the research and development works on forage production for long periods in Ethiopia, the limited knowledge of farmers and low adoption of improved forage production and utilization could justify the insufficient enabling factors provided to farmers. Among others inadequate extension support, lack of access to credit services and shortage of fertilizers are claimed as limiting constraints for sizable achievements of improved forage production and utilization. The shortage of human and animal labour may be due to the competing needs with crop production, and the farmers intention to invest more labour on crop than forage production. Moreover, the prevalence of forage pests, weeds and diseases are among the enumerated constraints adding to the staggering progress of improved forage production and utilization in the study area. The present claims of farmers are substantiated by research evidence of Geleti *et al.* (2014) who reported that even though focus has been given to the dissemination of feed technical interventions with less consideration to the feed value chain constraints, the adoption of the interventions were limited resulting in low contribution of improved forage production to the dairy sector in *Nekemte* and *Bako* areas. Moreover, Gebremedhin *et al.* (2003) investigated that the potential for forage adoption is limited under subsistence oriented livestock production as the economic incentives are low, however, it can be high under market oriented livestock production, such as dairying with crossbreds or improved breeds, and fattening of large and small ruminants. Hence, it should be noted than increasing livestock productivity is substantially dependent on improved nutrition which could be partly resolved through adoption of improved forage crops and better crop residues management. Therefore, those known constraints witnessed by farmers to affect improved forage production

need to be addressed to scale up the limited and stagnated experiences of improved forage production and utilization in the study area. Strengthening the promotion of forage innovations to increase the forage biomass yield per unit area and ensure the reliability of forage seeds system could help to realize that improved forage production and utilization will pay the cost through improvement in the health and productivity of livestock.

5.6.2. *Crop production constraints*

The shortage of land for crop production is the manifestation of exhibited trends of the ever increasing human and livestock densities due to population growth over time. This is in agreement with the report of Headey *et al.* (2014), that showed very small farm sizes ownership per household in the Ethiopian highlands and which is declining over time, with young rural households facing particularly severe land constraints. Besides fragmented holding, the land is degraded as the results of soil erosion and nutrient depletion which have compromised food security due to unmatched crop productivity and yield to comply with the population growth. Realizing this mismatch, Headey *et al.* (2014) noted that if farm sizes are shrinking, intensification (increased output per hectare) is therefore necessary to maintain or increase farm output per capita. In an attempt to increase crop productivity and alleviate food insecurity, use of improved agricultural technologies (improved crop varieties, commercial fertilizers, better agronomic practices and pest control measures) have been promoted by government and non-government organizations. However, the challenges remained unabated and continued to be limiting constraints to bring satisfactory level of crop productivity. As depicted from the response of farmers the inadequate supply of fertilizers to amend soil fertility coupled with shortage of locally adaptable improved seeds influenced their efforts to increase the crop yield per unit area. In addition, the soaring prices of inorganic fertilizers year-in and year-out adversely affected the farmers capability, especially the poorer to the use of productivity enhancing inputs. Moreover, the limited access to the financial institutions, which could provide credit to the smallholder farmers influenced the sufficient utilization of purchased inputs.

Keeping in mind the animal and human labour productivity (labour to land ratio), it looks strange that crop production on the limited land available is constrained by both animal and human labour shortages. This usually may happen in the poor group who may not have one or enough oxen and sufficient productively active family member with strengthen to take over the farming activities, but it was seldom in the wealthier group of farmers. The lack of both animal and human labour for crop production may be basically associated with the more labour demanding traditional agronomic practices experienced among farmers.

Numerous scholars underlined that adoption of improved agricultural technologies by farmers to increase crop productivity depends on relevant research innovations, the effectiveness of extension services and appropriate agricultural policies (Abebaw & Haile, 2013; Amede *et al.*, 2009; Deressa *et al.*, 2008; Gebremedhin *et al.*, 2003; Knowler & Bradshaw, 2007). However, irrespective of wealth status farmers frequently claimed the current provisions of extension services and trainings delivered are not satisfactory. This could be attributed to the provision of training not targeted to their particular needs and the gap in delivering appropriate hands-on training and in backing up with sufficient technical assistances. This is further confounded by inadequate demonstration, advocacy, followup and supply of affordable technologies to uptake for immediate practical actions. Weeds, pests and diseases are factors that cause a reduction of crop yields even when other nutrients and water are not limiting due to their competition for the nutrients and damaging effect to the main crop. Besides to the shortage of synthetic fertilizers and improved seeds, it is claimed that limited technological interventions on the control of weeds, pests and diseases and farmers capability to access such controlling mechanisms like chemicals posed an influence on increased crop yield.

In the mixed crop-livestock farming systems, a constraint that influenced one of the system component has a projected impact onto the others. For instance, a reduction in food crop biomass productivity due to limited availability and use of inputs will result in reduction of crop residues ultimately causing feed shortage where crop residues contribute a significant share of livestock feed supply. In the present cases, the contribution of crop residues is unprecedented; consequently, constraints of crop

production have an overwhelming influence on feed supply for the maintenance and productivity of livestock. Improved crop production interventions that include extension service activities to bring changes in the knowledge, skills and attitudes of farmers to use technologies and improved practices coupled with sufficient input supplies (fertilizers and improved seeds) are important for the effectiveness of livestock production besides to a number of factors affecting livestock production. Moreover, alleviating constraints of crop production to increase yield per unit area is among the complementary strategies that need to be implemented to increase livestock feed supply and to improve the water use of both crop and livestock.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Rainfed mixed crop-livestock production system is an overwhelming agricultural activity of the study area. The present study focused on characterization of the mixed system with particular emphasis on livestock-water interactions using livestock feed resources as a proxy. The study considered farm level analysis for farmers stratified in to three wealth groups (poor, medium and better-off). Farm resources holding, mainly land and livestock, formed the basis for stratification of farmers into varied wealth groups, the size of which arbitrated the wealth gradient. Cultivated croplands and grazing lands are the major agricultural land use types on which livestock feeds are sourced and water use of livestock are fundamentally linked.

The major annual food-feed crops grown by farmers during the main growing season are barley, wheat, faba bean and field pea in order of importance. The crops constituted the staple human food and major livestock feed supply. The area of grazing lands exhibited a decreasing trend as the result of conversion into cultivated cropland. This trend intensifies the livestock density and increases the pressure on the grazing land leading to aggravated land degradation and declining soil fertility, and feed biomass yields. The livestock density on grazing land is almost twice that of the cultivated cropland which shows the importance of crop production for livestock feed sourcing. The types and amounts of food grain and crop-residues harvested depend on the cropping pattern. Farmers' choices of cropping pattern and crop management practices have an influence on the food-feed crops productivity and feed supply for livestock. The prevailing cropping pattern, plot of land allocated per crop type and level of input utilization at farm level determine the seasonal quantity and quality of livestock feed sourced from crop production among wealth group of farmers.

The contribution of livestock labour to cropland preparation is among the key attributes which demonstrated the crop-livestock integration. Frequent tillage operations increase livestock labour contribution in the farming system and could contribute to improved feed and livestock water productivity. However, unnecessary soil disturbance due to

repeated and cross plowing without taking into account the soil type and slope of the cultivated land may lead to land degradation.

The numerical contribution of species in the mix of livestock kept varied along with wealth gradient of farmers. The cattle herd structure was dominated by males with highest proportion of oxen, followed by cows. The existing cattle structure justify the critical importance of breeding animals to produce replacements for oxen used for cropland preparation followed by milk production using the crossbred cows. Like cattle, the small ruminants ownership was aligned with the betterment of farmers wealth status. Numerically females dominate males; however, the present ram to ewe and buck to does ratio indicated the possibility to increases in an offtake of rams and bucks, provided the existence of more sires for flock mating in the individual farms. The possibility could also be justified by installing breeding programs in the community which promote sharing of superior sires among neighboring farmers. Equines are dominated by adults shows the relative importance of equines for transportation. The dominance of the adult females also depicts their numerical importance in reproduction to maintain the replacements of the herds.

The livestock herd dynamics portrays the periodical management of owners and natural events occurred in the herd. The outgoing of animals from the herd/flock was in the form of offtake (sale, slaughtered, given out) and death of the animals for various reasons, while the incoming was due to the natural reproduction (births), purchased, received as a gift. The outflow and inflow of cattle and equines over the year was not frequent and in large numbers either. Rather the conceivable beneficial outputs obtained from cattle were milk, traction services and manure, and that of equines was transportation. In case of small ruminants particularly sheep the dynamics were recurrent; correspondingly the most plausible beneficial output was due to annual offtake. This makes them the most versatile animals used to fulfill the immediate cash needs of farmers irrespective of their wealth status. However, the beneficial outputs were counteracted by the death and loss of animals. Generally low offtake rates and high death rates contributed to reduced annual benefit generated from livestock and impacted on livestock water productivity. In absolute number the offtake of sheep

followed the wealth gradient, the highest being among the better-off followed by medium and poor farmers.

Farmers rankings on the purposes of keeping livestock species across wealth groups were almost similar. Keeping cattle for draught power and milk production were prominent purposes, whereas keeping as an income source, live saving assets, source manure and meat are subsidiary purposes. Small ruminants are considered as an asset which can be easily liquidated whenever the need arises. Owing this fact keeping small ruminants as an income source and saving assets prevailed. Their importance as meat source is also appreciated. Farmers explicitly keep equines for transportation of agricultural products and humans; however, in the meantime used as income source and saving assets. Relatively, the importance of small ruminants and equines as a source of manure was not much valued as that of cattle.

Manure is enormously used as a source of bio-fuel energy and income after it is processed into dung cake. It is also used as organic fertilizer in the backyard and farm lands nearby homestead, by directly dumping or spreading onto the field or after it is composted. The vast majority of farmers collected manure daily and every other day and piled it or put in a pit. Despite frequent collections, the handling practices to minimize the loss of manure nutrients and reduce detrimental effects due to pollution were not sufficient irrespective of farmers wealth status. Majority of the farmers did not use shade and cover to protect the stored manure from deterioration due to exposure to sunlight, wind and rain. Composting larger amount of manure and use of bedding materials to retain urine are not common. On the other hand, manure is among the beneficial outputs regularly contributed by livestock throughout their entire life. In estimating the LWP, manure valuation in terms of inorganic fertilizers equivalent has contributed considerably to the total value of livestock beneficial outputs obtained per farm daily. However, mishandling of manure could compromise its role in increasing LWP as degraded water due to pollution is accounted as consumptive use of water by livestock.

The available annual feed dry matter, metabolizable energy and digestible crude protein supplies and requirements of livestock did not match at present, in the study area

characterized by smallholder mixed crop–livestock production system. The livestock feed insufficiency unanimously affects the whole group of smallholder farmers irrespective of wealth status. However, the wealthier group of farmers which owned larger size of livestock collected more quantity of feed on-farm and acquired additional feed through purchase were found to suffer more in terms of feed deficit than the poor farmers. Scarcity of grazing land due to expansion of cultivation coupled with low biomass yield from grazing and food-feed crops further exacerbated the mismatch between feed supply and demand. The trend of land scarcity testifies that smallholder livestock production in the MCL system is likely to continue to rely upon crop residues. Crop residues which are claimed to have suboptimal feeding value due to the high fiber content and low digestibility comprised the major portion of annual feed supply, and thus the inherent limitations of crop residues should not be ignored. Farmers who promoted cross-breeding of local animals with breeds of temperate origin to increase milk production were found unable to supply sufficient quantity and quality of feed to achieve the anticipated level of productivity. The present evidences implied that, unless the feed deficit is relieved through increasing the availability and quality of feeds and practicing strategic feeding, the productivity of livestock will be more profoundly affected.

