CONTRIBUTION OF SMALLHOLDER LIVESTOCK PRODUCTION TO GREENHOUSE GAS EMISSIONS IN ARSI ZONE, OROMIA REGION, ETHIOPIA

PhD Dissertation

By

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ADDIS ABABA UNIVERSITY

COLLEGE OF VETERINARY MEDICINE AND AGRICULTURE

DEPARTMENT OF ANIMAL PRODUCTION STUDIES

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A Dissertation Submitted to the College of Veterinary Medicine and Agriculture, Addis Ababa University in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Animal Production studies

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BIOGRAPHICAL SKETCH

The author was born in June 1979 in Bako Tibe District of West Showa Zone, Oromia Region, Ethiopia. He attended primary elementary school in Oda Gudaya School, Berobabala Junior School, and Gedo High School. After his High School education completion, he joined the then Debub University in September 1999 where he studied Animal Production and Range Land Management and graduated in July 2002. Soon after graduation, he was employed by the Ministry of Agriculture Department of Agricultural Technical and Vocational Educational Training (ATVET) as junior instructor at Assela ATVET College. He served for five years. In June 2007, he was enrolled at Haramaya University and pursued his M. Sc. study in Animal Production through financial grant from the Ministry of Agriculture and Rural Development and graduated in January 2010. The same year in May, he joined Adama University as lecturer where he served for five years and three years in Arsi University as lecturer and he joined Addis Ababa University, College of Veterinary Medicine and Agriculture (Department of Animal Production studies) in October 2017 for his PhD study in Animal Production. The author has served at different capacities when he was at Assela ATVET College: Head department of animal science, Teaching different courses of animal science, and at Adama and Arsi University as Head Department of Animal Science at different time and he joined Addis Ababa University. He has also attended different job trainings (national and international) and received certificates for successful completion. He has authored and co-authored 5 scientific publications (peer reviewed journal articles) of which 2 are parts of this dissertation work. The author is married and a father of two sons and a daughter.

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DEDICATION

This dissertation manuscript is dedicated to my wife Rut Duga, my son Henok Birhanu, Yonatan Birhanu and my daughter Salem Birhanu for their love, patience, encouragement and support in the success of my life.

ABBREVIATIONS

ADF	Acid detergent fiber
ADL	Acid detergent lignin
AOAC	Association of official analytical chemists
AWMS	Animal waste management systems
BW	Body weight
CDR	Community development research
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CP	Crude protein
CRGE	Climate resilient green economy
CSA	Central statistical agency
DCP	Digestible crude protein
DM	Dry matter
ECM	Energy-corrected milk
EF	Emission factor
EPA	Environmental protection agency
FAO	Food and agricultural organization of the United Nations
FDRE	Federal democratic republic of Ethiopia
FGD	Focus group discussion
GDP	Gross domestic product
GE	Gross energy
GEI	Gross energy intake
Gg	Gigagrams
GHG	Greenhouse gas
Gt	Gigatonne
GWP	Global warming potential
H	Head
HH	Household

ABBREVIATIONS (*Continued*)

IBC	Institute of Biodiversity Conservation
IFAD	International Fund for Agricultural Development
IGAD	Intergovernmental authority on development
ILCA	International livestock centre for Africa
IVDOMD	In vitro digestible organic matter in the dry matter
ILRI	International livestock research institute
IPCC	Intergovernmental panel for climate change
IUCN	International union for conservation of nature
Kg	Kilo gram
Km	Kilo meter
LDMPS	Livestock Development Master Plan Study
LGP	Length of growing period
MCLPS	Mixed crop livestock production system
ME	Metabolizable energy
MJ	Mega joule
Mt	Megatonne
MoA	Ministry of Agriculture
N	Nitrogen
N_2O	Nitrous oxide
NDF	Neutral detergent fiber
NMA	National metrological agency
Ppb	Parts per billion
SE	Standard error
VS	Volatile solid
Tg	Teragram
TLU	Tropical livestock unit
Y_m	Methane conversion factor

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CONTRIBUTION OF SMALLHOLDER LIVESTOCK PRODUCTION TO GREENHOUSE GAS EMISSIONS IN ARSI ZONE, OROMIA REGION, ETHIOPIA

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PhD Dissertation

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ABSTRACT

The study was conducted in the mixed crop-livestock production system of the Arsi zone to investigate major feed resources, feed intake, and digestibility, estimate enteric methane emission, and predict methane and nitrous oxide emissions from livestock manure. Using multistage purposive sampling, 150 households of the three agro-ecological areas (lowland, midland, and highland) of the Arsi zone were sampled for one year 2021. Data were collected through discussions with key informants and groups, formal surveys, observations, laboratory analysis, and secondary data and analyzed using SPSS and SAS software. The experimental design of the feeding trail was a crossover design with three treatments and three periods. Descriptive statistics, and chi-square, one-way, and two-way ANOVA tests were used to analyze the data. The mean land allocated for cultivation was 82.08%, 88.447%, and 80.97% for lowland, midland, and highland agro-ecologies respectively, while the remaining proportion of lands was uncultivated and used for grazing. The mean total cattle (7.48±0.2) and equine (1.52±0.1) in TLU showed a significant ($P<0.001$) different between the highland and other agro-ecologies. The mean total goats (0.9±0.1) in TLU was a significant ($P<0.01$) different between the lowland and other agro-ecologies. The communal grazing land stover crop DM yield was significant ($P<0.001$) different between the lowland and other agro-ecologies. The fallow land DM yield was significant ($P<0.01$) different between midland and other agro-ecologies. The Cereal straw DM yield was significant ($P<0.01$) different between the highland and other agro-ecologies. Cooperatively, straw (cereals and oil), haulms (pulse), stovers (maize and sorghum), and natural pasture DM yields contributed 96.67 % to the total HH annual feed supply. Total dry matter intake (DMI) was higher ($P<0.001$) for sheep fed in T_2 (706.9 g/day) compared to the rest of the treatments, because the presence of s.sesban leaves and NSC increase the intake. The

effects of S. sesban leaves decreased the total DMI. The digestibility of DM, OM and CP were significantly (P<0.01) different between T_1 and T_2, NDF and ADF were significantly (P<0.05) different between T_1 and the rest of treatments. The enteric methane emissions factor (4.73kg CH_4 $head^{-1}$ $yeay^{-1}$) and daily methane production (12.69g CH_4 $head^{-1}$ day^{-1}) were significant (P<0.01) different between treatments. The enteric methane emissions factor (5.5kg CH_4 $head^{-1}$ $yeay^{-1}$ and daily methane production (14.6g CH_4 $head^{-1}$ day^{-1}) were significant (P<0.01) different between T_3 and the rest of treatments. The estimated enteric methane EF (5.2-61.1kg CH_4 $head^{-1}$ $yeay^{-1}$) of different age groups of cattle were significantly (P<0.01) different between cattle subcategories. The estimated enteric CH_4 EF (41.7-40.9kg CH_4 $head^{-1}$ $year^{-1}$) of cattle were significant (P<0.001) different between the lowland agro-ecology and other agro-ecologies. The estimated enteric CH_4 EFs (3-6.7kg CH_4 $head^{-1}$ $yeay^{-1}$) of different age groups of sheep were significant (P<0.001) different between the sheep categories. The enteric EF (5.3-5.1kg CH_4 $head^{-1}$ $yeay^{-1}$) of sheep were significantly (P<0.001) different between the lowland agro-ecology and other agro-ecologies. The estimated enteric CH_4 FE (2.6-6.9kg CH_4 $head^{-1}$ $yeay^{-1}$) of different age groups of goats were significant (P<0.001) different between the goats' subcategories. The enteric CH_4 EF (5.7-5.5kg CH_4 $head^{-1}$ $yeay^{-1}$) of goats was significantly (P<0.001) different between the three agro-ecologies. Cattle contribute 45.76 % followed by horses (20.01 %), donkeys or mules (11.12 %), goats (6.22%), and sheep (5.78%). From the total population in the study area, cattle share (83.88%) the largest EF CH_4 followed by donkeys (4.31%), goats (4.19%), sheep (4.11%), and horses (3.23%). From the agro-ecologies point of view per head of animal, the lowland area took the highest share (33.61%), followed by midland (33.23 %) and highland (33.16 %). The shares of agro-ecologies per total population highland area (43.54 %) share the largest emissions, followed by midland (35.23%) and lowland (21.23%). The estimated CH_4 (0.74-4.5kg CH_4 $head^{-1}$ $yeay^{-1}$) emissions from manure handling practices in the study area of different age groups of cattle were significant (P<0.001) different between the cattle subcategories. The estimated CH_4 (3.17-3.06kg CH_4 $head^{-1}$ $yeay^{-1}$) emissions from the manure of cattle were significant (P<0.001) different between the lowland agro-ecology and other agro-ecologies.

The estimated methane emission factors(0.128-0.141kg CH_4 $head^{-1}$ $yeay^{-1}$) from the manure handling practices of different age groups of sheep were significantly ($P<0.001$) different between the sheep subcategories. The estimated CH_4 emission factors (0.137-0.129kg CH_4 $head^{-1}$ $yeay^{-1}$) from the manure of different categories of sheep were significant ($P<0.001$) different between the lowland agro-ecology and the other agro-ecologies. The estimated methane emission factors (0.09-0.177kg CH_4 $head^{-1}$ $yeay^{-1}$) of different age groups of goats were significant ($P<0.001$) different between the goats' subcategories. The CH_4 emission factors (0.154-0.145kg CH_4 $head^{-1}$ $yeay^{-1}$) from the manure handling practices of goats were significantly ($P<0.001$) different between the three agro-ecologies. The estimated nitrous oxide (1-10.2g CH_4 $head^{-1}$ $yeay^{-1}$) of different age groups of cattle was significantly ($P<0.001$) different between the cattle subcategories. The estimated nitrous oxide (7.85-7.7g CH_4 $head^{-1}$ $yeay^{-1}$) of dual-purpose cattle was significantly ($P<0.001$) different between the lowland agro-ecology and other agro-ecologies. The estimated nitrous oxide (1.14-1.32g CH_4 $head^{-1}$ $yeay^{-1}$) of different age groups of sheep were significant ($P<0.001$) different between the sheep subcategories. The estimated nitrous oxide (1.23-1.19g CH_4 $head^{-1}$ $yeay^{-1}$) was significant ($P<0.001$) different between the lowland agro-ecology and other agro-ecologies. The estimated nitrous oxide (1.-1.6g CH_4 $head^{-1}$ $yeay^{-1}$) of different age groups of goats were significant ($P<0.001$) different between goat subcategories. The estimated nitrous oxide(1.4-1.35g CH_4 $head^{-1}$ $yeay^{-1}$) was significant ($P<0.001$) different between the lowland agro-ecology and other agro-ecologies. Therefore, produce quality feed supply and proper handling husbandry, improved manure management system and promotion of farm level livestock technologies should be exercised astutely to increase productivity and reduce the GHG emission of the livestock sector.

Keywords: Agro-ecology; Digestibility; Feed intake; Livestock production; Methane emission; Nitrous oxide emission; Smallholders.

1. INTRODUCTION

The global livestock sector is facing a threefold challenge: the need to increase production to meet demand, adapt to a changing and increasingly variable economic and natural environment and, at the same time, improve its environmental performance (Gerber *et al.*, 2013). Although the positive effects of grazing systems are locally verified on biodiversity and landscapes major, concerns have been raised about the potential consequences associated with livestock sector growth. This includes increasing natural resource use and degradation, contributions to global warming, water resource depletion, biodiversity erosion, and habitat change. These concerns have resulted in widespread interest from governments, consumers, and industry in the assessment of the environmental performance of livestock production (Gerber *et al.*, 2013).

Livestock production in Africa accounts for approximately 30% of the gross value of agricultural production, with 92% of that coming from the production of beef cattle, dairy cattle, goats, sheep, and chickens (Arara, 2010). Livestock production is increasing throughout Africa, driven by the growth of the human population, living standards (increases in the demand for livestock products as incomes rise), and urbanization (Arara, 2010; Makkar and Harinder, 2007). Livestock production is a critical component of agriculture by generating income and improving the nutrition of people in developing countries. Despite such contributions, livestock production currently faces global climate change challenges in addition to feed shortages in developing and developed countries.