The mixed crop-livestock production system in the study area suffered with myriad of constraints, but land being common resource competed among crop, feed, livestock production and other sectors, its shortage became unprecedented problem. The ever-increasing population of both livestock and human further intensifies the pressure on this limited shared resource. Shortage of feed for livestock production is strongly linked with land availability and the capability to afford from alternative sources. Shortage of technological input supplies such as lack of improved livestock breeds, improved forage and crop seeds, lack of fertilizers, access to credit and training services and lack of human and animal labour are common limiting factors of the mixed farming components. Moreover, incidences of livestock diseases, weeds, pests and diseases of crop and forage plants coupled with inadequate interventions were also claimed to affect the productivity of livestock and crop in the mixed farming. Furthermore, constraint that influenced one of the system components has a projected impact onto the others. Limited availability and use of inputs cause a reduction of food-feed crop

biomass resulting shortage of crop residues for livestock feed supply. Feed shortage in turn affect the productivity of livestock including the level of draught power and manure supply to crop production. Lack of these complementarities will eventually be manifested in low feed and livestock water productivity of the farms.

Different factors influenced farm level FWP and LWP. The contrasting influence of farm labour force, which is positive on FWP and negative on LWP could be an indication of the variation in the labour productivity of feed and livestock production relative to the amount of water used. The positive relationship of FWP with area of cultivated cropland and value of harvested grains may be associated with the partitioning of water evapotranspired to produce crop biomass between grains and crop-residues for feeding livestock. An increase in the area of cropland cultivated is expected to require more animal traction services which will add to the amount of annual livestock beneficial output obtained per household; however, the negative relationship in the present study may be attributed to the low level of other livestock outputs (such as offtake, milk yield) to bring efficient water use and increased LWP. The positive influence of livestock holding size on LWP may be attributed to the attainable higher amount of livestock outputs and services from ownership of large livestock numbers. However, the negative relationship with FWP may be attributed to the use of degraded grazing lands on which small amount of livestock feed biomass is obtained for the volume water evapotranspired. The relationship of increased LWP with membership of dairy cooperatives may be associated with the services provided by the dairy cooperatives in milk collection, marketing and sometimes input supply such as concentrate feeds to the members. The positive relationship of access to credit and training services on both FWP and LWP is attributed to the role of these services in enabling farmers to acquire the means for improved technology uptake and practice to enhance the productivity of crop and livestock.

Livestock and feed production are dependent on finite freshwater. The need to meet the growing demand for livestock products and services coupled with multiple uses of water is expected to intensify the pressure on freshwater. To devise relevant strategies for efficient water use and allocation, we need to know the level of water consumption for livestock production in the system. This study reveals the water productivity of feed

and livestock based on the feed resources types in the mixed crop-livestock system. This will help to analyze the gaps and apply interventions for feed and livestock water productivity improvements.

6.2. Recommendations

The following recommendations are forwarded to improve the feed and livestock water productivity in the mixed crop-livestock system.

- Explore farmers wisdoms and initiatives gained through experiences to make the most use of water resources for crop and livestock production such as soil and water conservation practices, use of residual soil moisture to produce food-feed and forage crops. The local innovations are essential as entry points to strengthen processes of the selection and introduction of good practices and new technologies that will enhance crop-livestock water productivity.
- Engage communities to collaboration in the management, control and use of common resources such as openly used communal grazing lands and water resources to reduce the effects of overgrazing and water pollution due to livestock keeping. Rules and regulations can be developed in agreement for more equitable use and protection of communal resources.
- Undertake research to select food-feed and forage crop varieties that produce more biomass with less water input and adopt improved agronomic practices suited for the selected crops and varieties such as land preparation, fertilization and other practices. In the mixed crop-livestock systems priority for improvement in the water use efficiency and productivity and biomass yield should be given for food-feed crops with the largest share of contributions for human staple food and livestock feed resources.
- Avoid spoilage and wastage of crop residues through timely harvesting and proper storage.
- Improve the feeding value of crop residues (digestibility and nutrient availability) through treatment and supplementation.
- Expansion of grazing land is not a practical option to increase feed supply. Therefore, increasing food-feed crops production per unit area, conservation of surplus forages, strategic feeding based on productivity and traction services of

livestock, purchase of feeds, and increasing livestock offtake during time of scarcity would help to correct the observed feed shortage. Moreover, refinement of the feed balance analysis at specific nutrients level would be compulsory for effective strategic interventions.

- Rehabilitate mismanaged grazing lands by promoting soil and water conservation practices, improved forage production, feed conservation and cut-and carry feeding system to reduce land degradation, water and nutrient depletion due to overstocking and livestock grazing on such fragile lands.
- Identify the dominantly important native feed resources (grasses and legumes) on natural grazing lands and evaluate for feed biomass productivity, nutritive values and water use, to improve and use them for grazing land improvement.
- Introduce and promote the production and utilization of improved forages and evaluate their water utilization (water productivity).
- Promotion of dairying through breed improvement for milk production should be consolidated with comprehensive health, feeding and crossbreeding approaches. Record keeping should be installed at farm level for sound breeding plan and farm management.
- Strengthen veterinary services to reduce the mortality and morbidity of livestock as these resulted reductions in the outputs and services, and incur costs accounted to livestock production. Increase annual offtake rate especially for small ruminants.
- Improve the management and utilization of livestock manure. Evaluate the current storage and handling practices to preserve manure nutrients. Promote biogas as an alternative energy source and composting to use manure as organic fertilizer.
- Strengthen enabling institutions that support farmers, such as dairy cooperatives milk collection centers, marketing, credit, extension and training services.

7. REFERENCES

- Abebaw D. and Haile M. G. (2013): The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia. *Food Policy*, **38**(1): 82–91.
- Abebe T. (2013): Determinants of crop diversity and composition in Enset-coffee agroforestry home gardens of Southern Ethiopia. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, **114**(1): 29–38.
- Abegaz A., Keulen H. V. and Oosting S. J. (2007): Feed resources, livestock production and soil carbon dynamics in Teghane, Northern Highlands of Ethiopia. *Agricultural Systems*, **94**: 391–404.
- Abegaz S., Hegde B. P. and Taye M. (2011): Growth and physical body characteristics of Gumuz sheep under traditional management systems in Amhara Regional State, Ethiopia. *Livestock Research for Rural Development*, **23**(5): 10. Retrieved June 11, 2016, from <http://www.lrrd.org/lrrd23/5/abeg23117.htm>.
- Admassu B. and Shiferaw Y. (2011): Donkeys, horses and mules - their contribution to people's livelihoods in Ethiopia. The Brooke, Addis Ababa, Ethiopia, 70p.
- Admasu M. (2009): Environment and social assessment fertilizer support project report, Project ID: P113156. Ministry of Agricultural and Rural Development, Addis Ababa, Ethiopia, 74p.
- Alam M., Sumy S. A. and Parh Y. A. (2015): Selection of the samples with probability proportional to size. *Science Journal of Applied Mathematics and Statistics*, **3**(5): 230–233.
- Alemayehu K. and Tassew A. (2017): Challenges and opportunities for increased farm animal productivity in the Lake Tana Sub-Basin. In: K. Stave, G. Goshu and S. Aynalem (Eds.), *Social and ecological system dynamics: Characteristics, trends and integration in the Lake Tana Basin, Ethiopia* (pp. 399–415). Springer Nature, Cham, Switzerland.
- Alemayehu, M., Peden D., Taddesse G., Hailelassie A. and Ayalneh W. (2008): Livestock water productivity in relation to natural resource management in mixed crop-livestock production system of the Blue Nile river basin, Ethiopia. Pp 79-82. Proceedings of the CGIAR Challenge Program on Water and Food 2nd

- International Forum on Water and Food, Addis Ababa, Ethiopia, November 10–14, 2008. CGIAR Challenge Program on Water and Food, Colombo, Sri Lanka.
- Alemayehu M. A. (2013): Livestock-water interactions: The case of Gumara watershed in the Upper Blue Nile Basin, Ethiopia. PhD dissertation submitted to Der Humboldt-Universität zu Berlin, Germany, 141p.
- Alemayehu M., Amede T., Peden D., Kumsa T., Böhme M. H., & Peters K. J. (2017): Assessing livestock water productivity in mixed farming systems of Gumara watershed, Ethiopia. *Experimental Agriculture*, DOI 10.1017/S0014479717000321.
- Allen R. G., Pereire L. S., Raes D. and Smith M. (1998): Crop evapotranspiration (guidelines for computing crop water requirements). FAO irrigation and drainage paper No. 56. Rome, Italy: FAO.
- Amede T. (1998): Analysis of drought resistance in grain legumes: The case of *Vicia faba L.*, *Pisum sativum L.*, *Phaseolus vulgaris L.* and *Cicer arietin L.* PhD dissertation submitted to University of Hohenheim, Stuttgart, Germany, 135p.
- Amede T., Descheemaeker K., Everisto M., Peden D., Breugel P. van, Awulachew S. B. and Hailelassie A. (2011): Livestock-water productivity in the Nile Basin: Solutions for emerging challenges. In: A. M. Melesse (Ed.), Nile River Basin: Hydrology, climate and water use (pp. 297–320). New York: Springer Science+Business Media B.V.
- Amede T., Geheb K. and Douthwaite B. (2009): Enabling the uptake of livestock water productivity interventions in the crop–livestock systems of sub-Saharan Africa. *The Rangeland Journal*, **31**: 223–230.
- Amede T., Tarawali S. and Peden D. (2011): Improving water productivity in crop-livestock systems of drought-prone regions: Editorial Comment. *Experimental Agriculture*, **47**(S1): 1–5.
- Amsalu A. and de Graaff J. (2006): Farmers' views of soil erosion problems and their conservation knowledge at *Beressa* watershed, central highlands of Ethiopia. *Agriculture and Human Values*, **23**(1): 99–108.
- Amsalu A., Stroosnijder L. and Graaff J. de. (2007): Long-term dynamics in land resource use and the driving forces in the *Beressa* watershed, highlands of Ethiopia. *Journal of Environmental Management*, **83**(4): 448–459.

- Amsalu T. T. and Addisu S. (2014): Assessment of grazing land and livestock feed balance in Gumara-Rib watershed, Ethiopia. *Current Agriculture Research Journal*, **2**(2): 114–122.
- Andargachew K. and Brokken R. F. (1993): Intra-annual sheep price patterns and factors underlying price variations in the central highlands of Ethiopia. *Agricultural Economics*, **8**(2): 125–138.
- Asfaw A. and Admassie A. (2004): The role of education on the adoption of chemical fertilizer under different socioeconomic environments in Ethiopia. *Agricultural Economics*, **30**: 215–228.
- Asresie A. and Zemedu L. (2015): Contribution of livestock sector in Ethiopian economy: A review. *Advances in Life Sciences and Technology*, **29**: 79–90.
- Assefa D., Nurfeta A. and Banerjee S. (2013): Assessment of feed resource availability and livestock production constraints in selected Kebeles of Adami Tullu Jiddo Kombolcha district, Ethiopia. *African Journal of Agricultural Research*, **8**(29): 4067–4073.
- Astatke A. and Jabbar M. (2001): Low-cost animal drawn implements for Vertisol. In: J. K. Syers, F. W. T. P. De Vries, P. Nyamudeza and R. N. Leslie (Eds.), *The sustainable management of Vertisols* (pp. 189–201). Wallingford Oxon, UK: CABI Publishing.
- Astatke, A. (1993): Research on the draught animal power systems in Ethiopia. Pp. 199–204. Proceedings of the fourth workshop of the West Africa Animal Traction Network. Kano, Nigeria, 9-13 July 1990, International Livestock Centre for Africa.
- Awulachew S. B., Merrey D. J., Kamara A. B., Van Koppen B., Penning de Vries F., Boelee E. and Makombe G. (2005): Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia. Working Paper 98. International Water Management Institute (IWMI), Colombo, Sri Lanka, 86p.
- Awulachew S. B., Yilma A. D., Loulseged M., Loiskandl W., Ayana M., Alamirew T. (2007): Water resources and irrigation development in Ethiopia. Working Paper 123. International Water Management Institute (IWMI), Colombo, Sri Lanka: 78p.

- Ayele A. (2012): Small-holder farms livestock management practices and their implications on livestock water productivity in mixed crop-livestock systems in the highlands of Blue Nile basin: A case study from Fogera, Diga and Jeldu districts (Ethiopia). MSc thesis submitted to Hawassa University, Ethiopia, 111p.
- Ayele G., Bekele M. and Zekeria S. (2006): Productivity and efficiency of agricultural extension package in Ethiopia. The Ethiopian Development Research Institute (EDRI), Research Report 5. Addis Ababa, Ethiopia.
- Barrett C. B., Bellemare M. F. and Hou J. Y. (2010): Reconsidering conventional explanations of the inverse productivity–size relationship. *World Development*, **38**(1): 88–97.
- Bedasa, E. T. (2012): Study of smallholder farms livestock feed sourcing and feeding strategies and their implication on livestock water productivity in mixed crop-livestock systems in the highlands of the Blue Nile Basin, Ethiopia. MSc thesis submitted to Haramaya University, Ethiopia, 121p.
- Behnke R. (2010): The contribution of livestock to the economies of IGAD member States: Study findings, application of the recommendations for further work, IGAD Livestock Policy Initiative (LPI). Working Paper No. 02-10. Odessa Centre, Great Wolford, United Kingdom, 43p.
- Behnke R. and Fitaweke M. (2011): The contribution of livestock to the Ethiopian economy – Part II. IGAD Livestock Policy Initiative (LPI). Working Paper No. 02-11. Odessa Centre, Great Wolford, United Kingdom, 43p.
- Bekele M. (2008): Integrating livestock in to water resources development: Assessment on livelihood resilience and livestock water productivity at Golina and Alewuha Rivers. MSc thesis submitted to Hawassa University, Ethiopia, 248p.
- Bekele M., Mengistu A. and Tamir B. (2017): Livestock and feed water productivity in the mixed crop-livestock system. *Animal*, **11**(10): 1852–1860.
- Bitew A., Bahata M., Mekonnen K. and Duncan A. (2011): Dairy intensification and milk market quality in Amhara region, Ethiopia. International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia.
- Blümmel M., Hailelassie A., Samireddypalle A., Vadez V. and Notenbaert A. (2014): Livestock water productivity: feed resourcing, feeding and coupled feed-water resource data bases. *Animal Production Science*, **54**: 1584–1593.

- Blümmel M., Samad M., Singh O. P. and Amede T. (2009): Opportunities and limitations of food-feed crops for livestock feeding and implications for livestock water productivity. *The Rangeland Journal*, **31**(2): 207–212.
- Bogale S., Melaku S. and Yami A. (2008): Potential use of crop residues as livestock feed resources under smallholder farmers' conditions in Bale highlands of Ethiopia. *Tropical and Subtropical Agroecosystems*, **8**(1): 107–114.
- Bogale S., Melaku S. and Yami, A. (2008): Matching livestock systems with available feed resources in the Bale Highlands of Ethiopia. *Outlook on Agriculture*, **37**(2), 105–110.
- Bossio D., Geheb K. and Critchley W. (2010): Managing water by managing land: Addressing land degradation to improve water productivity and rural livelihoods. *Agricultural Water Management*, **97**(4): 536–542.
- Bouman B. (2007): A conceptual framework for the improvement of crop water productivity at different spatial scales. *Agricultural Systems*, **93**: 43-60.
- Church D. C. and Pond W. C. (1982): Basic animal nutrition and feeding. John Wiley and Sons, USA.
- Clement F., Hailelassie A., Ishaq S., Samad M., MitR., Shindey, D.N., Dey A., Khan M.A., Blümmel M., Acharya N.S., Radha A.V. (2010): Livestock water productivity in the Ganga Basin. Project Number 68". CGIAR Challenge Program on Water and Food (CPWF), International Water Management Institute (IWMI), Colombo, Sri Lanka, 103 pp.
- Cook S., Gichuki F., Turrall H. (2008): Water productivity: Estimation at plot, farm and basin scale. Working Paper No. 2. CGIAR Challenge Program on Water and Food. Retrieved January 8, 2015, from <http://www.waterforfood.org>.
- CSA (Central Statistical Agency of the Federal Democratic Republic of Ethiopia). (2015): Agricultural sample survey 2014/2015. Report on land utilization (private peasant holdings, *meher* season) (Vol. IV). Addis Ababa, Ethiopia, 331p.
- CSA and the World Bank. (2013): Ethiopia rural socioeconomic survey (ERSS) report. Addis Ababa, Ethiopia, 64p.
- CSA. (2015): Agricultural sample survey in 2014/15. Report on livestock and livestock characteristics (private peasant holdings) (Vol. II). Addis Ababa, Ethiopia, 188p.
- CSA. (2016): Agricultural sample survey in 2015/2016. Report on land utilization (private peasant holdings, *meher* season) (Vol. IV). Addis Ababa, Ethiopia, 333p.

- de Fraiture C. (2007): Integrated water and food analysis at the global and basin level. *Water Resources Management* **21**: 185-198.
- De Vries P., Rabbinge R., and Groot J. J. (1997): Potential and attainable food production and food security in different regions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **352**: 917–928.
- Delgado C., Rosegrant M., Steinfeld H., Ehui S. and Courbois C. (1999): Livestock to 2020: The next food revolution. A 2020 vision for food, agriculture and the environment. International Food Policy Research Institute (IFPRI), Washington, USA.
- Deressa, T., Hassan, R. M., Alemu, T., Yesuf, M. and Ringler, C. (2008): Analyzing the determinants of farmers' choice of adaptation methods and perceptions of climate change in the Nile Basin of Ethiopia. Discussion Paper 00798. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia, 26p.
- Derner J. D., Leigh H., Filho K. E., Ritten J., Capper J. and Han G. (2017): Livestock production systems. In: D.D. Briske (Ed.), Rangeland systems: processes, management and challenges, pp. 347–372. Springer Nature, Cham, Switzerland.
- Descheemaeker K., Amede T. and Hailelassie A. (2009): Livestock and water interactions in mixed crop-livestock farming systems of sub-Saharan Africa: interventions for improved productivity. Working Paper 133. International Water Management Institute (IWMI), Colombo, Sri Lanka, 34p.
- Descheemaeker K., Amede T. and Hailelassie A. (2010): Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. *Agricultural Water Management*, **97**(5): 579–586.
- Descheemaeker K., Amede T., Amare H. and Deborah B. (2011): Analysis of gaps and possible interventions for improving water productivity in crop livestock systems of Ethiopia. *Experimental Agriculture*, **47**(S1): 21–38.
- Descheemaeker K., Bunting S. W., Bindraban P., Muthuri C., Molden D., Beveridge M., van Brakel M., Herrero M., Clement F., Boelee E. and Jarvis D. I. (2013): Increasing water productivity in agriculture. In: E. Boelee (Ed.), Managing water and agroecosystems for food security, pp. 104–123. Wallingford, UK; Boston, USA: CAB International.
- Descheemaeker K., Hailelassie A., Amede T., Bossio D. and Tarawali S. (2010): Assessment of water productivity and entry points for improvement in mixed

- crop-livestock systems of the Ethiopian highlands. *Advances in Animal Biosciences*, **1**(02): 491–492.
- Descheemaeker K., Mapedza E., Amede T. and Ayalneh W. (2010): Effects of integrated watershed management on livestock water productivity in water scarce areas in Ethiopia. *Physics and Chemistry of the Earth*, **35**: 723–729.
- Desta K. B. (2002): Analyses of dairy cattle breeding practices in selected areas of Ethiopia. PhD dissertation submitted to der Humboldt-Universität zu Berlin, Germany, 164p.
- Desta S. and Coppock D. L. (2002): Cattle population dynamics in the southern Ethiopian rangelands (1980-97). *Journal of Range Management*, **55**: 439–451.
- Duguma B., Tegegne A. and Hegde B. P. (2012): Smallholder livestock production system in Dandi district, Oromia Regional State, central Ethiopia. *Global Veterinaria*, **8**(5), 472–479.
- Duncan A. J., Bachewe F., Mekonnen K., Valbuena D., Rachier G., Lule D., Bahta M. and Erenstein O. (2016): Crop residue allocation to livestock feed, soil improvement and other uses along a productivity gradient in Eastern Africa. *Agriculture. Ecosystems and Environment*, **228**: 101–110.
- Duncan A. J., Tarawali S. A., Thorne P. J., Valbuena D., Descheemaeker K. and Tui S. H. K. (2013): Integrated crop-livestock systems a key to sustainable intensification in Africa. *Tropical Grasslands-Forrajes Tropicales*, **1**(2): 202–206.
- Erkossa T., Hailelassie A. and MacAlister C. (2014): Enhancing farming system water productivity through alternative land use and water management in vertisol areas of Ethiopian Blue Nile Basin (Abay). *Agricultural Water Management*, **132**: 120–128.
- ESGPIP (Ethiopia Sheep and Goat Productivity Improvement Program). (2008): Sheep and goat production handbook for Ethiopia. (A. Yami and R. C. Merkel, Eds.), Addis Ababa, Ethiopia, 347p.
- Ethiopian Investment Agency. (2013): An investment guide to Ethiopia, opportunities and conditions. Retrieved August 16, 2016, from http://www.ethemb.se/TEXT%20files/Investment_Guide%202013.pdf.
- FAO (Food and Agriculture Organization of the United Nations). (1987): Master land use plan, Ethiopian range livestock consultancy Technical Report 3,

- AG/ETH/82/010/FAO. Rome, Italy, 188/77p.
- FAO. (2006): New_LocClim 1.10, Local Climate Estimator. Rome, Italy.
- FAO. (2009): CROPWAT 8.0 for Windows. Rome, Italy.
- FAO. (2011): The state of the world's land and water resources for food and agriculture. Managing systems at risk. Rome, Italy: Earthscan, 285p.
- FAO. (2012): Conducting national feed assessments. (M. B. Coughenour and H. P. S. Makkar, Eds.), FAO animal production and health manual No. 15. FAO, Rome, Italy, 200p.
- FAO. (2017): AQUASTAT Main Database. Retrieved February 10, 2017, from <http://www.fao.org/nr/water/aquastat/main/index.stm>.
- FAOSTAT (2018): FAO statistics database on the world wide web. Retrieved June 17, 2018 from [http://fenixservices.fao.org/faostat/static/bulkdownloads/Production_Livestock_E_All_Data_\(Normalized\).zip](http://fenixservices.fao.org/faostat/static/bulkdownloads/Production_Livestock_E_All_Data_(Normalized).zip).
- Faul F., Erdfelder E., Lang A. G. and Buchner A. (2007): G*Power 3: A flexible statistical power analysis program for the social, behavioral and biomedical sciences. *Behavior Research Methods*, **39**: 175-191.
- Fentie T., Temesgen W., Melaku A., Assefa G., Tesfaye S., Fufa F., Zemene A., Ayalew N., Bosenu A., Fikre Z. W., Birhanu H., Sentayehu G. and Mekonen G. (2016): Assessment of young stock mortality in major livestock production systems of Ethiopia. U.S. Agency for International Development (USAID) and University of Gondar, Ethiopia, 43p.
- Foltz J. D. (2004): Credit market access and profitability in Tunisian agriculture. *Agricultural Economics*, **30**(3): 229–240.
- Fuller R. J. and Aye L. (2012): Human and animal power - The forgotten renewables. *Renewable Energy*, **48**: 326–332.
- Gebreab F., Gebrewold A., Kelemu F., Ibro A. and Yilma K. (2004): Donkey utilization and management in Ethiopia. In P. Starkey and D. Fielding (Eds.), *Donkeys, people and development. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA)*, pp. 46–52. ACP-EU Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands.
- Gebregziabher S., Mouazen A. M., Van Brussel H., Ramon H., Nyssen J., Verplancke H., Behailu M., Deckers J. and De Baerdemaeker J. (2006): Animal drawn

- tillage, the Ethiopian ard plough, maresha: A review. *Soil and Tillage Research*, **89**(2): 129–143.
- GebreMariam S., Amare S., Baker D., Solomon A. and Davies R. (2013): Study of the Ethiopian live cattle and beef value chain. Discussion Paper 23. International Livestock Research Institute (ILRI), Nairobi, Kenya, 38p.
- GebreMedhin B., Ahmed M.M., Ehui S. K. (2003): Determinants of adoption of improved forage technologies in crop-livestock mixed systems: Evidence from the highlands of Ethiopia. *Tropical Grasslands*, **37**: 262–273.
- Gebreselassie S., Peden D., Hailelassie A., Mpairwe D. (2008): Cost-effective assessments of livestock-water productivity using previous feeding trials. In: Fighting poverty through sustainable water use. Pp 92-96. Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10 - 14, 2008. CGIAR Challenge Program on Water and Food, Colombo, Sri Lanka.
- Gebrewold A., Tegegne A. and Yami A. (2003): Research needs of donkey utilization in Ethiopia. In S. P. and F. D (Ed.), Donkeys, people and development. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA), pp. 77–81. ACP-EU Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands.
- Geleti D., Hailemariam M., Mengistu A. and Tolera A. (2014): Analysis of fluid milk value chains at two peri-urban sites in western Oromia, Ethiopia: Current status and suggestions on how they might evolve. *Global Veterinaria*, **12**(1): 104–120.
- Getachew T., Haile A., Tibbo M., Sharma A. K., Sölkner J. and Wurzinger M. (2010): Herd management and breeding practices of sheep owners in a mixed crop-livestock and a pastoral system of Ethiopia. *African Journal of Agricultural Research*, **5**(8): 685–691.
- Gizaw S., Tegegne A., GebreMedhin B. and Hoekstra D. (2010): Sheep and goat production and marketing systems in Ethiopia: Characteristics and strategies for improvement. Working Paper 23. International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, 49p.
- Gryseels G. (1988): Role of livestock on mixed smallholder farms in the Ethiopian highlands: A case study from the Baso and Worena Wereda near Debre Berhan.