Ethiopia is home to Africa's largest livestock population. Although domestic demand for animal products in Ethiopia is increasingly driven by the urban middle and upper classes export potential is the key force encouraging the expansion and intensification of livestock production (MacDonald and Simon., 2011). The livestock sector is an integral part of farming systems in the country. Livestock contribute to the production of food (meat, milk, eggs, honey, cheese, butter, etc.), sources of power (for cultivation, threshing, transportation, etc.), means of income (national and household income), inputs for crop production (draught power and manure); and export earnings (live animals, meat, skin, and hides) (Birara and Zemen, 2016). The recent livestock population of Ethiopia

estimates that the country has approximately 70 million heads of cattle, 42.9 million sheep, 52.5 million goats, 2.15 million horses, 10.8 million donkeys, 0.38 million Mules, 8.1 million camels, and 57 million poultry (CSA, 2021).

Environmental problems are becoming global issues because of their effects on all nations of the world. These are present-day major interests of political, economic, social, and environmental concerns because of their potential negative impacts on our lives and the ecosystem in general (IPCC, 2007). In recent decades, the impact of global warming and the continued uncontrolled release of greenhouse gases (GHGs) has negatively influenced livestock production and food security (Opio *et al.*, 2013). According to Scholtz *et al.*, (2014), global warming has a direct influence on ambient temperature that has a consequent effect on water supplies, distribution of livestock species and breeds, adaptability, incidence, type of diseases, feed supplies, and overall food security. This is due to the changes associated with temperature itself, relative humidity, rainfall distribution in time and space, altered disease distribution, changes in the ecosystem and biome composition, woody species encroachment, and alien plant invasion (Scholtz *et al.*, 2011, 2012).

Ethiopia is a country with distinct production system differences, due to differences in climate, breed, feed and feeding system, and manure management. These differences need to be considered to obtain an accurate estimate. For this, first, define the production system and then define categories and subcategories within these production systems. For example, the livestock production system in Ethiopia can be classified into urban and peri-urban production systems, mixed crop-livestock production systems (mixed moisture sufficient and mixed moisture deficit system) found in the highland, and pastoral and agro-pastoral production systems found in the low land areas. Both urban and peri-urban systems are located around Addis Ababa and regional towns and take advantage of urban markets. The production system is based on the use of pure exotic breeds and crossbred dairy cows for commercial purposes. Manures are managed in liquid based systems or pit forms, and feed and feeding systems are based on concentrate supplementation. The mixed crop-livestock production system is part of the subsistence farming system found in mixed highland areas. Feed resources are mainly natural grazing, crop residues, and a

small number of cultivated forages whereby a greater fluctuation in availability and quality is manifested almost throughout the year (Alemayehu, and Tegegn, 2012).

Over the last decade, there has been growing international interest in emissions of GHG. Greenhouse gases are atmospheric gases that absorb and remit longwave radiation back to the Earth's surface. These gases have been produced from livestock production and contribute a significant amount of GHG emissions worldwide, generating carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) throughout the production cycle. The global mean surface temperature has increased by 0.6 ± 0.2°C over the 20th century primarily due to increasing concentrations of GHG in the atmosphere (Forster *et al.*, 2007). Livestock contribute to total GHG emissions through land use and land-use change (2.5 Gt CO2-eq); feed production except C released from soil (0.4 Gt (gigatonne) CO2-eq); enteric fermentation from ruminants (CH_4) and on-farm fossil fuel use (CO2) (1.9 Gt CO_2-eq); manure management (2.2 Gt CO_2-eq); and processing and international transport (0.03 Gt CO_2-eq) (FAO, 2006).

Methane has a global warming potential approximately 28 times that of CO_2 over 100 years (IPCC, 2014). Methane production from the fermentation of feeds in the rumen represents a loss of up to 15% of the gross energy intake for dairy animals depending upon the type of diet (Holter & Young, 1992). Moreover, livestock production systems contribute a substantial share of greenhouse gases (GHG) to the atmosphere with an estimate of 7.1 gigatonnes (in CO_2 equivalent) annually representing 14.5% of total anthropogenic GHG (Gerber *et al.*, 2013), and methane production from enteric fermentation represents approximately 40% of total GHG emissions from livestock production systems (Gerber *et al.*, 2013; Patra, 2012). The major concern is that its global atmospheric concentration has increased from 715 ± 4 ppb in the 1750s to 1799 ± 2 ppb in 2010 (Kirschke *et al.*, 2013). This can increase mean surface temperatures by 2100 by approximately 1.5 to 2°C (Collins *et al.*, 2013). This rate of increase has differed over time, most noticeably with global atmospheric CH_4 concentrations appearing to stabilize between 1999 and 2007; however, it has been noted that CH_4 concentrations are once again rising (Kirschke *et al.*, 2013). In the developed world it is expected to decline due to increased productivity coupled with declining number of ruminants (FAO, 2006).

However, in the developing world and from the African continent it is expected to increase due to increases in animal numbers (Herrero *et al.*, 2008). Of the 3.3 Gt of direct cattle GHG emissions, CH_4 from enteric fermentation is the largest source, accounting for 71%. Manure N_2O, particularly from deposition on pasture, accounts for the next largest share (25%), whereas the remaining 4% is from manure CH_4 (Opio *et al.*, 2013).

It has been reported that farm animals from mixed farming contribute to climate change mainly through greenhouse gas emissions and natural resource degradation (Herrero *et al.*, 2008). Livestock and the environment are closely related, as livestock depend on land and water resources, while livestock emit pollutant gases to the environment. These factors have allowed the sector to recently be blamed for significant contributions to the global climate (CDR, 2011; IPCC, 2006a). Researchers underpin that livestock diets from mixed farming areas are composed of grazing, crop residues, cut and carry, concentrates and opportunistic feeds. These dietary differences were important for the disparity in methane (CH_4) emissions within the system. For example, an average figure of 31.1 kg CH_4 per TLU per year for African ruminants is high compared to the low production performance of the animals (Herrero *et al.*, 2008).

Globally, enteric methane emission from ruminants is estimated to represent 17–30% of total anthropogenic methane (Beauchemin *et al*., 2008). Herrero *et al*., (2008) has estimated a trend in the methane emissions of ruminants from the African continent, and it will likely increase from 7.8 million tonnes per year in 2000 to 11.1 million tonnes per year by 2030. This may be due to a possible increase in animal number (Herrero *et al*., 2008) that alerts the need to develop strategic intervention.

The loss of gross energy as methane is higher from ruminants grazing tropical pastures than temperate pastures (DeRamus *et al*., 2003). The emissions from the Ethiopian agricultural sector are not well documented as Ethiopian ruminant production systems utilize tropical grasses as roughage sources.

In Ethiopia, there are data on livestock numbers from different years of the census. However, these data are not fully aggregated to the districts and kebeles according to animal type, average annual population, productivity, feeding systems, or manure

management as they influence GHG emissions. This study can therefore go to grassroots level to generate data that is important for Tier 2 model. A major reason for this model use is the challenge in the collection of primary data related to infrastructure (e.g., access to farms, appropriate research facilities, and equipped laboratories). Another reason were absence of region-specific methods, feed digestibility, and gross energy of the feed converted to CH_4.

The accuracy of estimating enteric CH_4 emissions by using models has been a key interest of numerous studies *(Goopy et al., 2021; Ndung et al., 2019; Nyamushamba et al*., 2016; Wilkes *et al*., 2020). More than 70% of agricultural GHG emissions in Africa come from the livestock sector dominated by enteric methane (CH_4) emissions (Tubiello *et al.*, 2013). However, the Tier 2 EF approach relies on accurate cattle and feed characterization.

The purpose of this study is therefore to compensate for the lack of information on the interactions between livestock and the environment by assessing the livestock production system that can emit different gases into the environment in the three agro-ecologies of the production systems. In addition, addressing some of these challenges and deriving quantitative estimates of EF and the contribution of smallholder livestock systems in the Arsi zone to GHG emissions.

General Objective:

- To quantify the contribution of smallholder livestock production to greenhouse gas emissions in the study area.

Specific Objectives:

- *To characterize major feed resources in the study area*
- *To determine the feed intake, digestibility, and estimate enteric methane of Arsi-Bale sheep fed different treatments kept at the maintenance level.*
- *To estimate enteric methane emissions from livestock production in the study area.*
- *To quantify the methane and nitrous oxide emissions from livestock manure of the livestock production system in the study area.*

2. LITERATURE REVIEW

2.1. Livestock Production System in Ethiopia

Ethiopia has a large livestock population and diverse agro-ecological zones suitable for livestock production and for growing diverse types of food and fodder crops. However, livestock production has mostly been subsistence-oriented and is characterized by very low reproductive and production performance. Livestock production systems are determined by many factors. Among these are agro-ecological zones (including rainfall, temperature, soil type, and length of the growing season), the amount of land owned or farmed per household, the types of crop grown, the livestock species and numbers reared and their economic importance to the producer and the degree of integration of crops and livestock. Five production systems have been defined pastoral, agro-pastoral, mixed crop-livestock farming, urban and peri-urban dairy farming, and specialized intensive dairy farming systems (LDMPS, 2015).

In the highland livestock production system, animals are part of a mixed subsistence farming complex (Alemayehu, 1987). Livestock provides inputs (draught power, transport, manure) to other parts of the farm system and generates consumable or saleable outputs (milk, manure, meat, hides and skins, hair and eggs). approximately 88% of the human population, 70% of cattle and sheep, 30% of goats and 80% of equines are found in this region (Alemayehu, 2004). The principal objective of farmers engaged in mixed farming is to gain complementary benefits from an optimum mixture of crop and livestock farming and to spread income and risks over both crop and livestock production (Lemma & Smit, 2005).

Jabbar *et al*., (2007) stated that feed shortage is more serious during the dry season of the year for animals depending on natural pasture or kept under an extensive management system. Gebremedhin *et al*., (2017) stated that in midland and highland areas, where mixed farming systems predominate, the contribution of grazing land is declining from time to time due to poor grazing land management practices and ever-increasing human population/urbanization, and the expansion of cropland at the expense of grazing land.

(Suttie, 2000) explained that in the long dry season, this small grazing pasture land is unable to provide sufficient feed of reasonable quality and quantity to satisfy the nutritional demands of livestock.

2.2. Impacts of Climate Change on Livestock in Ethiopia

Global climate change is one of the most significant environmental challenges in the world. Erratic and a shortage of rainfall, degraded land, eroded ecosystems, and a deteriorated environment will remain the main basis for drought vulnerability in many rural areas in Ethiopia. Environmental degradation is aggravated by open-access grazing, poor soil and water conservation practices, and prolonged dry periods, which also create vulnerability in many parts of Ethiopia. The intergovernmental panel on climate change (IPCC, 2007) has indicated that global warming due to climate change could lead to many environmental threats i.e. drought, floods, sea level rise, decline in crop and animal production, and health hazards, among others. Greenhouse gases (GHGs) are released in the atmosphere from both natural sources and anthropogenic (human related) activities. However, during the past few decades, the amounts of GHGs released into the atmosphere due to human activities have increased significantly (FAO, 2006).

Climate change is expected to result in fall in productivity, and livestock productivity may be 50% lower in the 2050s than in the scenario without climate change. Agricultural GDP with climate change may be 3% to 30% lower than that without climate change in 2050. Climate change may increase the number of people looking for food aid by 30% (WorldBank, 2010), and increase drought expenses by 72% in the 2050s (FDRE, 2015). Increasing temperatures and decreasing rainfall reduce yields of rangelands and contribute to their degradation. Higher temperatures tend to reduce animal feed intake and lower feed conversion rates (Rowlinson, 2008). Pastoralists in the Borana area indicated that climate change had an effect on their livelihoods through various mechanisms. As prioritized by pastoralists, the four major effects of climate change on livestock production include feed shortage, shortage of water, reduced productivity, decreased mature weight and/or longer time to reach mature weight in their order of importance (Yilma *et al*., 2009).