- PhD dissertation submitted to Wageningen Agricultural University, The Netherlands, 249p.
- Haile A., Joshi B. K., Ayalew W., Tegegne A. and Singh A. (2009): Genetic evaluation of Ethiopian Boran cattle and their crosses with Holstein Friesian in central Ethiopia: milk production traits. *Animal*, **3**(4): 486–493.
- Hailelassie A., Blümmel M., Clement F., Descheemaeker K., Amede T., Samireddypalle A., Acharya N. S., Radha A. V., Ishaq S., Samad M., Murty M. V. R. and Khan M. A. (2011): Assessment of the livestock-feed and water nexus across a mixed crop-livestock systems' intensification gradient: An example from the Indo-Ganga Basin. *Experimental Agriculture*, **47**(S1): 113–132.
- Hailelassie A., Blümmel M., Clement F., Ishaq S. and Khan M. A. (2011): Adapting livestock water productivity to climate change. *International Journal of Climate Change Strategies and Management*, **3**(2): 156–169.
- Hailelassie A., Hagos F., Mapedza E., Sadoff C., Awulachew S. B., Gebreselassie S. and Peden D. (2008): Institutional settings and livelihood strategies in the Blue Nile Basin: Implications for upstream/downstream linkages. Working Paper 132. International Water Management Institute (IWMI). Colombo, Sri Lanka, 75p.
- Hailelassie A., Peden D., Gebreselassie S., Amede T. and Descheemaeker K. (2009): Livestock water productivity in mixed crop–livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement. *Agricultural Systems*, **102**: 33–40.
- Hailelassie A., Priess J. A., Veldkamp E. and Lesschen J. P. (2006): Smallholders' soil fertility management in the Central Highlands of Ethiopia: Implications for nutrient stocks, balances and sustainability of agroecosystems. *Nutrient Cycling in Agroecosystems*, **75**: 135–146.
- Hailelassie A., Priess J. A., Veldkamp E. and Lesschen J. P. (2007): Nutrient flows and balances at the field and farm scale: Exploring effects of land-use strategies and access to resources. *Agricultural Systems*, **94**: 459–470.
- Hailelassie A., Priess J., Veldkamp E., Teketay D. and Lesschen J. P. (2005): Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agriculture, Ecosystems and Environment*, **108**: 1–16.

- Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T., Wagnew, A. and Taddesse, G. (2009): Livestock water productivity in the Blue Nile Basin: assessment of farm scale heterogeneity. *Rangeland Journal*, **31**(2): 213–222.
- Hassen A., Ebro A., Kurtu M. and Treydte A. C. (2010): Livestock feed resources utilization and management as influenced by altitude in the central highlands of Ethiopia. *Livestock Research for Rural Development*, **22**(12): 19. Retrieved April 10, 2016, from <http://www.lrrd.org/lrrd22/12/hass22229.htm>.
- Headey D., Dereje M., Taffesse A. S. and Seyoum A. (2014): Land constraints and agricultural intensification in Ethiopia: A village-level analysis of high-potential areas. *Food Policy*, **48**: 129–141.
- Herrero M., Grace D., Njuki J., Johnson N., Enahoro D., Silvestri S. and Rufino M. C. (2013): The roles of livestock in developing countries. *Animal*, **7**(S1): 3–18.
- Herrero M., Thornton P. K., Notenbaert A. M., Wood S., Msangi S., Freeman H. A., Bossio D., Dixon J., Peters M., van de Steeg J., Lynam J., Parthasarathy R. P., Macmillan S., Gerard B., McDermott J., Seré C., Rosegrant M. (2010): Smart investments in sustainable food production: revisiting mixed crop-livestock systems. *Science*, **327**: 822–825.
- Hoekstra A. Y., Chapagain A. K., Aldaya M. M. and Mekonnen M. M. (2011): The water footprint assessment manual: Setting the global standard. London, UK: Earthscan, 203p.
- Hussen M., Kechero Y. and Molla M. (2016): Availability, Yield and utilization practices of livestock feed resources in Gilgel Gibe catchments of Jimma Zone, southwestern Ethiopia. *Global Veterinaria*, **17**(1): 78–94.
- International Livestock Research Institute (ILRI). (2014): Feed assessment tool (FEAST) individual farmer interview questionnaire. Nairobi, Kenya: ILRI. Retrieved January 10, 2015, from <https://www.ilri.org/feastmethodology>.
- Jackson H. L. and Mtengeti E. J. (2005): Assessment of animal manure production, management and utilization in southern highlands of Tanzania. *Livestock Research for Rural Development*, **17**(10): 9. Retrieved January 23, 2015, from <http://www.lrrd.org/lrrd17/10/jack17110.htm>.
- Jahnke H. E. (1982): Livestock production systems and livestock development in tropical Africa. Kiel, Germany: Kieler Wissenschaftsverlag Vauk, 253p.

- Jaleta M., Kassie M. and Shiferaw B. (2013): Tradeoffs in crop residue utilization in mixed crop-livestock systems and implications for conservation agriculture. *Agricultural Systems*, **121**: 96–105.
- Kassa H. (2000): Livestock production, household food security and sustainability in smallholder mixed farms: A case study from Kombolcha Woreda of eastern Ethiopia. MSc dissertation submitted to Swedish University of Agricultural Sciences, Uppsala, Sweden, 98p.
- Kassa, H., Gibbon, D. and Tamir, B. (2003): Use of livestock feed balance as a potential indicator of sustainability of tropical smallholder mixed farms – prevailing knowledge gaps: A case study from the Harar highlands of eastern Ethiopia. *Journal of Sustainable Agriculture*, **22**(4): 37–41.
- Kassie M., Zikhali P., Manjur K. and Edwards S. (2009): Adoption of sustainable agriculture practices: Evidence from a semi-arid region of Ethiopia. *Natural Resources Forum*, **39**: 189–198.
- Kassie M., Zikhali P., Pender J. and Köhlin G. (2011): Sustainable agricultural practices and agricultural productivity in Ethiopia. Does agroecology matter? Environmental Economics Policy Forum for Ethiopia (EEPFE) and Ethiopian Development Research Institute (EDRI/AAU), Addis Ababa, Ethiopia.
- Kearl L. C. (1982): Nutrient Requirements of Ruminants in Developing Countries. PhD dissertation submitted to Utah State University, Logan Utah, 381p.
- Kebebe E. G., Oosting S. J., Hailelassie A., Duncan A. J. and de Boer I. J. M. (2015): Strategies for improving water use efficiency of livestock production in rain-fed systems. *Animal*, **9**(05): 908–916.
- Keftasa D. (1988): Role of crop residues as livestock feed in Ethiopian highlands. Pp. 27–30. Proceedings of the African forage plant genetic resources, evaluation of forage germplasm and extensive livestock production systems, Arusha, Tanzania, 27-30 April 1987, Pasture Network for Eastern and Southern Africa (PANESA).
- Ketema H. (1998): Dairy development in Ethiopia. Pp 26-39. Proceedings of the role of village dairy cooperatives in dairy development: Prospects for improving dairy in Ethiopia 22 - 24 April 1998, Addis Ababa, Ethiopia, Smallholder Dairy Development Project (SDDP), Ministry of Agriculture (MoA).

- Ketema T. K. (2007): Production and marketing systems of sheep and goats in Alaba, Southern Ethiopia. MSc thesis submitted to University of Hawassa, Ethiopia, 159p.
- Kijne J. W., Barker R. and Molden D. (Eds.). (2003): Water productivity in agriculture: Limits and opportunities for improvement. Wallingford Oxon, UK; Colombo, Sri Lanka: CABI, 332p.
- Knowler D. and Bradshaw B. (2007): Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy*, **32**: 25–48.
- Kosgey I. S., Rowlands G. J., van Arendonk J. A. M. and Baker R. L. (2008): Small ruminant production in smallholder and pastoral/extensive farming systems in Kenya. *Small Ruminant Research*, **77**(1): 11–24.
- Kossila V. (1988): The availability of crop residues in developing countries in relation to livestock populations Pp 28–39. Proceedings of plant breeding and the nutritive value of crop residues, Addis Ababa, Ethiopia, 7-10 December 1987. International Livestock Centre for Africa (ILCA).
- Kumsa T., Madsen J. O. and Tegegne A. (2004): Manure production, handling and use around Holetta Agricultural Research Center. Pp 3–11. In: T. Degefa and F. Feyissa (Eds.), Proceedings of the role of agricultural Universities/Colleges in transforming animal agriculture in education, research and development in Ethiopia: Challenges and opportunities, Addis Ababa, Ethiopia, Ethiopian Society of Animal Production (ESAP).
- Lardy G., Stoltenow C., Johnson R. (2008): Livestock and water. North Dakota State University. Retrieved March 11, 2015, from www.ag.ndsu.nodak.edu.
- Lekasi J. K., Tanner J. C., Kimani S. K. and Harris P. J. C. (2003): Cattle manure quality in Maragua District, Central Kenya: Effect of management practices and development of simple methods of assessment. *Agriculture, Ecosystems and Environment*, **94**: 289–298.
- Lenne J. M., Fernandez-Rivera S. and Blümmel M. (2003): Approaches to improve the utilization of food-feed crops-synthesis. *Field Crops Research*, **84**: 213–222.
- Lupindu A. M. (2017): Public health aspect of manure management in urban and peri-urban livestock farming in developing countries. In: Livestock Science (pp. 74–89). InTechOpen. Retrieved July 18, 2018, from <http://www.intechopen.com/books/livestock-science>.

- Lupwayi N. Z., Girma M. and Haque I. (2000): Plant nutrient contents of cattle manures from small-scale farms and experimental stations in the Ethiopian highlands. *Agriculture, Ecosystems and Environment*, **78**(1): 57–63.
- MAFF (Ministry of Agriculture Fisheries and Food). (1984): Energy allowances and feeding systems for ruminants. London, UK.
- Maimbo M. M., Alex R. O. and Orod J. O. (Eds). (2007): Green water management handbook: Rainwater harvesting for agricultural production and ecological sustainability. Technical manual No. 8 Nairobi, Kenya: World Agroforestry Centre (ICRAF), 219p.
- Mandal R. and Bezbaruah M. P. (2013): Diversification of cropping pattern: Its determinants and role in flood affected agriculture of Assam plains. *Indian Journal of Agricultural Economics*, **68**(2): 169–181.
- Marshall K. and Ali Z. (2000): Gender issues in donkey use in rural Ethiopia. In: Donkeys, people and development. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA), pp. 62–68. ACP-EU Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands.
- Mcdermott J. J., Staal S. J., Freeman H. A., Herrero M. and Steeg J. A. Van De. (2010): Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science*, **130**: 95–109.
- Mekonnen S., Descheemaeker K., Tolera A. and Amede T. (2011): Livestock water productivity in a water stressed environment in northern Ethiopia. *Experimental Agriculture*, **47**(S1): 85–98.
- Mengistu A. (2010): Comparative analysis of maize-livestock innovation systems in Awassa, Bako and Ambo areas of Ethiopia. PhD dissertation submitted to Haramaya University, Ethiopia, 123p.
- Mengistu T., Teketay D., Hulten H. and Yemshaw Y. (2005): The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments*, **60**(2): 259–281.
- Mohammed T., Kebede K., Mekasha Y. and Abera B. (2014): Herd management and breeding practices of sheep owners in North Wollo Zone, Northern Ethiopia. *Middle East Journal of Scientific Research*, **21**(9): 1570–1578.

- Molden D., Frenken K., Barker R., de Fraiture C., Mati B., Svendsen M., Sadoff C., Finlayson C. M. (2007): Trends in water and agricultural development. In: D. Molden (Ed.) *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*, pp. 57-89. International Water Management Institute (IWMI), Colombo, Sri Lanka.
- Molden D., Murray R. H., Sakthivadivel R. and Makin I. (2003): A Water-productivity framework for understanding and action. In: J.W. Kijne, R. Barker and D. Molden (Eds.) *Water productivity in agriculture: Limits and opportunities for improvement*, pp 1-18. CABI International, Wallingford, UK.
- Moore A. D., Bell L. W. and Revell D. K. (2009): Feed gaps in mixed-farming systems: Insights from the grain and graze program. *Animal Production Science*, **49**: 736–748.
- Mwanyumba P. M., Wahome R. W., MacOpiyo L. and Kanyari P. (2015): Livestock herd structures and dynamics in Garissa County, Kenya. *Pastoralism*, **5**(1): 26.
- Negassa A. (2009): Improving smallholder farmers’; marketed supply and market access for dairy products in Arsi Zone, Ethiopia. Research Report 21. International Livestock Research Institute (ILRI), Nairobi. Kenya, 87p.
- Negassa A. and Jabbar M. (2008): Livestock ownership, commercial offtake rates and their determinants in Ethiopia. Research Report 9. International Livestock Research Institute (ILRI), Nairobi, Kenya, 40p.
- Negassa A., Bachewe F. N., Taffesse A. S. and Dereje M. (2017): An assessment of the livestock economy in mixed crop-livestock production systems in Ethiopia. Working Paper 101. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia, 25p.
- NRC (National Research Council). (2001): Nutrient requirements of dairy cattle (6th rev. ed.) Washington, D.C.
- Nugroho B. D. A. and Nuraini L. (2016): Cropping pattern scenario based on global climate indices and rainfall in Banyumas District, Central Java, Indonesia. *Agriculture and Agricultural Science Procedia*, **9**: 54–63.
- Olkowski A. A. (2009): Livestock water quality: A field guide for cattle, horses, poultry and swine. University of Saskatchewan and Minister of Agriculture and Agri-Food, Canada, 166p.

- Onduru D., Snijders P., Muchena F., Wouters B., Jager A. De, Gachimbi L. and Gachini G. (2008): Manure and soil fertility management in sub-humid and semi-arid farming systems of Sub-Saharan Africa: Experiences from Kenya. *International Journal of Agricultural Research*, **3**(3): 166–187.
- Passioura J. B. and Angus J. F. (2010): Improving productivity of crops in water-limited environments. *Advances in Agronomy*, **106**(10): 37–75.
- Peden D., Faki H., Alemayehu M., Mpairwe D., Herrero M., Breugel P. Van, Hailelassie A., Tadesse G. and Bekele S. 2008. Opportunities for increasing livestock water productivity in the Nile River Basin. Proceedings of the Second Nile Basin Development Forum, Khartoum, Sudan, November 17-19, 2008. Nairobi, Kenya: ILRI.
- Peden D., Freeman A., Astatke A., Notenbaert A. (2006): Investment options for integrated water-livestock crop production in sub-Saharan Africa. Working Paper 1. International Livestock Research Institute (ILRI), Nairobi, Kenya, 51p.
- Peden D., Tadesse G. and Hailelassie A. (2009): Livestock water productivity: implications for sub-Saharan Africa. *The Rangeland Journal*, **31**: 187–193.
- Peden D., Tadesse G. and Mammo M. (2003): Improving the water productivity of livestock: an opportunity for poverty reduction. Pp.57-65. Proceedings of a workshop on integrated water and land management research and capacity building priorities for Ethiopia held on 2-4 December 2002, Addis Ababa, Ethiopia.
- Peden D., Tadesse G., Misra, A. K., Ahmed F.A., Astatke A., Ayalneh W., Herrero M., Kiwuwa G., Kumsa T., Mati B., Mpairwe D., Wassenaar T. and Yimegnuhail A. (2007): Water and livestock for human development. In: D. Molden (Ed.), *Water for food, water for life: A comprehensive assessment of water management in agriculture*, pp. 485–514. International Water Management Institute (IWMI), Colombo, Sri Lanka.
- Pond W.G., Church D.C., Pond K.R. and Schoknecht P.A. (2006): *Basic animal nutrition and feeding* (5th ed). John Wiley and Sons, Inc. USA.
- Qasim M. (2012): Determinants of farm income and agricultural risk management strategies: The case of rain-fed farm households in Pakistan's Punjab. PhD dissertation submitted to Kassel University Press GmbH, Kassel, Germany, 208p.

- Rockström J. and Barron J. (2007): Water productivity in rainfed systems: Overview of challenges and analysis of opportunities in water scarcity prone savannahs. *Irrigation Science*, **25**: 299-311.
- Rockström J., Kaumbutho P., Mwalley J., Nzabi A. W., Temesgen M., Mawenya L., Barron J., Mutua J. and Damgaard L. S. (2009): Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. *Soil and Tillage Research*, **103**(1): 23–32.
- Rosegrant M. W., Fernandez M., Siha A. (2009): Looking into the future for agriculture and AKST (Agricultural Knowledge Science and Technology). In: B. D. McIntyre, H. R. Herren, J. Wakhungu and R. T. Watson (Eds.) *Agriculture at a crossroads*, pp. 307–376. Island Press, Washington, DC.
- Rufino M. C., Rowe E. C., Delve R. J. and Giller K. E. (2006): Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. *Agriculture, Ecosystems and Environment*, **112**: 261–282.
- Rufino M. C., Tittonell P., van Wijk M. T., Castellanos-Navarrete A., Delve R. J., de Ridder N. and Giller K. E. (2007): Manure as a key resource within smallholder farming systems: Analyzing farm-scale nutrient cycling efficiencies with the NUANCES framework. *Livestock Science*, **112**: 273–287.
- Sandford L. and Ashley S. (2008): Livestock livelihoods and institutions in the IGAD Region. IGAD Livestock Policy Initiative (LPI) Working Paper No. 10 - 08. Inter-Governmental Authority on Development (IGAD).
- Schlink A., Nguyen M. and Viljoen G. (2010): Water requirements for livestock production: a global perspective. *Scientific and Technical Review of the Office International Des Epizooties*, **29**(3): 603–619.
- Séré C., Steinfeld H. and Groenewold J. (1995): World livestock production systems: current status, issues and trends. FAO Animal production and health paper no. 127. Rome, Italy.
- Shapiro B.I., Gebru G., Desta S., Negassa A., Nigussie K., Aboset G. and Mechal H. 2015: Ethiopia livestock master plan. ILRI Project Report. Nairobi, Kenya: International Livestock Research Institute (ILRI).
- Sharma K., Pattanaik A. K., Anandan S. and Blümmel M. (2010): Food-feed crops research: A synthesis. *Animal Nutrition and Feed Technology*, **10S**: 1–10.

- Sileshi Z., Tegegne A. and Tsadik T. (2003): Water resources for livestock in Ethiopia: Implications for research and development. Pp 66-79. Proceedings of integrated water and land management research and capacity building priorities for Ethiopia, Addis Ababa, Ethiopia 2-4 December 2002, International Livestock Research Institute (ILRI).
- Singh G. (2012): Factors influencing cropping pattern in Bulandshahr District with special reference to the size of land. *International Journal of Scientific and Research Publications*, **2**(5): 1–10.
- Sinnathurai V., Vijayakumar S. and Sinnathurai V. (2013): An empirical study on the nexus of poverty, GDP growth, dependency ratio and employment in developing countries. *Journal of Competitiveness*, **5**(2): 67–82.
- Sonder K., Astatke A., Wakeel E., Molden D. and Peden D. (2004): Strategies for increasing livestock water productivity in water stressed agricultural systems. Retrieved January 12, 2013, from <http://cpwf-theme1.irri.org/documents3.htm>.
- StataCorp. (2013): Stata statistical software in statacorp LP. StataCorp, College Station, TX, USA.
- Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C. (2006): Livestock's long shadow: environmental issues and options. Rome: Food and Agriculture Organization. p390.
- Steinfeld H., Wassenaar T. and Jutzi S. (2006): Livestock production systems in developing countries: status, drivers, and trends global drivers of the livestock sector. *Scientific and Technical Review of the Office International Des Epizooties*, **25**(2): 505–516.
- Sumberg J. (2003): Toward a dis-aggregated view of crop-livestock integration in Western Africa. *Land Use Policy*, **20**(3): 253–264.
- Swanepoel F., Stroebel A. and Moyo S. (2010): The role of livestock in developing communities: Enhancing multi-functionality. Bloemfontein, South Africa: The Technical Centre for Agricultural and Rural Cooperation (CTA), 213p.
- Teenstra E., De Buissonjé F., Ndambi A. and Pelster D. (2015): Manure management in the (sub-) tropics - Training manual for extension workers. Wageningen, Wageningen, Livestock Research Report 919, 41p.

- Temesgen M. (2007): Conservation tillage systems and water productivity implications for smallholder farmers in semi-arid Ethiopia. PhD dissertation submitted to Delft University of Technology, the Netherlands, 113p.
- Temesgen M., Hoogmoed W. B., Rockstrom J. and Savenije H. H. G. (2009): Conservation tillage implements and systems for smallholder farmers in semi-arid Ethiopia. *Soil and Tillage Research*, **104**(1): 185–191.
- Temesgen M., Rockstrom J., Savenije H. H. G., Hoogmoed W. B. and Alemu D. (2008): Determinants of tillage frequency among smallholder farmers in two semi-arid areas in Ethiopia. *Physics and Chemistry of the Earth*, **33**: 183–191.
- Tessema Z., Aklilu A. and Ameha S. (2003): Assessment of the livestock production system, available feed resources and marketing situation in Belesa Woreda: A case study in drought prone areas of Amhara Region. Pp 165-175. Proceedings of the 10th annual conference of the Ethiopian Society of Animal Production (ESAP), Addis Ababa, Ethiopia, August 22-24, 2002.
- Thornton P. K. (2010): Livestock production: recent trends, future prospects. *Philosophical Transactions of the Royal Society B*, **365**: 2853–2867.
- Tibbo M. (2006): Productivity and health of indigenous sheep breeds and crossbreeds in the central Ethiopian highlands. PhD dissertation submitted to Swedish University of Agricultural Sciences, Uppsala, Sweden, 76p.
- Tittonell P., Vanlauwe B., Leffelaar P. A., Rowe E. C. and Giller, K. E. (2005): Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. *Agriculture, Ecosystems and Environment*, **110**: 149–165.
- Tolera A. (1998): Production situation and some productivity and physical characters of traditionally managed sheep and goats in Kochore district, Southern Ethiopia. *Journal of Applied Animal Research*, **13**: 49–59.
- Tolera A. (2007): Feed resources for producing export quality meat and livestock in Ethiopia: examples from selected Woredas in Oromia and SNNP regional states. Ethiopia Sanitary and Phytosanitary Standards and Livestock and Meat Marketing Program (SPS-LMM), Addis Ababa, Ethiopia, 79p.
- Tolera A. and Said, A. (1992): Prospects for integrating food and feed production in Welayita Sodo, Ethiopia. Pp 309–318. Proceedings of the joint feed resources