The impact of climate change on animal production has been broadly categorized as direct and indirect effects (Naqvi & Sejian, 2011). The direct effects are absolute outcomes observed in animals such as heat stress due to the increase in ambient temperature, reduced feed intake and abnormal physiological processes, changes in animal behavior and metabolism, stunted growth, reduced productivity, and reproductive malfunction. The indirect effects of climate change are due to changes in the animal environment such as reduced feed quality and quantity, reduced water resources and quality, increased severity and distribution of diseases and parasites, and financial losses due to the cost of production and animal performance (Hansen, 2004). Both the direct and indirect effects of climate change result in a decline in the production and reproductive performance of livestock.

There are some livestock species that can thrive well under harsh climate conditions either due to natural selection or through human genetic improvement programs (Jahnke, 1982). Natural selection is a biological adaptation process that requires a long period, and changes occur slowly (Desta, 2000). Humans interfere with natural adaptation processes by adapting animals and plants through domestication and selective breeding. Hansen, (2004) reported that *Bos indicus* cattle breeds of the tropics are capable of regulating body temperature in response to heat stress much better than *Bos taurus* cattle breeds of European origin. The superior ability to regulate body temperature during heat stress is the result of lower metabolic rates as well as increased capacity for heat loss. Once specific genes that are responsible for thermo-tolerance in *B. indicus* cattle have been identified or mapped, breeding strategies such as marker-assisted selection and transgenic tools can be applied for further exploitation of the *B. indicus* genotype for cattle production systems under increased temperature or heat stress conditions (Hansen, 2004).

2.3. Impact of Livestock on Climate Change

Livestock contribute 14.5% of the total annual anthropogenic GHG emissions globally (Gerber *et al*., 2013). Livestock influence climate through land use change, feed production, animal production, manure, and processing and transport. Feed production and manure emit CO_2, nitrous oxide (N_2O), and methane (CH_4), which consequently affects climate change. Animal production increases CH_4 emissions. The processing and

transport of animal products and land use change contribute to the increase in CO_2 emissions.

The livestock sector is often associated with negative environmental impacts such as land degradation, air and water pollution, and biodiversity destruction (Bellarby *et al.*, 2013; Thornton & Gerber, 2010). Increases in livestock production are expected to originate from a declining natural resource base, which will cause further environmental damage without proper natural resource management (Thornton & Herrero, 2010a).

Among Ethiopian livestock species the major contributors to GHG emissions are cattle, which are used for meat, dairy products, and draught animals, and are treated as financial assets. Given current practices, the cattle population is likely to increase from approximately 60.39 million (CSA, 2021) to more than 90 million in 2030 (FDRE-CRGE, 2011), thereby almost reaching the cattle carrying capacity of the country and doubling emissions from the livestock sector. In a business-as-usual scenario, emissions from livestock are projected to increase as a function of livestock population growth from 55 Mt CO_2e in 2013 to 124 Mt CO_2e in 2030 (FDRE-CRGE, 2011), mainly driven by an increase in methane from enteric fermentation and manure management (accounting for 112 Mt CO_2e or 90% of emissions in 2030). Emissions from manure left on pasture, range and paddock account for the remaining 10% of livestock emissions in 2030 (FDRE-CRGE, 2011).

2.4. Sources of Greenhouse Gases in Livestock Production

Greenhouse gas (GHG) emissions from agriculture, including crop and livestock production, forestry and associated land use changes, are responsible for a significant fraction of anthropogenic emissions, up to 30% according to the IPCC (Tubiello *et al.*, 2013). Greenhouse gas emissions from livestock and manure management occur at different stages along the livestock value chain. However, the relative importance of each source varies considerably. Understanding the qualitative differences among them is crucial to many steps in inventory development, including emission calculation, emission reporting and inventory quality control. The greenhouse effect is a natural phenomenon necessary for life on Earth. Greenhouse gases are atmospheric gases that absorb and re-

emit long-wave radiation released by the earth back to the surface and as a consequence average global temperatures are predicted to rise (0.5 to 2.5^{o}C by 2030) (Houghton *et al.*, 2001).

The GHGs that contribute to global warming are CO_2, CH_4, N_2O, and others. CH_4 and N_2O are the most important GHGs from the animal production system and have very high global warming potentials (GWPs) of 28 and 265 CO_2 equivalents (eq), respectively based on the 5th Assessment Report IPCC (IPCC, 2014). CH_4 is emitted through methanogenesis under anaerobic conditions through enteric fermentation, in soils and manure storage, N_2O is primarily emitted as a byproduct of nitrification and de-nitrification.

2.5.The Contribution of Ruminants to Greenhouse Gas Emission

Methane is produced in herbivores as a byproduct of enteric fermentation, a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream. The amount of methane released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed. Ruminant livestock (e.g., cattle, sheep) are major sources of methane with moderate amounts produced from non-ruminant livestock (e.g., pigs, horses). The ruminant gut structure fosters extensive enteric fermentation of their diet (IPCC, 2019).

Digestion in ruminants (e.g., cattle and sheep) differs from that in mono-gastric animals (e.g., pigs and poultry) in that substantial fermentation occurs in their large stomach called the rumen, resulting in large quantities of CH_4 being produced which are voided through belching (Frank *et al.*, 2000). Methane originates from anaerobic microbial fermentation processes in the gastrointestinal tract of ruminant animals particularly in the reticulorumen or rumen. In an adult cow, the rumen occupies a volume of over 100 liters of which 85 to 90% is fluid (Moss *et al.*, 2000). The high moisture content and temperature that is kept rather constant at approximately 37^{o}C make this an eminently suitable environment for microbes to survive and grow, provided that the microbes are regularly supplied with a suitable substrate. Substrates needed by microbes are provided

through the ingestion of feed by the host animal. The feed ingested by a ruminant is attacked by microbes and degraded in a wide range of end products, including CH_4.

Ruminant animals release methane into the atmosphere through exhalation or rumination through the mouth and nostrils (Kebede, 2006). Enteric fermentation also produces volatile fatty acids. Among the volatile fatty acids, acetic and butyric acids promote methane production. Global emissions of methane from the digestion process in ruminants are in the range of 70-220 million tons per year (Reilly *et al.*, 2003) and are considered to be the largest source of anthropogenic methane emissions (IPCC, 2007).

The enteric fermentation produced by ruminant livestock (e.g. cattle, sheep, and goats) emits between 87 and 94 Tg (teragram) of methane annually globally (Thomas *et al.*, 2013). Mixed crop-livestock systems account for 64% of global enteric fermentation methane emissions; grazing systems account for 35%, and industrial systems account for 1% (FAO, 2006). The high percentage from mixed crop-livestock systems reflects that two-thirds of total livestock animals are present in those systems (FAO, 2006). The countries that contribute the most methane emissions related to livestock production are India, China, Brazil, and the United States (IPCC, 2013; Olivier and Janssens-Maenhout, 2012). India, with the largest livestock population in the world, emitted 11.8 Tg of CH_4 in 2003, 91% of which was derived from enteric fermentation and 9% from manure management (Chhabra *et al.*, 2013).

In Africa, methane emissions are expected to increase due to increases in livestock populations. (Herrero *et al.*, 2008) estimated that African cattle, goats, and sheep, which produced approximately 7.8 million tonnes of methane in 2000, are likely to increase to 11.1 million tons by 2030. If this linear relationship between methane emissions and livestock population continues, global methane emissions from livestock production may increase 60% by 2030 (FAO, 2003).

Enteric fermentation is the largest source of GHG emissions from cattle, buffalo, and small ruminants, comprising between 43% and 63% of livestock sector emissions. However, for pigs and chickens the largest source of emissions is due to feed production (between 25% and 27%), which includes fertilizer production, machinery use, and feed transportation. Enteric fermentation from pigs is much lower than in ruminants because

their digestive process does not produce as much methane as a byproduct (Gerber *et al.*, 2013).

Enteric fermentation causes the emission of CH_4, which is a byproduct of the breakdown of carbohydrate molecules into soluble particles by methanogens residing within the rumen. Thus, formed CH_4 is eructated by the animal and becomes a GHG. Feed quality is a major determinant of CH_4 production. High fiber content (cellulose) in the feed will increase CH_4 emissions. Methane is also produced, as is N_2O via the breakdown of manure.

The average emission factor for African domestic ruminants is 31.1 kg methane/year per TLU, which is similar to the value of 32 kg methane/year quoted by (IPCC, 1997). In addition, the impact of livestock on the environment in Africa is high and it is estimated that> 70% of African agricultural greenhouse gas (GHG) emissions are due to livestock production, dominated by CH_4 emissions from enteric fermentation (Tubiello *et al.*, 2014). Overall differences in emission factors between regions, irrespective of production system, were found to be small and on the order of 4.1 kg methane/year per TLU.

However, they range from 21 to 40 kg methane/year per TLU depending on the type of production system and the region. The largest emission factors were found in the more intensive mixed rain fed systems, especially in the humid and temperate regions where intakes, and diet quality and diversity and production are higher; and in the temperate rangeland systems, where the quality of the rangelands permits higher intakes and production. All rangeland grazing systems and mixed arid systems exhibited lower emission factors. This is a result of the lower intakes observed in the dry season due to lack of forage availability, as wet season values were similar to those from the mixed systems (Herrero *et al.*, 2008).

In inventory-based estimation of national livestock methane (CH_4) emissions, annual standing populations of each animal type are multiplied by species, and region-specific emissions factors to obtain annual emissions quantities. The emissions factors are derived using sets of mathematical formulae with inputs that vary depending on regional livestock qualities and management (e.g., feed intake quantity and quality; milk

production quantity; amount of energy used for growth, draft work, foraging, and pregnancy; and utilization of various manure management systems) (IPCC, 2006a).

The intensity of methane production (kg methane/km^2) differs significantly between production systems, but will increase in all systems from 2000 to 2030. Rangeland based grazing systems produce significantly lower amounts of methane/km^2 than mixed crop/livestock systems (136.3 vs. 773.2 kg/km^2 in 2000 and 169.7 vs. 977.1 kg/km^2 in 2030). The most intensive methane production systems are those in temperate areas, where the agro-climatological characteristics of the regions permit more intensive production practices (i.e. dairy). Mixed temperate systems, while diminishing in area and livestock numbers from 2000 to 2030, will also have substantial increases in the methane production intensity (1932.3 vs. 2958.2 kg/km^2 for 2000 and 2030, respectively) in the remaining areas (Herrero *et al.*, 2008).

2.6.Contribution of Livestock to Greenhouse Gas through Manure Management

Manure from livestock is a source of nitrous oxide and methane emissions as a result of storage and processing. Methane is released from anaerobic decomposition, while nitrogen is released as ammonia or nitrous oxide (Gerber *et al.*, 2013).

2.6.1. Methane emission from manure

Livestock manure is primarily composed of organic material and water. Anaerobic bacteria decompose organic material under anaerobic conditions, releasing CH_4 (EPA, 1999). Methane emissions from manure management are mostly associated with confined animals where manure is managed under different management systems (Baggott *et al.*, 2006; IPCC, 1997, 2006). The quantity of CH_4 emitted from manure management operations is a function of three primary factors: (1) the manure management system, (2) the environmental conditions and (3) the amount and composition of the manure (Bull *et al.*, 2005; EPA, 1999). The management system determines key factors that affect CH_4 production, including contact with oxygen, water content, pH and nutrient availability (EPA, 1999). When manure is stored or treated as a liquid in a lagoon, pond or tank, it

tends to decompose anaerobically and produce a significant quantity of CH_4. In contrast, when manure is handled as a solid or deposited on pastures, it tends to decompose aerobically, and little or no CH_4 is produced (IPCC, 2006a, 2019). According to Bull *et al.*, (2005), temperature, pH and moisture content also affect CH_4 formation, with high temperature, high moisture level and neutral pH conditions favoring CH_4 production. The composition of manure is directly related to animal types and diets, with dairy cattle being associated with higher feed intake and therefore higher manure excretion rates than nondairy cattle.