- networks workshop, Gaborone, Botswana, 4-8 March 1991, International Livestock Centre for Africa.
- Tschopp R., Aseffa A., Schelling E. and Zinsstag J. (2010): Farmers' perceptions of livestock, agriculture and natural resources in the rural Ethiopian highlands. *Mountain Research and Development*, **4**: 381–390.
- Tsega W., Tamir B., Abebe G. and Zaralis K. (2014): Characteristics of urban and peri-urban sheep production systems and economic contribution in highlands of Ethiopia. *Iranian Journal of Applied Animal Science*, **4**(2): 341–349.
- Tulu M., Boelee E., Tadesse G., Peden D. and Aredo D. (2008): Estimation of livestock, domestic use and crop water productivities of SG-2000 water harvesting pilot projects in Ethiopia. Pp 88-91. Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10 - 14, 2008. CGIAR Challenge Program on Water and Food, Colombo, Sri Lanka.
- Valbuena D., Tui S. H. K., Erenstein O., Teufel N., Duncan A., Abdoulaye T., Swain B., Mekonnen K., Germaine I. and Gérard B. (2015): Identifying determinants, pressures and trade-offs of crop residue use in mixed smallholder farms in Sub-Saharan Africa and South Asia. *Agricultural Systems*, **134**: 107–118.
- van Breugel P., Herrero M., van de Steeg J. and Peden D. (2010): Livestock water use and productivity in the Nile basin. *Ecosystems*, **13**(2): 205–221.
- WBISPP (Woody Biomass Inventory and Strategic Planning Project). (2002): A Strategic plan for the sustainable development, conservation and management of the woody biomass resources. Amhara Regional State. Addis Ababa, Ethiopia, 158p.
- Wondatir Z. (2010): Livestock production systems in relation with feed availability in the Highlands and Central Rift Valley of Ethiopia. MSc thesis submitted to Haramaya University, Ethiopia, 139p.
- Wondatir Z. and Mekasha Y. (2014): Feed resources availability and livestock production in the central rift valley of Ethiopia. *International Journal of Livestock Production*, **5**(2): 30–35.
- Wondatir Z., Mekasha Y. and Wouters B. (2011): Assessment of productive and reproductive performance of dairy cattle nexus with feed availability in selected

- peri-urban areas of Ethiopia. *Journal of Cell and Animal Biology*, **5**(15): 308–315.
- World Bank. (2006): Managing water resources to maximize sustainable growth, a World Bank water resources assistance strategy for Ethiopia. Washington, DC. Retrieved June 17, 2018 from http://wss.cee.wisc.edu/Papers/Ethiopia_Managing_Water_Resources_WB.pdf.
- Wright I. A., Tarawali S., Blümmel M., Gerard B., Teufel N. and Herrero M. (2012): Integrating crops and livestock in subtropical agricultural systems. *Journal of the Science of Food and Agriculture*, **92**: 1010–1015.
- Yadessa E., Ebro A., Fita L. and Asefa G. (2016): Livestock feed production and feed balance in Meta-Robi district, West Shewa Zone, Oromiya Regional State, Ethiopia. *Academic Research Journal of Agricultural Science and Research*, **4**: 45–54.
- Yilma Z., Guernebleich, E. and Sebsibe, A. (2011): A review of the Ethiopian dairy sector. (R. Fombad, Ed.). Food and Agriculture Organization of the United Nations, Sub Regional Office for Eastern Africa (FAO/SFE), Addis Ababa, Ethiopia, 72p.
- Ying-bin H. and Wei-min C. (2016): Linking a farmer crop selection model (FCS) with an agronomic model (EPIC) to simulate cropping pattern in Northeast China. *Journal of Integrative Agriculture*, **15**(10): 2417–2425.
- Yisehak K. and Janssens G. P. J. (2014): The impacts of imbalances of feed supply and requirement on productivity of free-ranging Tropical Livestock Units: Links of multiple factors. *African Journal of Basic and Applied Sciences*, **6**(6): 187–197.
- Zereu G. and Lijalem T. (2016): Status of improved forage production, utilization and constraints for adoption in Wolaita Zone, Southern Ethiopia. *Livestock Research for Rural Development*, **28**(5): 10. Retrieved November 17, 2017, from <http://www.lrrd.org/lrrd28/5/zere28078.htm>.
- Zingore S., Murwira H. K., Delve R. J. and Giller K. E. (2007): Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, Ecosystems and Environment*, **119**: 112–126.

8. APPENDICES

Appendix I. Analysis of variance and other supplementary tables

Appendix Table 1. Analysis of household heads farming experience, family size, family labour force and age dependency ratio variations across wealth groups

Parameters	Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Farming Experience (Years)	Between Groups	1093.9	2	547.0	4.6	0.012
	Within Groups	18658.0	156	119.6		
	Total	19752.0	158			
Total Family size	Between Groups	73.2	2	36.6	12.9	0.000
	Within Groups	442.5	156	2.8		
	Total	515.7	158			
Male	Between Groups	27.4	2	13.7	9.0	0.000
	Within Groups	236.6	156	1.5		
	Total	264.0	158			
Female	Between Groups	5.9	2	2.9	1.6	0.197
	Within Groups	274.5	153	1.8		
	Total	280.4	155			
Family labour force (adult equivalents)	Between Groups	49.4	2	24.7	19.3	0.000
	Within Groups	199.6	156	1.3		
	Total	249.0	158			
Male	Between Groups	19.3	2	9.7	14.1	0.000
	Within Groups	107.3	156	0.7		
	Total	126.7	158			
Female	Between Groups	7.0	2	3.5	6.1	0.003
	Within Groups	88.9	156	0.6		
	Total	95.8	158			
Age dependency ratio	Between Groups	4.1	2	2.0	6.3	0.002
	Within Groups	50.4	156	0.3		
	Total	54.5	158			

Appendix Table 2. Analysis of farm resources holding variations across wealth groups

Parameters	Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Livestock holding (TLU)	Between Groups	1210.4	2	605.2	160.1	0.000
	Within Groups	589.8	156	3.8		
	Total	1800.2	158			
Own cropland (ha)	Between Groups	13.1	2	6.6	20.5	0.000
	Within Groups	49.8	156	0.3		
	Total	63.0	158			
Fallow land (ha)	Between Groups	1.7	2	0.8	16.4	0.000
	Within Groups	7.9	156	0.1		
	Total	9.6	158			
Cultivated and grazing lands (ha)	Between Groups	60.7	2	30.4	97.8	0.000
	Within Groups	48.4	156	0.3		
	Total	109.1	158			
Cultivated cropland (ha)	Between Groups	21.7	2	10.8	39.1	0.000
	Within Groups	43.2	156	0.3		
	Total	64.9	158			
Grazing land (ha)	Between Groups	10.2	2	5.1	78.7	0.000
	Within Groups	10.1	156	0.1		
	Total	20.4	158			

Appendix Table 3. Analysis of grain yield per household and productivity per ha variations across wealth groups

Parameters	Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Grain yield (t/hh)						
Barley	Between Groups	16.0	2	8.0	10.7	0.000
	Within Groups	117.2	156	0.8		
	Total	133.2	158			
Wheat	Between Groups	11.9	2	6.0	21.1	0.000
	Within Groups	44.1	156	0.3		
	Total	56.0	158			
Faba bean	Between Groups	3.9	2	2.0	10.2	0.000
	Within Groups	29.8	156	0.2		
	Total	33.7	158			
Field pea	Between Groups	0.1	2	0.1	1.6	0.200
	Within Groups	6.3	156	0.0		
	Total	6.4	158			
Grain yield (t/ha)						
Barley	Between Groups	1.3	2	0.7	3.8	0.025
	Within Groups	26.8	156	0.2		
	Total	28.1	158			
Wheat	Between Groups	5.8	2	2.9	9.2	0.000
	Within Groups	44.8	141	0.3		
	Total	50.7	143			
Faba bean	Between Groups	0.6	2	0.3	1.0	0.367
	Within Groups	43.5	152	0.3		
	Total	44.1	154			
Field pea	Between Groups	0.7	2	0.3	2.7	0.076
	Within Groups	6.9	57	0.1		
	Total	7.6	59			

Appendix Table 4. Analysis of cropland tillage repeat variations across wealth groups

Parameters	Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Barley	Between Groups	50.8	2	25.4	116.8	0.000
	Within Groups	33.9	156	0.2		
	Total	84.8	158			
Wheat	Between Groups	55.2	2	27.6	82.1	0.000
	Within Groups	52.5	156	0.3		
	Total	107.7	158			
Faba bean	Between Groups	2.7	2	1.4	6.7	0.002
	Within Groups	30.2	150	0.2		
	Total	32.9	152			
Field pea	Between Groups	2.4	2	1.2	10.5	0.000
	Within Groups	5.6	48	0.1		
	Total	8.0	50			
Average for all cereals	Between Groups	51.7	2	25.8	165.2	0.000
	Within Groups	24.4	156	0.2		
	Total	76.1	158			
Average for all pulses	Between Groups	2.6	2	1.3	7.4	0.001
	Within Groups	26.2	150	0.2		
	Total	28.8	152			

Appendix Table 5. Analysis of animal labour use for traction service variations across wealth groups

Parameters	Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Ploughing (Animaldays)	Between Groups	150437.1	2	75218.6	75.1	0.000
	Within Groups	156197.8	156	1001.3		
	Total	306634.9	158			
Threshing (Animaldays)	Between Groups	19282.2	2	9641.1	33.7	0.000
	Within Groups	44617.4	156	286.0		
	Total	63899.7	158			
Transportations (Animaldays)	Between Groups	7228970.6	2	3614485.3	131.1	0.000
	Within Groups	4302012.0	156	27577.0		
	Total	11530982.5	158			
Total traction (Animaldays)	Between Groups	34666355.7	2	17333177.8	146.2	0.000
	Within Groups	18501286.2	156	118598.0		
	Total	53167641.8	158			

Appendix Table 6. Analysis of annual livestock feed supply, demand and balance variations across wealth groups

Parameters	Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
DM demand (kg)	Between Groups	6308.3	2	3154.2	159.4	0.000
	Within Groups	3086.5	156	19.8		
	Total	9394.8	158			
On-farm DM supply (kg)	Between Groups	502.4	2	251.2	75.4	0.000
	Within Groups	520.0	156	3.3		
	Total	1022.5	158			
Total DM supply (kg)	Between Groups	1006.2	2	503.1	74.1	0.000
	Within Groups	1059.1	156	6.8		
	Total	2065.3	158			
On-farm DM balance (kg)	Between Groups	3249.8	2	1624.9	76.9	0.000
	Within Groups	3296.4	156	21.1		
	Total	6546.2	158			
Total DM balance (kg)	Between Groups	2284.4	2	1142.2	56.2	0.000
	Within Groups	3170.7	156	20.3		
	Total	5455.1	158			
ME demand ('000 MJ)	Between Groups	74673.1	2	37336.5	167.5	0.000
	Within Groups	34779.9	156	222.9		
	Total	109453.0	158			
On-farm ME supply ('000 MJ)	Between Groups	28192.0	2	14096.0	73.6	0.000
	Within Groups	29866.3	156	191.5		
	Total	58058.3	158			
Total ME supply ('000 MJ)	Between Groups	55613.8	2	27806.9	72.9	0.000
	Within Groups	59530.6	156	381.6		
	Total	115144.4	158			
On-farm ME balance ('000 MJ)	Between Groups	11118.8	2	5559.4	14.5	0.000
	Within Groups	59859.9	156	383.7		
	Total	70978.7	158			
Total ME balance ('000 MJ)	Between Groups	1526.3	2	763.1	1.5	0.226
	Within Groups	79237.1	156	507.9		
	Total	80763.3	158			
DCP demand (kg)	Between Groups	4295282.8	2	2147641.4	147.2	0.000
	Within Groups	2275743.9	156	14588.1		
	Total	6571026.7	158			
On-farm DCP supply (kg)	Between Groups	930353.0	2	465176.5	96.2	0.000
	Within Groups	754106.8	156	4834.0		
	Total	1684459.8	158			
Total DCP supply (kg)	Between Groups	2142441.5	2	1071220.8	73.5	0.000
	Within Groups	2273066.5	156	14570.9		
	Total	4415508.0	158			
On-farm DCP balance (kg)	Between Groups	1227612.0	2	613806.0	41.5	0.000
	Within Groups	2305087.8	156	14776.2		
	Total	3532699.7	158			
Total DCP balance (kg)	Between Groups	384408.0	2	192204.0	9.6	0.000
	Within Groups	3122318.3	156	20014.9		
	Total	3506726.3	158			

Appendix Table 7. Analysis of feed dry matter, water depleted and water productivity of feed and livestock variations across wealth groups

Parameters	Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Dry matter of livestock feed (tons)	Between Groups	441.5	2	220.7	78.3	0.000
	Within Groups	439.8	156	2.8		
	Total	881.3	158			
Dry matter on grazing land (tons)	Between Groups	46.8	2	23.4	66.0	0.000
	Within Groups	55.3	156	0.4		
	Total	102.2	158			
Dry matter of crop residues (tons)	Between Groups	201.8	2	100.9	42.4	0.000
	Within Groups	371.7	156	2.4		
	Total	573.5	158			
Water depleted for livestock feed ('000 m ³)	Between Groups	1426.1	2	713.1	98.4	0.000
	Within Groups	1130.8	156	7.2		
	Total	2556.9	158			
Water depleted on grazing land ('000 m ³)	Between Groups	817.2	2	408.6	72.6	0.000
	Within Groups	878.6	156	5.6		
	Total	1695.8	158			
Water depleted on crop residues ('000 m ³)	Between Groups	90.7	2	45.4	30.6	0.000
	Within Groups	231.4	156	1.5		
	Total	322.1	158			
Water productivity of livestock feed (kg m ⁻³)	Between Groups	0.014	2	0.007	0.5	0.580
	Within Groups	1.985	156	0.013		
	Total	1.999	158			
Water productivity of grazing land (kg m ⁻³)	Between Groups	0.002	2	0.001	11.6	0.000
	Within Groups	0.012	156	0.000		
	Total	0.013	158			
Water productivity of crop residues (kg m ⁻³)	Between Groups	0.690	2	0.345	8.9	0.000
	Within Groups	6.083	156	0.039		
	Total	6.774	158			
Total livestock beneficial outputs ('000 USD y ⁻¹)	Between Groups	290.6	2	145.3	146.9	0.000
	Within Groups	154.3	156	0.989		
	Total	444.9	158			
Milk value ('000 USD y ⁻¹)	Between Groups	106.0	2	53.0	72.2	0.000
	Within Groups	114.5	156	0.734		
	Total	220.5	158			
Offtake value ('000 USD y ⁻¹)	Between Groups	0.075	2	0.037	16.4	0.000
	Within Groups	0.356	156	0.002		
	Total	0.431	158			
Traction value ('000 USD y ⁻¹)	Between Groups	26.19	2	13.09	166.2	0.000
	Within Groups	12.29	156	0.079		
	Total	38.48	158			
Manure value ('000 USD y ⁻¹)	Between Groups	1.948	2	0.974	163.9	0.000
	Within Groups	0.927	156	0.006		
	Total	2.875	158			
Livestock water productivity (USD m ⁻³)	Between Groups	0.464	2	0.232	49.8	0.000
	Within Groups	0.726	156	0.005		
	Total	1.191	158			

Appendix Table 8. Physical water productivity of major food-feed crops (kg/m³)

Crop type	Wealth group						Total (n=159)	
	Poor (n=50)		Middle (n=58)		Better-off (n=59)		Mean	SD
	Mean	SD	Mean	SD	Mean	SD		
Barley	1.14	0.27	1.08	0.22	1.21	0.21	1.14	0.24
Wheat	0.92	0.21	1.12	0.33	1.19	0.34	1.09	0.32
Faba bean	0.87	0.26	0.93	0.27	1.00	0.24	0.93	0.26
Field pea	1.05	0.14	1.22	0.36	1.04	0.19	1.11	0.27

Appendix Table 9. Market prices of milk, traction services and fertilizers

Item/activity	Ethiopian Birr
Ploughing (animalday)	150
Threshing (animalday)	50
Transportation (animalday)	25
Milk (liter)	10
Urea ('000 kg)	988
Diammonium phosphate ('000 kg)	1236

Appendix Table 10. Effect of mortality on offtake, total beneficial output and livestock water productivity values

Percent loss due to mortality	Poor (n = 50)	Medium (n = 58)	Better-off (n = 51)	Total (n = 159)
Total offtake	42.5	33.3	29.1	34.8
Beneficial output	1.22	0.36	0.34	0.63
Livestock water productivity	1.22	0.36	0.34	0.63

Appendix Table 11. Conversion factors used to compute standardized farm family labour force in man equivalent

Age group (years)	Man Equivalent	
	Male	Female
<10	0.00	0.00
10-13	0.20	0.20
14-16	0.50	0.40
17-50	1.00	0.80
>50	0.70	0.50

Source: Storck *et al.* (1991) as used in Solomon Gebreselassie (1993) and Natalina (2003).

Appendix II. The questionnaire used to collect household level data

Questionnaire ID _____

1. General Information

- 1.1. Enumerators' Name _____ Signature _____ Date _____
 1.2. Respondents Name (HH) _____ Sex _____ Age (Years) _____
 1.3. Address: Woreda _____ Kebele _____ Village _____ Milk Collection Center _____
 1.4. Is the respondent member of the dairy cooperative? 1) Yes 2) No
 1.5. Respondents wealth group 1) Poor 2) Medium 3) Rich
 1.6. GPS data: Latitude (N) _____ Longitude (E) _____ Altitude (masl) _____

2. Household Characteristics: (Include all persons living permanently in the household and taking food from the same kitchen)

- 2.1. Total number of household: _____ Male: _____ Female: _____
 2.2. List of household and characteristics (fill details of household head at #1)

No.	Name	Sex	Age	Level of Education (Grade Completed)	Marital Status	Relation to Household Head	Major/Primary Occupation	Farming Experience (Years)
#1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Codes:

Sex: 1=Male 2=Female
 Level of Education: 0=Illiterate, 1=Grade 1, 2=Grade 2, 3=Grade 3, ... etc. 88=Read and Write (Informal)
 Marital Status: 1=Single 2=Married 3=Divorced 4=Widowed 99=Not Applicable (Under Age)
 Relation to Household Head: 1=Husband 2=Wife 3=Daughter 4=Son 5=Grandchild 6=Parent 7=Hired 8=Sister
 Major/Primary Occupation: 1=Farmer 2=Trader 3=House wife 4=Construction 5=Weaver 6=Black smith 7=Carpenter
 8=Student 9=Herder 10=Hired labourer 11= Other 99=Not Applicable (Under Age)

3. Land holding size and land use: own land (entitled), rented in/out, shared in/out

Land Use	Cultivated		Rented in	Rented out	Shared in	Shared out	Fertility status of cultivated land (ha)			Grazing land condition with respect to fertility status and vegetative ground cover (ha)				
	**Total	*Own land					Good	Fair	Poor	Excellent	Very good	Good	Fair	Poor
Cropland														
Rainfed														
Irrigated														
Fallow land														
Grazing land														
Private														
Communal														
Back yard														
Other														

Cultivated land: area of land cultivated by farmer of his own, including rented/shared in and excluding rented/shared out cropping.
Own land: area of land privately entitled that due tax including rented out and shared out land.

4. Cropland cultivated (Area in local units “*timad*” or hectare): **crop type, yield and input used** in the cropping calendar

Crop type	Number of passes (from first plowing to sowing)	Own land cultivated		Rented in cultivated		Rented out cultivated		Shared in cultivated		Shared out cultivated		Amount of input used					
		Area (<i>timad</i> /ha)	Yield (qt)	Area (<i>timad</i> /ha)	Yield (qt)	Area (<i>timad</i> /ha)	Yield (qt)	Area (<i>timad</i> /ha)	Yield (qt)	Area (<i>timad</i> /ha)	Yield (qt)	Impro ved seed (kg)	Urea (kg)	DAP (kg)	Pestici de/Her bicide (kg/lit)	Com post 1=used 0=not used	Man ure
<i>Main rainy season</i>																	
1	Barley																
2	Wheat																
3	Teff																
4	Oat																
5	Bean																
6	Pea																
7	Lentil																
8	Chickpea																
9	Flax																
10	Grass pea																
11	Potato																
12	Other																
<i>Short rainy season</i>																	
1																	
2																	
3																	
<i>Irrigated</i>																	
1																	
2																	
3																	

Area measurement: 1 local unit “*timad*” = _____ hectare; Yield measurement: 1 local unit = _____ kg or _____ quintal.

4.1. Dividend rules for Cropland rented in/out and shared in/out:

- a) When Cropland is shared in/out: proportion of dividend for the cultivator = grain _____%, crop residues/straw _____%
- b) When Cropland is rented in/out: proportion of dividend for the cultivator = grain _____%, crop residues/straw _____%

4.2. For how long the contract agreement will sustain/last (months/years): when Cropland shared in/out _____ rented in/out _____

4.3. Price of inputs (Birr/kg): Urea _____, DAP _____

5. Livestock traction services over the year (consider different codes entry in the cell, where multiple responses are applicable)

* Types of livestock that are used for the different traction services: 1=Oxen 2=Cows 3=Other cattle 4=Donkeys 5=Horses 6=Mules

Traction Services	Production season/cycle	Crop type											
		Barley	Wheat	Teff	Oat	Bean	Pea	Lentil	Chickpea	Flax	Forages	Veg.	Others
Ploughing (number of animals used from 1 st ploughing to sowing)	Main rainy season (<i>Meher</i>)												
	Short rainy season (<i>Belg</i>)												
	Irrigation												
	<i>*Types of livestock used</i>												
Threshing	Main rainy season (<i>Meher</i>)												
	Short rainy season (<i>Belg</i>)												
	Irrigation												
	<i>*Types of livestock used</i>												
Grain transport	Main rainy season (<i>Meher</i>)												
	Short rainy season (<i>Belg</i>)												
	Irrigation												
	<i>*Types of livestock used</i>												
Crop residues transport	Main rainy season (<i>Meher</i>)												
	Short rainy season (<i>Belg</i>)												
	Irrigation												
	<i>*Types of livestock used</i>												
Others (specify)													
Equines use for other than mentioned above (number of days the equines used per year): estimate per week, per month and then per year	Equines type	Human transport		Merchandize			Fetch water		Fire wood, stone, others				
	Donkeys												
	Horses												
	Mules												

- 5.1. Do you use cows for traction purpose? 1) Yes 2) No; If yes, for what purpose? 1) Ploughing
2) Threshing
- 5.2. Do you hire animals for traction? 1) Yes 2) No; If yes, for what purpose? 1) Ploughing 2)
Threshing 3) Transportation
- 5.3. Do you rent-in animals for traction? 1) Yes 2) No; If yes, for what purpose? 1) Ploughing 2)
Threshing 3) Transportation
- 5.4. Do you rent-out animals for traction? 1) Yes 2) No, If yes, for what purpose? 1) Ploughing 2)
Threshing 3) Transportation
- 5.5. Estimated hours animals used per day for: Threshing, _____ Ploughing, ___ Transportation _____
- 5.6. Hiring prices of livestock types for different traction services

Livestock types	Average hiring price for traction services (Birr/animal/day)		
	Ploughing	Threshing	Transportation
Ox			
Cow			
Bull			
Heifer			
Donkey			
Horse			
Mule			

6. Feed resources utilization

Feed resources	Proportion used for (%)					Total Value (Birr) if sold
	Feed	Fuel	Housing	Mulch	Sell	
Grazing land						
Private						
Communal						
Fallow land						
Crop residue						
Barley						
Wheat						
Teff						
Oat						
Bean						
Pea						
Chickpea						
Lentil						
Flax						
Grass pea						
Forage crops grown						

6.1. Seasonal Feed Availability

How much do the various feeds types are available to contribute for the diet of the animal in each month over the year? (on a scale of 0-10, where 10 = excess feed available, 5 = adequate feed available and 0 = no feed available)