2.6.2. Nitrous oxide emission from manure

Nitrous oxide is produced directly and indirectly during the storage and treatment of manure and urine. Direct emissions occur through the processes of nitrification and de-nitrification, while indirect emissions occur through volatilization, leaching and runoff (Bull *et al.*, 2005; Olander *et al.*, 2013).

The production and emission of N_2O from manure depends on the digestibility and composition of animal feed, manure management practices, duration of waste management and environmental conditions (IPCC, 2006a). High N_2O emissions are related to a high intake of feed with a high nitrogen concentration. N_2O emissions depend on the amount of oxygen and moisture level of the managed manure (Bull *et al.*, 2005; IPCC, 1997). Manure stored for long periods of time results in relatively high emissions of N_2O. The environmental conditions that favor the development of N_2O in managed manure are low pH, high temperature, increased aeration and low moisture (IPCC, 2006a).

The emission of N_2O from manure depends on the nitrogen and carbon content of manure, and the duration of storage and type of treatment (IPCC, 2006a, 2019). Nitrous oxide emissions were estimated using input data on nitrogen excretion by the animal, the emissions factor for direct N_2O emissions (IPCC, 2006a) and the fraction of total annual nitrogen excretion that is deposited on pasture and rangelands. The fraction of manure that is deposited on pasture in Ethiopia is assumed to be 45% (FDRE-CRGE, 2011).

Table 1. Summary of GHG emissions from cattle subcategories in different areas

Species	Subcategories	Body weight (kg)	Enteric CH_4 (kg/h/y)	Manure		Authors
				Methane (kg/h/y)	N_2O (g/h/y)	
Cattle sub categories	Mature cattle	280	40.08	11.22	NA	Defar *et al.*, (2018)
	Growing cattle	200	20.42			
	Mature females > 3 years	255	65	4.972	NA	Million & Getahun, (2021)
	Heifers (2-3 years)	176	37	2.86		
	Growing females 1-2 years	125	56	4.333		
	Mature draught oxen	335	66	5.06		
	Mature breeding bulls	265	58	4.467		
	Growing males 1-2 year	162	63	4.879		
	Calves < 1 year	57	11	1.713		
	Adult multipurpose cows	285.8	57.87	4.19	141.37	Wilkes *et al.*, (2020)
	Adult males used for draught (3-10 years)	342.8	57.49	4.16		
	Adult males used for breeding & other purpose	342.8	61.72	4.47		
	Growing females	181.4	41.39	3.0		
	Growing males	226.9	53.87	3.9		
	Calves < 6 months (male & female)	53.8	5.16	0.75		
	Calves 6 m–<1 year (male & female)	105.5	14.62	1.06		
	Females (>2 years)	275	60			IPCC, (2019) default values
	Males (>2 years)	340	65			
	Heifers (1–2 years)	185	42			
	Young males (1–2 years)	185	42			
	Calves (<1 year)	75	30			
	Females (>2 years)	307	47.8	NA		Ndung'U *et al.*, (2019)
	Males (>2 years)	266	37.2			
	Heifers (1–2 years)	187	28.5			
	Young males (1–2 years)	157	27.2			
	Calves (<1 year)	73	25.8			
	Females (>2 years)	280.6	50.1	NA		Ndung'u *et al.*, (2021)
	Males (>2 years)	259.5	37.1			
	Heifers (1–2 years)	167.5	28.3			
	Young males (1–2 years)	136.5	26.4			
	Calves (<1 year)	69.3	18.3			

NA=not available; h=Head; y=Year

Table 2. Summary of GHG emissions from goat subcategories and equines

Species	Subcategories	Body weight (kg)	Enteric CH_4 (kg/h/y)	Manure		Authors
				Methane (kg/h/y)	N_2O (g/h/y)	
Goats	Adult does (2+ years)	26.72	6.76	0.16	6	Wilkes *et al.*, (2020)
	Bucks (>2 years)	27.9	6.39			
	Yearling (1-2 years)	20.95	8.86			
	Kids (males & females, <1 year)	10.5	3.82			
	Goats (West Africa)	14.2	2.3	NA	NA	Ndao *et al.*, (2019)
	Goats (Nandi)	20.2	3.4	NA	NA	Goopy *et al.*, (2021)
	Goats (Bomet)	20.9	3.8			
	Goats (Nyando)	18.4	3.7			
	Goats (Kenya)	19.3	3.7			
Equine	Horse	238	18	0.96	NA	Defar *et al.*, (2018)
	Donkey	130	10	1.28		

NA=not available; h=Head; y=Year

Table 3. Summary of GHG emissions from sheep subcategories in different areas

Species	Subcategories	Body weight (kg)	Enteric CH_4 (kg/h/y)	Manure		Authors
				Methane (kg/h/y)	N_2O (g/h/y)	
Sheep	Sheep > 1 year		3.53	0.48	NA	Defar *et al.*, (2018)
	Sheep up to 1 year		1.77			
	Breeding ewes (>2 years)	27.95	6.7	0.16	9	(Wilkes *et al.*, 2020)
	Mature male (>2years)	28.81	6.02			
	Female (1-2 years)	24.89	7.24			
	Male (1-2 years)	25.47	7.84			
	Intact male lambs (<1 year)	17.89	7.54			
	Female lambs (<1 year)	17.46	6.62			
	Sheep (Nandi)	25.2	4.6	NA	NA	Goopy *et*

	Sheep (Bomet)	27.3	4.8			*al.*, (2021)
	Sheep (Nyando)	18.3	3.8			
	Sheep (Kenya)	23.7	4.4			
	Sheep (West Africa)	17.1	2.3	NA	NA	Ndao *et al.*, (2019)

NA=not available; h=Head; y= Year

2.7.Manure Management and Pasture, Paddock and Range Emissions

Nitrous oxide emissions from manure management systems and field urine/fecal deposition during grazing (i.e., pasture, paddock, range emissions) are principally based on the amount of N excreted/head for each population category. Total manure management emissions are the product of the amount of N excreted during storage multiplied by the associated (default or Tier 2) emission factor for that manure management system and animal population. In addition, a proportion of N that volatilizes as NH_3 is considered to be re-emitted as N_2O upon wet or dry deposition to soils from N excretion by animals. Pasture, paddock and range emissions are estimated from annual N excretion, less the amount of excretion during storage, for each animal population (Crosson *et al.*, 2011).

2.8.Livestock Feed Resources and Implications for Greenhouse Gas Emissions

Livestock feed resources in Ethiopia are mainly natural grazing and browsing, crop residues, improved pasture, forage crops and agro-industrial byproducts. Feeding systems include communal or private natural grazing and browsing, cut-and-carry feeding, hay and crop residues. At present, stock is fed almost entirely on natural pasture and crop residues. Grazing is on permanent grazing areas, fallow land and cropland after harvest. Forage availability and quality are not favorable year round, and hence, gains made in the wet season are totally or partially lost in the dry season. At present, around dairy and fattening areas, there is insignificant production of improved pasture and forages. The contribution of agro-industrial byproducts is also minimal and restricted to some urban and peri-urban farms (dairying, poultry and fattening) (Mengistu *et al.*, 2017). Feed

processing for ruminant and nonruminant farm animals is aimed at increasing feed energy intake use and animal productivity. Gerber *et al.* (2010) suggested that in ruminant feeding, forage particle size reduction is important to enhance digestibility, providing greater microbial access to the substrate, and reducing energy expenditure, feed intake and animal productivity, which helps to reduce CH_4 emissions.

Changes in temperature and CO_2 levels will affect the composition of pastures by altering the species competition dynamics due to changes in optimal growth rates (Herrero *et al.*, 2008; IFAD., 2010). Plant competition is influenced by seasonal shifts in water availability (Polley *et al.*, 2013). Primary productivity in pastures may be increased due to changes in species composition if temperature, precipitation, and concurrent nitrogen deposition increase (IPCC, 2007). The quality of feed crops and forage may be affected by increased temperatures and dry conditions due to variations in the concentrations of water-soluble carbohydrates and nitrogen. Temperature increases may increase lignin and cell wall components in plants (Polley *et al.*, 2013; Sanz-Sáez *et al.*, 2012), which reduce digestibility and degradation rates (IFAD., 2010; Polley *et al.*, 2013), leading to a decrease in nutrient availability for livestock (Thornton *et al.*, 2009).

Improving feeding practices as an adaptation measure could indirectly improve the efficiency of livestock production (Havlík *et al.*, 2013). Some of the suggested feeding practices include, modification of diet composition, changing feeding time and/or frequency (Renaudeau *et al.*, 2012), incorporating agro-forestry species in the animal diet (Thornton & Herrero, 2010), and training producers in the production and conservation of feed for different agro-ecological zones (IFAD., 2010). These practices can reduce the risk from climate change by promoting higher intake or compensating for low feed consumption, reducing excessive heat load (Renaudeau *et al.*, 2012), decreasing feed insecurity during dry seasons (Thornton & Herrero, 2010), and reducing animal malnutrition and mortality (IFAD., 2010).

Concentrate feeds due to higher concentrations of DE than forages usually have a positive effect on the productivity of ruminants. Thus, increasing the proportion of concentrate in the diet should increase animal production and reduce enteric CH_4 emissions. The combined effect of concentrate supplementation and forage quality (i.e.,

forage digestibility expressed as maturity) is a recent study by (Randby *et al.*, 2012). In addition to no concentrate, these authors investigated the effect of three grass silage maturities (16.6, 14.5, and 11.3 percent CP and 47.7, 53.3, and 60.1 percent NDF; silage harvested at very early, early, and normal maturity) and three levels of concentrate supplementation on the milk production of dairy cows. Concentrate supplementation reached up to 50 to 60% of DMI. Silage intake decreased with increasing grass maturity and total DMI increased with increasing concentrate supplementation. The energy corrected milk (ECM) yield decreased with increasing grass silage maturity and increased with increasing concentrate supplementation, most significantly up to 30 percent concentrate inclusion with little gain in milk production above 30 percent. However, ECM feed efficiency tended to decrease with increasing concentrate inclusion in the diet and was not significantly affected by silage maturity.

Diet composition and quality are key determinants of the productivity and feed-use efficiency of farm animals (AFRC, 1993). Together with animal characteristics, such as body weight and physiological state, they largely regulate feed intake, animal productivity, methane emissions, and manure and urine output and composition. Diets for ruminants exhibit considerable variation in composition and quality, mainly explained by agro-ecology, type of production system, and intensity of production. In general terms, the higher the quality of the diet is, the higher the feed efficiency (Herrero *et al.*, 2013). The same author suggested that diets in arid areas are typically of lower digestibility and crude protein concentration and have slower fiber and nitrogen degradation rates than those in humid or temperate regions. The result of this is lower ME concentrations [8–9.5 MJ/kg dry matter (DM)] than in humid or temperate areas (9.5–12.5 MJ/kg DM)(Leng, 1991). These lower energy densities led to lower intake and animal productivity and resulted in lower feed-use efficiencies. In addition, animals in smallholder systems are generally offered feeds low in digestibility and protein, which are associated with higher enteric CH_4 emissions per kilogram dry matter intake (DMI). Animals fed imbalanced rations produce more methane per unit of dry matter intake due to lower microbial protein production and higher acetate production (Leng, 1991).

3. MATERIALS AND METHODS

3.1.Description of the Study Area

The study was conducted in the Arsi Administrative Zone, southeastern part of the Oromia Regional State, Ethiopia. The Arsi zone was one of the 22 zones of the Oromia National Regional State. Assela is the capital town of the zone, which is located 175 km from Addis Ababa on the Addis Ababa Adama-Bale Robe main road in the southeastern part of the country (OBoFED, 2011). It is also situated between 6^{o}45'N to 8˚50'N latitude and 38˚32'E to 40˚50'E longitude (OBoFED, 2011). It has a surface area of approximately 20,737.24 km^2 and the altitudinal range of the Zone is from 500 to 4,245 m.a.s.l. with the highest mountain peak of Mt. Kaka and characterized by a mixed farming system. The mean annual temperature of the Zone ranges between 20˚C - 25˚C in the low land and 10˚C -15˚C in the central highland, and the area has an annual rainfall that ranges from 700-1658 mm and annual average relative humidity, ranging from 43-60%. The area has a bimodal rainfall occurring from March to April (short rainy season) and from July to October (long rainy season). The common and widely used livestock production system in the area was an extensive type of production system where animals are kept only on grazing with no extra supplementary feed except crop residues during the dry season. However, there are few indoor, intensive animal production systems particularly around the town (OBoFED, 2011).