Feed resource	Rank	Availability score in each month											
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Grazing land													
Private													
Communal													
Fallow land													
Crop residue													
Barley													
Wheat													
Teff													
Oat													
Bean													
Pea													
Chickpea													
Lentil													
Grass pea													
Flax													
Others													
Forage crops grown													
Purchased feed types													

- 6.2. Do you produce or provide enough feed for your livestock throughout the year? 1) Yes 2) No
- 6.3. If No, which months/periods are critical in feed shortage? _____
- 6.4. What measures you take to cope up with the feed shortage problem? 1) purchase feed 2) sell animals 3) shared out animals 4) preferential or selective feeding of animals 5) conserve hay and crop residues 6) Others specify _____
- 6.5. If you produce excess, do you sell feed? 1) Yes 2) No; If yes how much income do you get per year? _____
- 6.6. Is grazing land 1) increasing 2) decreasing 3) remain the same, what are the reasons for your answer? _____

7. Water resources type and access

Water resource	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1.River												
Distance (km)												
Travel hours												
Water quality												
2.Stream												
Distance (km)												
Travel hours												
Water quality												
3.Well												
Distance (km)												
Travel hours												
Water quality												
4.Pond												
Distance (km)												
Travel hours												
Water quality												
5.Tap water												
Distance (km)												
Travel hours												
6.Frequency of access*												
Oxen												
Dry cows												
Lactating cows												
Calves												
Sheep												
Goats												
Donkeys												
Horses												
Mules												
Poultry												

*Frequency: 0= free access 1= once in a day, 2= twice in a day, 3=3 times in a day, 4=every other day (once in two days), 5=Other (specify), distance and travel hours from home. Water quality: 1=clean, 2=muddy, 3=others

- 7.1. Is there shortage of drinking water for livestock? 1. Yes 2) No, If there is, months of critical shortage in order _____
- 7.2. If there is water scarcity, what are the measures taken to alleviate the problem? 1. Selective drinking of animals 2. Water harvesting 3. Reduce frequency of drinking 4. Digging wells 5. Others (specify)_
- 7.3. Have you ever practiced rain water harvesting for livestock production? 1. Yes 2. No
- 7.4. If yes, what is the container/structure type _____

8. Livestock holding and productivity

8.1. Number owned at the beginning and changes observed over the year

Type of Animal	Stock at Beginning		Stock at End		Died/lost in the year		Bought in/gifted-in (received) in the year			Offtake (sold /slaughtered/gifted-out) in the year			Born in the year	
	<i>N₀</i>	<i>Value (Birr)</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>*Reason for bought</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>**Reason for sold</i>	<i>N₀</i>	<i>Value (Birr)</i>
Cattle														
Lactating cows (local)														
Lactating cows (cross)														
Non-lactating cows														
Non-lactating cows														
Pregnant cows (local)														
Pregnant cows (cross)														
Heifer (local)														
Heifer (cross)														
Bulls (local)														
Bulls (cross)														
Oxen (local)														
Oxen (cross)														
Calf (local) - male														
Calf (local) - female														
Calf (cross) - male														
Calf (cross) - female														
Sheep														
Lambs <6 months														
6-12 months -male														
6-12 months -female														
Ewes														
Ram uncastrated (>1 year)														
Castrated														
<p>*Reason if bought: 1= Replace animal that died, 2= Breeding and increase herd size, 3= Breed improvement, 4=Fattening, 5= other (specify) **Reason if sold: 1=to meet household expenses + clothing, 2=business; 3= Culling (3a=unproductive, 3b= old, 3c= diseased, 3d= Bad temperament), 4= Fattened, 5=others (specify) Calf = < 1 year, young bull and heifer = 1-3 years, matured cattle => 3 years.</p>														

Table 8.1. (Continued)

Type of Animal	Stock at Beginning		Stock at End		Died/lost in the year		Bought in/gifted-in (received) in the year			Offtake (sold /slaughtered/gifted-out) in the year			Born in the year	
	<i>N₀</i>	<i>Value (Birr)</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>*Reason bought for</i>	<i>N₀</i>	<i>Value (Birr)</i>	<i>**Reason sold for</i>	<i>N₀</i>	<i>Value (Birr)</i>
Goats														
Kids <6 months														
6-12 months - male														
6-12 months -female														
Does														
Buck uncastrated (>1 year)														
Castrated														
Donkeys														
Foals and < 3 years														
Jenny														
Jack /Ass														
Horses and Mules														
Foals and < 3 years														
Mare														
Stallion														
Mules														
Poultry														
Pullets														
Cockerels														
Hen														
Cock														
*Reason if bought: 1= Replace animal that died, 2= Breeding and increase herd size, 3= Breed improvement, 4=Fattening, 5= other (specify) **Reason if sold: 1=to meet household expenses + clothing, 2=business; 3= Culling (3a=unproductive, 3b= old, 3c= diseased, 3d= Bad temperament), 4= Fattened, 5=others (specify) Calf = < 1 year, young bull and heifer = 1-3 years, matured cattle = > 3 years.														

8.2. Livestock dynamics over the year (indicate number of animals in each over the year)

Livestock species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Born												
Calves (local) - male												
Calves (local) - female												
Calves (cross) - male												
Calves (cross) - female												
Lambs (<1 year) - male												
Lambs (<1 year) - female												
Kids (<1 year) - male												
Kids (<1 year) - female												
Donkey foal (<1 year)-male												
Donkey foal (<1 year)-female												
Horse foal (<1 year) - male												
Horse foal (<1 year) - female												
Mule (<1 year) - male												
Mule (<1 year) - female												
Purchased												
Received as gift												
Sold												
Slaughtered												
Given out												
Died												
Lost												

8.3. Information on cows' production and reproduction performances presently maintained at farmers herd: (discuss each individual cow and fill along the column)

N o	Particulars/descriptions	Cow1	Cow2	Cow3	Cow4	Cow5
1	Cow Id/Name					
2	Breed (1=Local or 2=Crossbred) if crossbred, name of the exotic breed					
3	Age (months)					
4	Source: 1=purchased, 2=home grown, 3=gift from relatives, 4=gift from NGOs, 5= credit 6=shared, 7=other (specify)					
5	Is the cow lactating or dry? (1=lactating, 2=dry)					
6	Parity (1,2,3, so on)					
7	No of lactation a cow is maintained in the herd					
8	Date of last calving (when delivered the present calf?)					
9	Month of Lactation (Months since Lactating in this parity)					
10	Average milk yield of each cow (liter per day)					
	during the first 3 months					
	3 to 6 months					
	6 months to end of lactation					
11	Daily milk yield at present (lit/day)					
12	Is the cow pregnant ? (1=Pregnant, 2=Non-pregnant)					
13	Months/days if pregnant					
14	Date / month of last successful mating					
15	Number of AI/natural mating required to make the cow pregnant					
16	Average lactation length (months/days)					
17	Average days open (months/days)					
18	Average dry period (months/days)					
19	Average calving intervals (months/days)					
20	Age at first service (if heifer) (months/days)					
21	Age at first calving (if heifer) (months/days)					
22	Reasons for culling of cows: (0=not practiced, 1=poor production, 2=mastitis, 3=reproductive problems, 4=sale for money, 5=feed shortage), 6=other (specify)					
23	Udder health: 1= one teat blind/absent, 2= two teats blind /absent, 3= three teats blind/absent, 4= four teats blind /absent, 5= clinical mastitis, 6= no clinical mastitis, 7= other					
24	Vaccination history: vaccinated? 1=yes 2=no					
25	Short notes on other health aspects:					

9. Manure utilization and management practices

9.1. Manure source, storage and management methods

Manure source (livestock type)	How frequent you collect manure?	Storage method 1) Pit 2) Heap 3) Deep litter 4) Other (specify) ---	Do you keep manure in		Type of shade used 1) roof 2) under tree 3) other specify ----- -----	Type of cover used 1) grass/hay 2) plastic 3) soil/mud layer 4) dung plastering 5) other (specify)	Do you produce		Do you add organic bedding in manure? 1) Yes 2) No 3) rejected fodder 4) other plant sources
			Shade? 1) Yes 2) No	Cover? 1) Yes 2) No			Compost? 1) Yes 2) No	Dung cake? 1) Yes 2) No	
Cattle									
Sheep and goats									
Equines									
Poultry									

9.2. Manure utilization and management (*Consider different codes entry in the cell where multiple responses are applicable)

Manure source (livestock type)	Proportion (%) of manure used for				Do you sell manure? 1) Yes 2) No	In what form you sell? 1) fresh 2) dung cake 3) composted	Do you buy manure? 1) Yes 2) No	In what form you buy? 1) fresh 2) dung cake 3) composted	Do you mix manure from different types of livestock or store separately? 1) Mixed 2) Separately	Do you collect and mix dung with urine to store livestock waste? 1) Yes 2) No
	Fuel (home) %	Wall/home plastering %	As organic fertilizer							
			Compo sting %	Direct spreading %						
Cattle										
Sheep and goat										
Equines										
Poultry										

9.3. How long do you need to store the manure before it is applied to the field? For mixed ____; If separately: Cattle ____; Sheep and goats ____; Equines ____; Poultry ____

10. Quantity and cost of inputs (Birr) for livestock production (purchased over the year)

Item	Unit	Total		Months											
		Quantity	Cost (Birr)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Green fodder															
Hay															
Crop residues															
Concentrates															
Others (specify)															

11. Access to agricultural training and credit services

11.1. Have you got agricultural training? 1= Yes 2= No

11.2. Have you got credit service? 1= Yes 2= No

12. Rank Purposes of Livestock Keeping

Purposes of keeping	Rank for livestock species reared			
	Cattle	Small ruminant	Equine	Chicken
Meat				
Milk				
Work/draft				
Transport				
Income source				
Manure				
Hides/skin				
Saving				
Prestige status				
Dowry				
Other (specify)				

13. Major livestock production constraints

Constraints of production	Rank for livestock species reared				
	cattle	sheep	goat	equines	poultry
Feed shortage					
Shortage of land (grazing land)					
Water shortage					
Livestock disease					
Inadequate veterinary coverage					
Lack of improved/crossbred animals					
Lack of AI					
Inadequate extension support					
Lack of marketing infrastructures					
Less market demand					
Lack of human labour					
Lack of credit					

14. Major forage and crop production constraints

Constraints of production	Rank for constraints of	
	Forage production	Crop production
Land shortage		
Shortage of improved seeds/seedlings		
Lack of locally adaptable species		
Lack of awareness		
Inadequate extension support		
Lack of credit		
Lack of human labour		
Lack of animal labour		
Lack of fertilizer		
Weeds		
Diseases		
Pests		
Other (specify)		

15. Agricultural activities and division of labor (0=not involved, 1=low contribution, 2=medium contribution, 3=high contribution)

Agricultural activities	Based on the time the person involved (hours/day)				
	Husband	Wife	Boys	Girls	Hired labour
Livestock production activities					
Herding/attending on grazing					
Feed collection and storage/conservation					
Cut and carry					
Supplement feeding					
Watering					
Tethering					
Manure collection and storage					
Shed cleaning and maintenance					
Selling live animals					
Buying live animals					
Dung cake preparation					
Selling and buying dung/manure					
Milking					
Processing – butter (churning)					
Processing – cheese making					
Products delivery/sell					
Market transportation					
Health care					
Other (specify)					
Crop production activities					
Ploughing					
Sowing					
Weeding					
Harvesting					
Threshing					
Marketing					
Other (specify)					

Thank You Very Much!!!

Appendix III. List of publications

1. Bekele M., Mengistu A. and Tamir B. (2017): Livestock and feed water productivity in the mixed crop-livestock system. *Animal*, **11**(10): 1852–1860.
<https://doi.org/10.1017/S1751731117000416>
2. Bekele M., Mengistu A. and Tamir B. (2018): Evaluation of livestock feed balance under mixed crop-livestock production system in the central highlands of Ethiopia. *Agriculture and Food Security*, **7**(19): 17.
<https://doi.org/10.1186/s40066-018-0170-8>