The topography of the study area has great physiographic diversity. There are great altitudinal differences between the highest and the lowest places. The lowest point of the area is 805 m. a. s. l. which was found at the extreme east of the Seru district in Wabi Gorge. On the other hand, the mountain peak of Kaka with a height of 4195 m. a. s. l. was the highest in the area. The vegetation of the study area varies from the Acacia-wooded grassland in the Central Rift Valley to the degraded Afro-alpine mountain forests and associated grassland in the highlands (White, 1983; Friis, 1992) and a few sparsely distributed trees, while eucalyptus is dominant around the settlement areas. Native mountain tree species, such as Cordia africana, Juniperus procera, Hagena abyssinica,

Olea africana and Podocarpus fulcatus, were found in the study area. The dominant soil types in the study area are Chromic, Pellic Vertisols, Luvisols, Cambisols, Andosols and

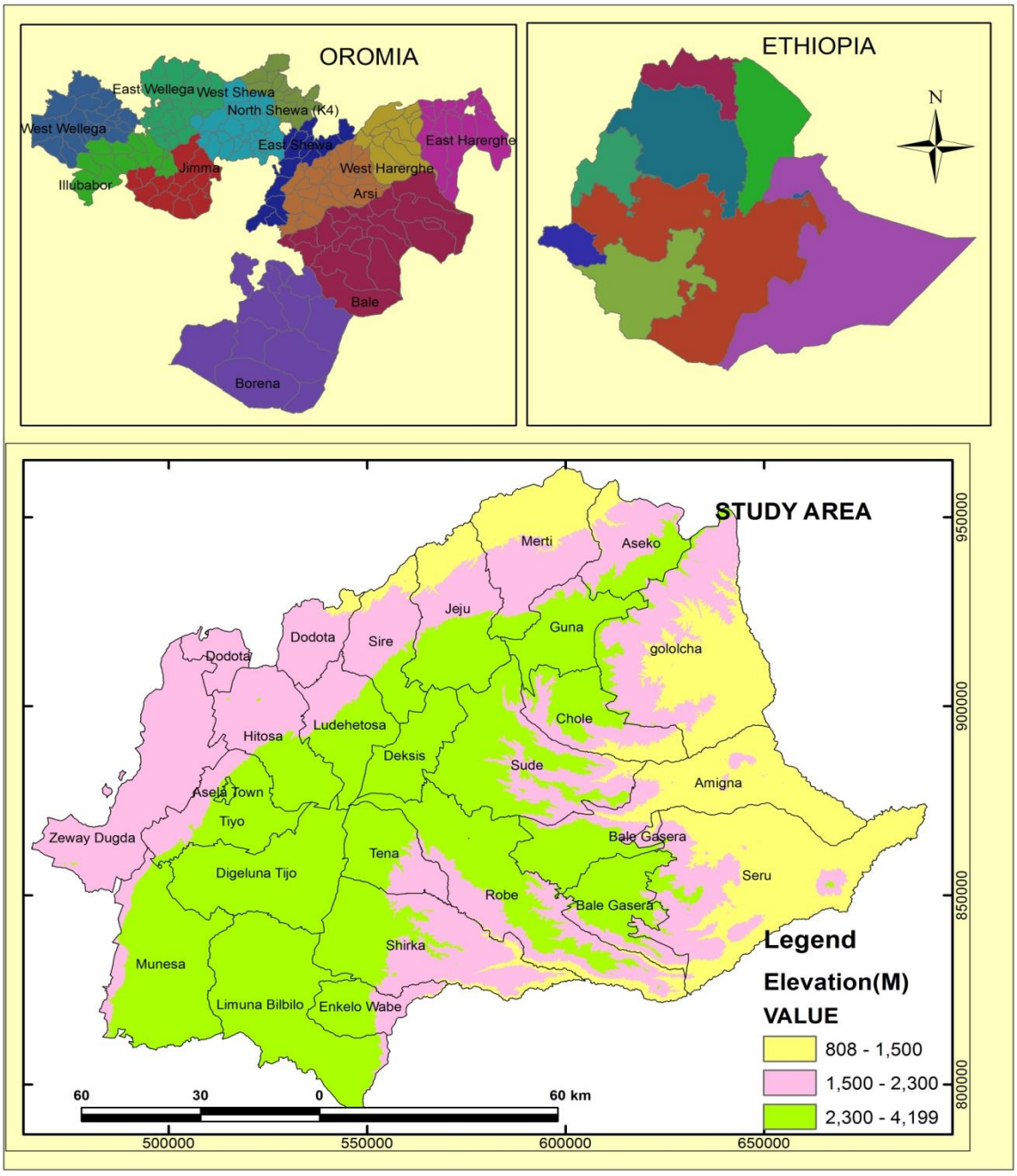


Figure 1: Location map of the study areas

Lithosols, which usually occur in flat plateau highland areas and are suitable for various crop production and natural vegetation of a wide range (OBoFED, 2011).

The major crops cultivated in the area are wheat, barley, teff, faba bean, field pea, maize, sorghum and some oil crops. Other crops including vegetables, fruits, root crops and stimulants were also grown. Moreover, the study area has large livestock resources since the smallholder livelihood bases were livestock herding and cultivation. The major livestock species traditionally reared by the study area inhabitants include cattle, sheep, goat, donkey, horse, mule and chicken (CSA, 2021).

Part one

Survey

3.2. Sample Size and Sampling Procedure

3.2.1. Stratified sampling method

The study sites were selected purposively by the agro-ecological conditions, proximity to the main road, cattle population and potentially mixed farming system (cereal-cattle dominant). The study areas were stratified into three agro ecological areas. Those were stratified into highland (greater than 2,300 meters above sea level), which is 45.54% cover, midland (1,500-2,300 meters above sea level), which is 34.88% cover, and low land (less than 1,500 meters above sea level), which is 19.58% cover based on the Ethiopian agro-ecological classification (Dereje & Eshetu, 2011) and (Table 4) and secondary data obtained from the zone Livestock Resource Development Office (AZLRDO, 2018).

The coverage areas of agro-ecology were calculated depending on the above categories. Hence, the total area of the zone was 2,073,724 ha (20,737.24 km^2) and the proportion of each agro-ecological type was 9,444.294 km^2 (45.54%) for highland, 7,233.567 km^2 (34.88%) for midland, and 4,059.379 km^2 (19.58%) for lowland, each used as sampling frames. Then, the sampling fraction of each of the three agro-ecology synthesized and sampled elements was drawn from each agro-ecology. First, the smallest area of agro-

ecology was selected and decided, and then the area of each agro-ecology was divided by the smallest area (ILCA, 1990). As a result, the proportion of the three agro-ecologies was 2:2:1.

Table 4. Traditional classification of land uses and livestock systems in Ethiopia

	Traditional Classifications		
	Lowland	**Midland**	**Highland**
Altitudes (meter)	<1500	1500-2300	>2300
Rainfall (mm/year)	<800	800-1200	>1200 mm
Average annual temperature (^{0}C)	>20	16-20	<16
Length of growing periods (days)	<120	120-240	>240
Moisture regimes	Arid to semiarid	Submoist to moist	Sub humid to per-humid
Total land area (million hectares)	57.5	50.2	22.9

Sources (Cecchi *et al.*, 2010; Dereje & Eshetu, 2011)

Thus, these proportions mean that when 2 households were drawn from highlands and midlands, at the same time, 1 household was drawn from lowland. In such a way, the total sample sizes were drawn as proportional to the size method from the three agro-ecologies. Accordingly, the sampling ratio was calculated using the addition of proportions (2+2+1) that give 5 as the value of the total proportion. Finally, the smallest proportion equal to 1 is divided by the total sum of proportions of 5, and the sampling ratio was calculated to obtain the correction factor: 1/5=0.2.

Hence, to calculate the number of HHs sampled in the study area by, $N = 0.25/SE^2$, where N = number of sampled HHs and SE = standard error (Arsham, 2005). Considering SE of 4.09% at a precision level of 5% and a 95% confidence interval. Accordingly, 150HHs were selected purposively based on land holding, livestock holding and experience of keeping livestock. Then, when you distribute HHs into the proportions of each agro-ecology highland area (150*0.4=60HHs), midland (150*0.4=60HHs) and lowland (150*0.2=30HHs).

3.2.2. Data collection

A single visit multiple subject formal survey (ILCA, 1990) was performed using a pretested structured questionnaire. Before the commencement of the actual interview, the questionnaire was pretested with farmers and experts for further refinement. Following the pretest, appropriate modifications were made to some questions to fit the purpose.
The questionnaire covered and assessed various topics from each household, including socioeconomic characteristics (age, family size and educational status), farming activities, farmland characteristics (land size, allocation/land use pattern, major crops grown with their area and productivity), livestock ownership (herd size and herd composition), manure management and utilization, and major feed sources.

Secondary data sources, including journal articles, books, and statistical reports, were gathered from (the Arsi Zone Livestock Resource Development Office (AZLRDO), Central Statistical Agency (CSA), Food and Agricultural Organization of the United Nations (FAO) such as FAOSTAT Agriculture, International Livestock Research Institute (ILRI) and directives of Line Ministries, and national policies). The numbers of livestock in each agro-ecology at the year (2021/22) were used to estimate GHG emissions.

3.2.3.Feed sample collection and chemical composition analysis

Mixed natural pasture herbages from protected private grazing or fallow land of agro-ecology at the midway mature age were harvested from the 1 m * 1 m quadrant (Tessema *et al.*, 2011), and the collected samples from each private grazing or fallow land of agro-ecology were bulked and dried under shade for further chemical analysis. The dominant mixed native pasture species from these lands were taken. The mixed representative subsamples were taken per feed type and packed in a paper bag at room temperature pending chemical analysis at the Debrezeit/ Bishoftu Agricultural Research Center and Hawassa University Animal Nutrition Laboratory.

In the agro-ecologies, pooled subsamples (mixed natural pasture, cereal crops straws, pulse crops haulms and crop aftermaths) were collected and dried in an air draft oven at 65^{o}C for 72 hours to determine the DM percentage. The DM and ash contents were

determined by oven drying at 105^{o}C overnight and igniting in a muffle furnace at 500^{o}C for 6 hours. The nitrogen (N) content was determined by the Kjeldahl method, and crude protein (CP) was calculated as N * 6.25 (AOAC, 1995).

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were analyzed according to Van Soest and Robertson (1985). The in vitro digestible organic matter in the dry matter (IVDOMD) was determined by the Tilley and Terry method as modified by Van Soest and Robertson (1985).

The metabolizable energy contents of a given feed were estimated from IVDOMD:

ME (MJ kg^{-1} DM) = [0.15*IVDOMD (%)] (MAFF, 1984)

where, IVDOMD=in vitro digestible organic matter in the dry matter

Part Two

Feeding trial

3.3. Experimental Diets and Treatments

The natural grass hay was harvested at approximately the 50% flowering stage manually and sun-dried. The dried hay was piled and stored as loose hay under shade. The hay was chopped to a size of approximately 5-6 cm to facilitate intake. The *S. sesban* leaf meal was collected and prepared grown in the university area. Green leaves of the plant were harvested by manually cutting the branches with sickle and spreading them on plastic sheets. The harvested leaves were subjected to air-drying under a shed separately for three to four days and turned up four times a day to ensure uniform drying and maintain a green color as described by (Solomon *et al.*, 2004a). The leaves were then packed in polythene sacks and stored for later use. Noug seed (*Guizotia abyssinica*) cake (NSC) was purchased from the Adama oil processing factory. The experimental diets were formulated according to the nutritional requirements and recommendations of the National Research Council (NRC, 2001) to satisfy the maintenance requirements of adult sheep (26.7 (±0. 14) kg). The proportions of the dried *S. sesban* leaf meal and concentrates were calculated based on the CP contents to make the supplements iso-

nitrogenous in all treatments. The experimental feed ingredients were mixed uniformly to avoid the selection by the experimental animals. The three treatments were

Treatment 1:- Hay + *S. sesban* leaves

Treatment 2:-mixed ration (27.6% hay +27.6% *S.sesban* leaves+ 44.8% NSC) and

Treatment 3:-mixed ration (38.6% hay + 61.4% NSC)

Sheep were fed individually during the experimental period. The experimental feeds were offered twice a day in two equal portions at 08:00 and 16:00 hours. There was an adaptation period of 15 days to the experimental feeds before the commencement of data collection. Water was given *ad libitum*. Feed offered and refused was measured daily using a 5 kg sensitive balance with one gram precision, and the difference between the daily total feed offered and the daily refused was considered daily feed intake on a DM basis. Experimental sheep were managed in individual pens (0.70 m × 1.70 m) with a concrete floor, a feeding trough and a watering bucket. The pens were disinfected before moving animals in and then cleaned daily. The composition and nutrition levels of the three diets based on the NRC (2001) are shown above. The three diets were fed according to the 3 × 3 crossover design over 90 days in three periods.

Table 5. Chemical composition of ingredients and experimental feeds

Feeds	DM	OM	CP	NDF	ADF	ADL	EE	NFS*	HC*	Cel.*
	g/kg	g/kg DM								
Hay	924.3	932.0	65.9	595.0	348.8	54.7	-	-	246.2	294.1
NSC	927.0	930.9	270.5	324.1	163.6	99.7	74.6	-	160.5	63.9
S.sesban leaves	908.4	945.9	195.3	411.9	317.8	96.5	24.7	310.6	94.1	221.3
27.6 (hay:SSL):44.8NSC	921.1	931.3	193.1	428.6	234.0	82.3	45.6	260.0	194.6	151.7
38.6hay:61.4NSC	926.0	935.3	194.5	423.1	260.5	86.4	49.5	263.3	162.6	174.1

DM=dry matter; OM= organic matter; CP=crude protein; NDF= neutral detergent fiber; ADF = acid detergent fiber; ADL= acid detergent lignin; EE= Ether extract*; NFS=Non fibrous carbohydrate;HC=Hemicellulose; NSC=Noug seed cake; Cel.=Cellulose; *NFS, HC & Cel. were calculated.*

=NFC = non fibrous carbohydrate (% of DM) = 100 – (NDFn + CP + EE + ash) where NDFn = NDF.93

3.3.1.Digestibility

To determine the digestibility of the experimental diets the sheep were fitted with fecal collection bags (harness) for at least a three-day adaptation period followed by a 7-day

feces collection period, during which time the daily feed intake of each animal was recorded. Samples of feed offered, feed refused and feces were collected every day in the morning. Total feces voided in the harness were weighed daily during the collection period. After the collected feces from each animal were mixed thoroughly, 20% representative samples were taken daily and kept in a dip freezer at -20^{o}C. At the end of the collection period, each sample from each animal was thoroughly mixed, and enough samples were taken and dried at 60^{o}C in a draft oven for 72 hours to a constant weight. The apparent digestibility of DM, OM, CP, NDF, and ADF was determined using the following formula.

$$\text{Apparent DM digestibility coefficient} = \frac{\text{DMI} - \text{Fecal DM output}}{\text{DMI}} \times 100$$

$$\text{Apparent digestibility of nutrient (\%)} = \frac{\text{Nutrient intake - Fecal nutrient excreted}}{\text{Nutrient intake}} \times 100$$

3.3.2. Laboratory analysis of feeds and feces

Samples of feeds offered and refusals as well as partially dried feces were ground to pass through 1 mm sieve and oven dried at 100^{o}C for 24 hours. All feed analysis was analyzed according to procedure written under the title 3.2.3. The metabolizable energy (ME) concentration (MJ/kg DM) of the rations was estimated using the equation of (Mcdonald *et al.*, 2002) based on digestible organic matter (OM) in DM (DOMD) as:

$$\text{DOMDM} = \frac{\text{(OM intake (kg/d)) – (OM in feces (kg/d))}}{\text{DM intake (kg/d)}} \quad \text{and as:}$$

$$\text{ME (MJ/kg DM)} = 0.016 \times \text{DOMD (g/kg DM)}$$

3.3.3. Estimating enteric methane EF from the feed trial

A precise estimate of EME (enteric methane emission) would be necessary for accurate preparation of a national GHG inventory and assessment of costs and benefits of GHG mitigation from sheep. The development of EME prediction models could precisely estimate methane emissions from sheep.

When GE intake (MJ/day) was not reported in the published papers, it was estimated from DM intake, and GE concentration (MJ/kg DM) was calculated from the chemical composition of diets (Jentsch *et al.*, 2003) as follows:

GE intake (MJ/day) = DM intake (kg/day) * {[23.6 * CP (g/kg) + 39.8 * EE (g/kg) + (17.3* NFC$^{\$}$ (g/kg) + 18.9 * NDF (g/kg)]/1000}
$=NFC was calculated

Estimation of enteric methane emission for each treatment was calculated using the following equation according to (IPCC, 2006a, 2019).

$$EF = \left[\frac{GE\left(\frac{Ym}{100}\right)*365}{55.65}\right] \text{---------- (1)}$$

where:

EF = Emission factor, kg CH_4 head^{-1} year^{-1}
GEI = gross energy intake, MJ head^{-1} day^{-1}
Y_m = methane conversion factor, which is the percentage of gross energy in feed converted to methane, %
55.65 = the energy content of methane, MJ kg $^{-1}$ CH_4

Part III

3.4. Estimation of Greenhouse Gas Emissions from the Total Population of Livestock in the Study Area

3.4.1.Prediction of enteric methane emission

Enteric CH_4 emission factors for cattle, sheep and goats were estimated using the Tier 2 method and enteric methane emission factors for equine (horse, donkey and mule) Tier 1 method following the IPCC (2006) methodology or guidelines with reference to the 2019 Refinement (IPCC, 2019; Wilkes *et al.*, 2020). In the mixed crop livestock production system (MCL), cattle, sheep and goats were defined as local and indigenous breeds, which were mostly dual-purpose breeds. Input data to estimate cattle, sheep, goats, horses, donkeys and mules populations and characterize animal performance and diet by all livestock subcategory were collected from country-specific data sources through systematic searches using bibliographic references and Google Scholar or web sites.

These include research reports, official government reports, masters and doctoral theses and scientific publications (IPCC, 2019; Wilkes *et al.*, 2020). Studies were used if they were conducted on livestock species and reported parameter values related to one or more of these variables, such as population system, herd structure, mature weight, live weight (LW) weight gain, feed digestibility (DE), feed type, and the nutritional composition of the overall diets. Mixed crop-livestock systems use multipurpose cattle (indigenous breeds), sheep and goats. The main data sources for cattle, sheep, goats, horses, donkeys and mules populations in MCL systems were the annual livestock sample survey reports of Ethiopia's Central Statistical Agency (CSA).

The IPCC, (2006, 2019) and Wilkes *et al.* (2020) recommends that cattle, sheep and goats populations classified as shown in Table 5 below. Depending on the level of detail in the emission estimation method, subcategories could be further classified based on animal or feed characteristics. The classification in the present study reflected livestock into dual-purpose, production system and animal characteristics (age, sex).

A comprehensive literature review was undertaken to estimate the live weight (LW) of each subcategory in each species. The available data on LW, weight gain and mature weight for each subcategory were found from the report (Wilkes *et al.*, 2020) and some studies conducted over several years on these breeds. For adult cattle, mature sheep and mature goats, no report of weight gain was identified, and consistent with the IPCC (2006) guidelines, weight gain for adult cattle, mature sheep and mature goats was assumed to be zero. The assumptions and methodological approach used to estimate LW and weight gain in cattle, sheep and goats were taken from reported by (Wilkes *et al.*, 2020) in Ethiopia.

The proportions of dual-purpose cows, ewes and does giving birth (calving, lambing and kidding rate respectively) in MCL were estimated using CSA data on the number of total calves, lambs and kids born and the number of cows, ewes and does in milk in the reference year (CSA, 2021). The proportions of cows, ewes and does giving birth (P) were estimated by using the report of (Wilkes *et al.*, 2020).

P= (total number of calves (dead + CSA-reported)/ number of cows in milk) *100

P= (total number of lambs (dead + CSA-reported) / number of breeding ewes) *100

P= (total number of kids (dead + CSA-reported)/ number of breeding does) *100

Where dead calves, lambs and kids were estimated using calf, lamb and kid mortality rates of 21.3%, 26.9% and 21.2%, respectively, reported in the MCL production systems (Fentie *et al.*, 2016; Getahun Legesse, 2008).

Table 6. Cattle, sheep and goats subcategories in MCL in the study area

Production system	Species	Animal subcategory
Mixed crop livestock production system	cattle	Adult multipurpose cows >3 years
		Adult males used for draught (>3-10 years)
		Adult males used for breeding & other purpose (>3-10 years)
		Calves < 6 months (male & female)
		Calves 6 m–<1 year (male & female)
		Growing males 1–<3 years
		Growing females1-<3 years
	Sheep	Breeding ewes (>2 years)
		Mature male (>2years)
		Female (1-2 years)
		Male (1-2 years)
		Intact male lambs (<1 year)
		Female lambs (<1 year)
	Goats	Adult does (>2 years)
		Bucks (>2 years)
		Yearling (1-2 years)
		Kids (males & females, <1 year)

Sources (Wilkes *et al.*, 2020)

The number of cows in milk was taken from the CSA annual surveys. For cattle, the average daily milk yield in the MCL system was obtained from CSA surveys (CSA, 2020/21). The CSA survey reported daily milk yield was converted to annual average daily milk production (average over 365 days) by multiplying the reported daily milk yield by the average lactation length of milking cows (248 days) taken from published literature(Wilkes *et al.*, 2020), and by the proportion of cows giving birth. This average daily milk yield in liters was converted to kg using a standard conversion of 1.031 kg per liter. Since the CSA daily milk did not consider the portion suckled by calves, calf milk consumption was estimated according to (NRC, 2001) and added to the adjusted CSA estimate. The average daily milk off-take thus calculated does not take into account the milk suckled by calves. Calf milk consumption can be estimated following the methods and assumptions described by NRC (2001, Table 10-1). NRC (2001) estimates energy requirements of calves based on metabolizable energy for maintenance and growth: Metabolizable energy (Mcal) = $(0.1*(LW^{0.75})) + (((0.84*(LW^{0.355}))* (LWG^{1.2})))$ where LW is average live weight of a calf between birth and weaning, and LWG is calf live weight gain before weaning (kg day-1). The resulting daily milk yields in the MCL system are presented in supplementary Table A3.2c reported by (Wilkes *et al.*, 2020) were 0.96 kg/head/day for cows. A default value of 4% was used (IPCC, 2006a) for milk fat content for all cows.

Only male cattle in the MCL system are commonly used for draught power. Limited information was available on the number of hours of work per calendar day in Ethiopia. The Holeta Agricultural Research Centre reported in (Wilkes *et al.*, 2020) an estimate of 1.28 hours per calendar day based on the assumption that oxen plow for two months of the year (not including Sundays) and six hours per day, making an annual daily average of 0.85 hours, and thresh for one month (not including Sundays) and six hours per day, making an annual daily average of 0.43 hours.

The diet composition for cattle, sheep and goats in the MCL system was incurred or obtained from CSA(CSA, 2021) annual sample surveys and surveys collected from the study area. The survey collected from the studied area and CSA data on livestock feed utilization was obtained by asking farmers to estimate the proportions of feed

components in the total feed, which were grouped into six categories: natural pastures (grazing and browsing), crop residues, improved feed, hay, agro-industrial byproducts and other non-conventional feeds (CSA, 2020). The chemical composition and nutritive values of feedstuffs, including digestible energy (DE) and metabolizable energy (ME), were taken from chemical compositions analyzed from collected data and the national feed database (Bediye *et al.*, 2007). Gross energy was calculated using (IPCC, 2006a, 2019) equations (2) listed below for each cattle, sheep and goats subcategories in each species production system (Table 5 above). Feed energy digestibility as a percentage of gross energy values of each feedstuff was estimated using the following equations from (CSIRO, 2007):

Feed energy digestibility (DE, %) = digestible energy (DE, MJ)/18.4

DE (MJ) = metabolizable energy (ME, MJ)/0.81

The DE (%) value of each feed component was calculated as the average of each feedstuff DE value from the collected data and EIAR database. For crop residues, the DE values were calculated from the eight major cereals and pulse crops (teff, barley, wheat, pea, bean, maize, sorghum and oats), which are considered available as crop residues for livestock feed. The DE value of crop residues was calculated according to the description of (Wilkes *et al.*, 2020).

3.4.2. Estimation of gross energy intake from livestock subcategories

Average GE intake was estimated from net energy requirement for maintenance, activity, work, lactation, pregnancy, and net energy for growth for young animals using IPCC tier-2 methodology using the (IPCC, 2006a, 2019). The equation (2) below used to estimate gross energy intake (GE) is as follows:

$$GE = \left[\frac{\left(\frac{NEm+NEa+NEl+NEwork+NEp}{REM}\right)+\left(\frac{NEg}{REG}\right)}{DE} \right] \text{---------- (2)}$$

where:

GE = gross energy, MJ day^{-1}

NE_m = net energy needed by the animal for maintenance, MJ day^{-1}

NE_a = net energy for animal activity, MJ day^{-1}

NE_l = net energy for lactation, MJ day^{-1}

NE_{work} = net energy for work, MJ day^{-1}

NE_p = net energy needed for pregnancy, MJ day^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy

NE_g = net energy needed for growth, MJ day^{-1}

REG = ratio of net energy available for growth in a diet to digestible energy consumed

DE = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy)

Table 7. The formula used to estimate different forms of net energy used by the animal

S.N.	Type of energy required	Model used to estimate the needed energy
1	Net energy for maintenance	$NE_m = Cfi * (weight)^{0.75}$
2	Net energy for activity	$NE_a = C_a * NE_m$
3	Net energy for activity (sheep and goats)	$NE_a = C_a * (weight)$
4	Cattle Net energy for growth	$NE_g = 22.02 * (BW/C.MW)^{0.75} * WG^{1.097}$
5	Net energy for work	$NE_w = 0.1 * NE_m *$ working hours
6	Cattle net energy for lactation	Nel= Milk *(1.47+0.40*Fat)
7	Net energy for pregnancy	$NE_p = C_{pregnancy} * NE_m$
8	Net energy for growth (sheep and goats)	$Ne_g=[WG_{lambs/kids}*(a+0.5b(BW_i+BW_f))]/365$
9	Sheep and goats net energy for lactation	$NE_l= [(5 *Wg_{wean})/365]*Ev_{milk}$
		(EV_{milk}=4.6 MJ/kg (sheep), 3 MJ/kg (goats)
10	REM	$REM = [1.123 – (4.092 * 10^{-3} * DE) + (1.126* 10^{-5} * (DE)^2))-(25.4/DE)]$
11	REG	$REG=[1.164-(5.16*10^{-3}*DE)+(1.308*10^{-5} * (DE)^2)-(37.4/DE)]$

REM=ratio of net energy available in a diet for maintenance to digestible energy consumed; DE%=digestible energy expressed as a percentage of gross energy; REG=ratio of net energy available for growth in a diet to digestible energy consumed; BW=the average live body weight of the animals in the population (kg); MW = the mature body weight of an adult animal individually, mature females, mature males and steers) in moderate body condition4 , kg; WG=the average daily weight gains of the animals in the population (kg day^{-1}); EV_{milk} = the net energy needed to produce 1 kg of milk; $WG_{lamb/kid}$ = the weight gain (BWf – BWi), kg yr^{-1}; BW_i = the live bodyweight at weaning, kg; BW_f = the live bodyweight at 1-year old or at slaughter (live-weight) if slaughtered prior to 1 year of age, kg; a, b = constants as described in Table 10.6. (IPCC, 2019); WG_{mean} = the weight gain of the lamb between birth and weaning, kg; Cf_i=a coefficient which varies for each animal category (MJ day^{-1} kg^{-1});Ca = coefficient corresponding to animal's feeding situation (MJ day^{-1} kg^{-1})

Source: (IPCC, 2006a, 2019)

3.4.3.Estimating enteric methane emission factors from livestock subcategories

Enteric methane emission factors were estimated for each cattle, sheep and goats subcategory in each production system using the (IPCC, 2006a, 2019) equation (1) above.

The value for Y_m was the IPCC default of 6.5% (IPCC, 2019) for cattle greater than one year old, and for calves younger than 6 months and calves between 6 months and 1 year old 3.3% were used as a methane conversion factor. The value for sheep and goats Y_m were used from the IPCC default of 6.7% and 5.5% respectively (IPCC, 2019).

3.4.4.Prediction of methane emissions from animal manure

Manure management emissions from livestock were from the anaerobic decomposition of organic material in the manure in the report of IPCC (2006). These conditions occur mostly when large numbers of animals are managed in a confined area, and where manure is disposed of in liquid-based systems. In this study, approximately 4 manure management practices in smallholder production systems in central highlands were identified during survey work. The majority of manure produced was handled as pasture/range, burn, sold and daily spread sourced from (Wilkes *et al.*, 2020). The IPCC (2019) Tier 2 approach was used for calculations of cattle, sheep and goats. The IPCC (2019) Tier 1 approach was used to calculate the rest of the livestock species as reported by (IPCC, 2006, 2019; Wilkes *et al.*, 2020).

These manure management systems may be associated with different housing types (e.g., traditional or improved kraals and zero-grazing units), but this association is currently not well documented. Specific manure management practices have also not been documented in detail in Ethiopia, in (Wilkes *et al.*, 2020) describes the data sources and assumptions used to estimate the proportion of manure managed in different manure management systems.

The emission factors for manure management were calculated using the IPCC Tier 2 methodology using IPCC (2006) Equation (3) below:

$$EF_{(T)} = \left(VS_{(T)} * 365\right) * \left[B_{0_{(T)}} * \frac{0.67kg}{m^3} * \sum_{sk} \frac{MCF_{s,k}}{100} * MS_{T,S,K}\right] \text{---------- (3)}$$

where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category *T*, kg CH_4 animal^{-1} yr^{-1}

$VS_{(T)}$ = daily volatile solid excreted for livestock category *T*, kg dry matter animal^{-1} day^{-1}

365 = basis for calculating annual VS production, days yr^{-1}

$B_{0\,(T)}$ = maximum methane producing capacity for manure produced by livestock category *T*, m^3 CH_4 kg^{-1} of VS excreted

0.67 = conversion factor of m^3 CH_4 to kilograms CH_4

$MCF_{(S,k)}$ = methane conversion factors for each manure management system *S* by climate region *k*, %

$MS_{(T,S,k)}$ = fraction of livestock category *T*'s manure handled using management system *S* in climate region *k*, dimensionless

Ethiopia has no specific data identified for Bo or MCF. For Bo, the IPCC (2019) default value of 0.13 for all other cattle, sheep and goats (IPCC 2019, Table 10.16). For MCF values, the IPCC default values (IPCC 2019, Table 10.17) were used, assuming a tropical montane climate for the mixed crop-livestock systems.

The value of VS is estimated using IPCC (2006) Equation (4):

$$VS = \left[GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)\right] * \left[\left(\frac{1-ASH}{18.45}\right)\right] \text{---------- (4)}$$

where:

GE is gross energy intake, MJ day^{-1}, as calculated in the enteric fermentation equations above

DE% is digestibility of feed as used in the enteric fermentation equations above

UE X GE is urinary energy expressed as a fraction of GE (IPCC default value of 0.04). There are no country-specific values available in Ethiopia.

ASH is the ash content of manure, calculated as a fraction of the dry matter feed intake (default IPCC value of 0.08 for livestock). There are no country-specific values available in Ethiopia.

18.45 is the conversion factor for dietary GE per kg dry matter (MJ kg^{-1}).

3.4.5. Direct nitrous oxide emissions from manure management

Manure also releases nitrous oxide at different rates for different manure management systems. This section only covers the nitrous oxide released during the storage and treatment of manure before it is applied to the land or used elsewhere. Therefore, this section does not include the nitrous emissions from manure deposited directly on pasture. Emission factors for direct N_2O emissions were calculated using the IPCC Tier 2 approach by applying IPCC (2006) Equation (5):

$$N_2O_{D\,(MM)} = \left[\sum_S \left[\sum_T \left(\left(N_{(T)} * Nex_{(T)}\right) * MS_{(T,S)}\right)\right] * EF_{3(S)}\right] * \frac{44}{28} \text{---------- (5)}$$

where:

$N_2O_{D\,(mm)}$ = direct N_2O emissions from manure management in the study area, kg N_2O yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the study area

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the study area in kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the study area, dimensionless

$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system *S* in the study area, kg N_2O-N/kg N in manure management system *S*

S = manure management system

T = species/category of livestock

44/28 = conversion of N_2O-N (mm) emissions to N_2O (mm) emissions

N excretion was estimated as the balance of N intake and N retention calculated using IPCC (2019) Equations (6) as shown below. The data sources and values used for crude protein content of the diet (CP%) were from feed analyzed in (Wilkes *et al.,* 2020). Default values for milk protein content (milk PR %) were used (3.5% taken from IPCC 2006. Other values used in these calculations (i.e., GE, milk, WG, NEg) were the values used in the calculation of methane emissions from enteric fermentation. Manure management system activity data are the same as those used to estimate methane manure

management emissions taken from (Wilkes *et al.*, 2020). The emission factors, EF_3 were from the IPCC default emission factors from IPCC (2019).

Similar to cattle, direct N_2 O emissions from manure management for sheep and goats were estimated using IPCC (2006). Annual N excretion rates, option 1 (tier 2) for sheep and goats were calculated as equation (6) below:

$$Nex_{(T)} = \left(N_{intake\ (T)} * (1 - N_{retention\_frac\ (T)}\right) * 365 \text{---------- (6)}$$

where:

$Nex_{(T)}$ = annual N excretion rates, kg N animal^{-1} yr^{-1}

$N_{intake\ (T)}$ = the daily N intake per head of animal of species/category T, kg N animal^{-1} day^{-1}

$N_{retention\_frac(T)}$ = fraction of daily N intake that is retained by animals of species/category T, dimensionless (where, $N_{retention\_frac(T)}$ = 0.1 kg N animal^{-1} day^{-1}) (IPCC, 2019.

365 = Number of days in a year.

Annual N excretion rates, option 2 (tier 2) for cattle were calculated as equation (7) below:

$$Nex_{(T)} = \left(N_{intake\ (T)} - N_{retention\ (T)}\right) * 365 \text{---------- (7)}$$

where:

$Nex_{(T)}$ = annual N excretion rates, kg N animal^{-1} yr^{-1}

$N_{intake\ (T)}$ = the annual N intake per head of animal of species/category *T*, kg N animal^{-1} day^{-1}

$N_{retention\ (T)}$ = fraction of daily N intake that is retained by animal of species/category *T*

365 = Number of days in a year.

The amount of nitrogen excreted by cattle, sheep and goats were estimated as the difference between the total nitrogen taken in by the animal and the total nitrogen retained for growth and milk production.

The daily nitrogen intake rates for cattle, sheep and goats were derived as equation (8):

$$N_{intake\ (T)} = \frac{GE}{18.45} * \left(\frac{\frac{CP\%}{100}}{6.25}\right)$$ ---------- (8)

where:

$N_{intake\ (T)}$ = daily N consumed per animal of category *T*, kg N animal^{-1} day^{-1}

GE = gross energy intake of the animal, MJ animal^{-1} day^{-1} (GE used from enteric methane calculated)

18.45 = conversion factor for dietary GE per kg of dry matter, MJ kg^{-1}. This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

CP% = percent crude protein in dry matter

6.25 = conversion from kg of dietary protein to kg of dietary N, kg feed protein (kg N)$^{-1}$

The total nitrogen retained for cattle was derived using equation (9):

$$N_{retention(T)} = \left[\frac{milk * \left(\frac{milk\ PR\%}{100}\right)}{6.38}\right] + \left[\frac{WG * \left[\frac{268 - \left(\frac{7.03 * NEg}{WG}\right)}{1000}\right]}{6.25}\right]$$ ---------- (9)

where:

N retention (T) = daily N retained per animal of category *T*, kg N animal^{-1} day^{-1}

Milk = milk production, kg animal^{-1} day^{-1}

Milk PR% = percent of protein in milk, calculated as [1.9 + 0.4 ● %Fat], where % Fat is an input, assumed to be 4%.

6.38 = conversion from milk protein to milk N, kg Protein (kg N)$^{-1}$

WG = weight gain, input for each cattle category, kg day^{-1}

268 and 7.03 = constants from Equations 3-8 in NRC (1996)

1000 = conversion from g protein to kg protein

NE_g = net energy for growth, calculated in livestock characterization, based on current weight, mature weight, rate of weight gain, and IPCC constants, MJ day^{-1}

6.25 = conversion from kg dietary protein to kg dietary N, kg Protein (kg N)$^{-1}$

3.5. Data Analysis

The data were analyzed using Statistical Packages for Social Sciences (SPSS) software packages version 22.0 (SPSS, 2013). Descriptive statistics (means, standard deviation, and percent) were used to analyze the effect of different independent variables on the dependent variables to summarize data on the agro-ecology household characteristics, landholding, livestock holding, and annual feed DM yield were analyzed using the Statistical Package for Social Sciences version 22.0 (SPSS, 2013). The collected feeding trial data (feed intake and digestibility) and estimated GHG emission data (enteric methane, methane and nitrous oxide from manure) were subjected to analysis of variance (ANOVA) using Statistical Analysis Systems 9.3 (SAS, 2002). The tests were performed at the 95% level of confidence ($\alpha = 0.05$). Tukey's' HSD and LSD (Fisher's protected least significant difference) test mean comparison procedure was used to test mean differences.

Therefore, the following models were used,

The mathematical design used for the feeding trials was a 3X3 crossover design

- ✓ Arsi-Bale feeding trial model: $Y_{ijk} = \mu + t_i + a_j + p_k + e_{ijk}$,

where

Y_{ijk}= is the dependent variable

μ =overall mean,

t_i =is the effect of i^{th} treatment (diets),

a_j =is the effect of j^{th} animal,

p_k =is the effect of the k^{th} period,

e_{ijk} =is the associated random error.

- ✓ Model for GHG emissions from livestock , $Y_{ij} = \mu + A_i + SC_j + e_{ij}$,

where

Y_{ij}=is the dependent variable (agroecology and subcategory of species)

μ= overall mean,

A_i= is the effect of i^{th} agro-ecology (lowland, midland and highland)

SC_j= the effect of j^{th} subcategory species of livestock

e_{ij}=is the associated random error.

4. RESULTS

4.1. **Socioeconomic Characteristics of the Respondents**

4.1.1. Demographic characteristics of the households

Table 8 presents the demographic characteristics of the study area sample units. The mean age of respondents and farm experience were significantly (P<0.001) different between highland and midland agro-ecologies and lowland agro-ecology. The total family size per HH and productive age of the respondent were not significantly different (P<0.05) for all agro-ecology.

Table 8. Respondents of household characteristics in the study area

Description of variables	Agro-ecology			Overall	P
	Lowland (30)	Midland (60)	Highland (60)	mean (150)	Value
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	
Household total family size	6.0(0.4)	6.33(0.3)	5.6(0.2)	5.97(0.2)	0.213
Respondent age (years)	36.3(1.8)[b]	43.67(1.8)[a]	47.2(1.4)[a]	43.6(1)	0.0001
Productive age (15-64) (years)	4.29(0.4)	4.17(0.3)	4.02(0.2)	4.13(0.2)	0.81
Unproductive (<15&>64)(years)	2.22(0.3)	2.48(0.2)	2.07(0.1)	2.27(0.1)	0.305
Farm experience (years)	16.8(1.8)[b]	24.8(1.7)[a]	27.78(1.5)[a]	24.4(1)	0.0001

ab= means within the same row with different superscripts are significantly different

Respondents of the educational level showed a significant (P<0.01) relationship in the agro-ecology of the households. Household family size levels showed a significant (P<0.01) relationship with the agro-ecology of the households (Table 9.)

Table 9. Households' educational level and family size in the three agro-ecologies of the study area

Description of variables	Agro-ecology			Overall mean (150)	X^2 value	P Value
	Lowland (30)	Midland (60)	Highland (60)			
Respondent education level					26.3	0.001
Illiterate	4(13.3)	2(3.3)	3(5)	9(6)		
Read and write	11(36.7)	7(11.7)	5(8.3)	23(15.3)		
Primary (1-6)	1(3.3)	8(13.8)	14(23.3)	23(15.3)		
Secondary (7- 10)	9(30)	33(55)	34(56.7)	76(50.7)		
Preparatory & above	5(16.7)	10(16.7)	4(6.7)	19(12.7)		
Level of family size					10.4	0.034
≤5 family member	12(40)	30(50)	32(53.3)	74(49.3)		
6-9 family member	16(53.3)	19(31.7)	26(43.3)	61(40.7)		
>9 family member	2(6.7)	11(18.3)	2(3.3)	15(10)		

Numbers outside and inside parentheses are observed counts and percentages, respectively.

4.1.2. Household resource holding and utilization

Table 10 presents different types of land owned and utilization patterns of the different agro ecological HHs in the study area. The average land allotted for crop cultivation, fallow land, private forestland and forage land were significantly ($P<0.05$) different between the agro-ecologies of the study area, while the area of fallow land was significantly different ($P<0.05$) between the lowland and the rest of the agro-ecology. The study revealed that a major portion of the land (80.97%, 88.44% and 82.08%) were allocated for crop cultivation of highland, midland and lowland, respectively, looking at how much of the land was utilized for cultivation compared to grazing land.

In terms of cropping pattern, wheat and barley were significantly different ($P<0.001$) between midland and the rest of agro-ecologies. Teff was significantly different ($P<0.05$) between midland and the rest of the agro-ecologies, while there was no significant different ($P<0.05$) between the agro-ecologies for oats, maize, sorghum, pulse, oil and vegetable crops.

Table 11 depicts the mean livestock categories and herd structures in the TLU of the HHs. The mean total cattle and cow were significantly ($P<0.001$) different between the highland and lowland; nevertheless, there was no difference between the midland. The

mean total number of goats, mature goats and yearlings were significantly (P<0.01) different between the lowland and highland.

Table 10. Household landholding, land use types and cropping pattern (ha/HH) in the study area

Description of variables	Agro-ecology			Overall	P
	Lowland (30) Mean (SE)	Midland (60) Mean (SE)	Highland (60) Mean (SE)	mean (150) Mean (SE)	Value
Land use type					
Grazing land	0.98(0.2)	0.67(0.1)	0.84(0.2)	0.8(0.1)	0.391
Cropland	2.2(0.2)^{ab}	2.7(0.2)^{a}	2.1(0.2)^{b}	2.3(0.1)	0.021
Fallow land	0.17(0.04)^{b}	0.68(0.2)^{a}	0.12(0.02)^{b}	0.28(0.07)	0.003
Private forestland	0.02(0.0)	0.05(0.0)	0.17(0.03)	0.12(0.03)	0.026
Forage crops land	0.05(0.0)	0.09(0.0)	0.12(0.01)	0.1 (0.0)	0.033
Rented in/out cropland	0.32(0.04)	0.36(0.05)	0.41(0.04)	0.38(0.03)	0.451
Total land holding	3.74(0.3)	4.55(0.3)	3.76(0.3)	3.98(.2)	0.54
Cropping pattern					
Wheat	0.69(0.1)^{b}	1.27(0.1)^{a}	0.85(0.1)^{b}	0.94(0.05)	0.0001
Barley	-	0.61(0.06)^{b}	1.14(0.1)^{a}	0.92(0.07)	0.000
Teff	0.62(0.09)^{b}	0.94(0.09)^{a}	0.4(0.08)^{b}	0.65(0.06)	0.003
Oats	-	0.1(0.01)	0.11(0.0)	0.11(0.0)	0.487
Maize	0.55(0.06)	0.45(0.04)	0.24(0.07)	0.41(0.03)	0.117
Sorghum	0.52(0.06)	0.47(0.04)	-	0.51(0.05)	0.67
Pulse crops	0.27(0.0)	0.34(0.04)	0.45(0.04)	0.41(0.03)	0.226
Oil crops	0.06(0.01)	0.1 (0.02)	0.08(0.0)	0.08(0.0)	0.424
Vegetable crops	-	0.13(0.03)	0.16(0.05)	0.15(0.02)	0.119

ab= means within the same row with different superscripts are significantly different

The mean equine TLU holding was significantly (P<0.001) different between highland and lowland HHs but not between midland HHs; similar poultry was significantly (P<0.05) different between lowland and highland HHs. Of the total livestock owned in the agro-ecology area, on average cattle accounted for 68.9% at the HH level. Within the cattle herd structure, an ox (44.5%) was the largest, followed by cows (37.3%) across the agro-ecologies area.

Table 11. Household level livestock subcategories and herd structure (TLU) in the mixed crop livestock production area of the Arsi zone

Livestock category	Herd structure	Agro-ecology			Overall	P
		Lowland (30) Mean (SE)	Midland (60) Mean (SE)	Highland (60) Mean (SE)	mean (150) Mean (SE)	Value
Cattle	Total	7.91(0.4)[b]	7.54(0.2)[b]	9.13(0.5)[a]	8.22(0.2)	0.001
	Cow	2.56(0.1)[b]	2.29(0.09)[b]	3.4(0.3)[a]	2.79(0.1)	0.0001
	Ox	3.1(0.3)	3.2(0.2)	3.6(0.2)	3.3(0.1)	0.17
	Heifer	0.95(0.06)	0.93(0.06)	1.0(0.09)	0.97(0.04)	0.707
	Steer	0.88(0.1)	0.75(0.1)	0.7(0.05)	0.76(0.04)	0.255
	Calves	0.42(0.03)	0.37(0.02)	0.43(0.03)	0.4(0.02)	0.197
Sheep	Total	0.81(0.06)	0.77(0.05)	0.93(0.07)	0.85(0.04)	0.241
	Mature	0.46(0.04)	0.38(0.03)	0.45(0.04)	0.43(0.02)	0.312
	Yearling	0.35(0.03)	0.39(0.03)	0.48(0.04)	0.42(0.02)	0.056
Goat	Total	1.42(0.1)[a]	0.98(0.2)[ab]	0.45(0.05)[b]	0.96(0.1)	0.004
	Mature	0.67(0.07)[a]	0.47(0.08)[ab]	0.26(0.02)[b]	0.47(0.05)	0.004
	Yearling	0.75(0.08)[a]	0.51(0.1)[ab]	0.19(0.03)[b]	0.49(0.07)	0.009
Equine	Total	2.33(0.1)[b]	2.66(0.1)[ab]	2.88(0.2)[a]	2.78(0.1)	0.001
	Horse	0.8(0.0)	1.09(0.2)	1.38(0.1)	1.24(0.09)	0.074
	Donkey	0.83(0.2)	0.8(0.1)	0.61(0.04)	0.72(0.05)	0.135
	Mules	0.7(0.0)	0.77(0.05)	0.89(0.07)	0.82(0.04)	0.215
Poultry	Chicken	0.18(0.02)[a]	0.15(0.02)[ab]	0.11(0.01)[b]	0.15(0.0)	0.016

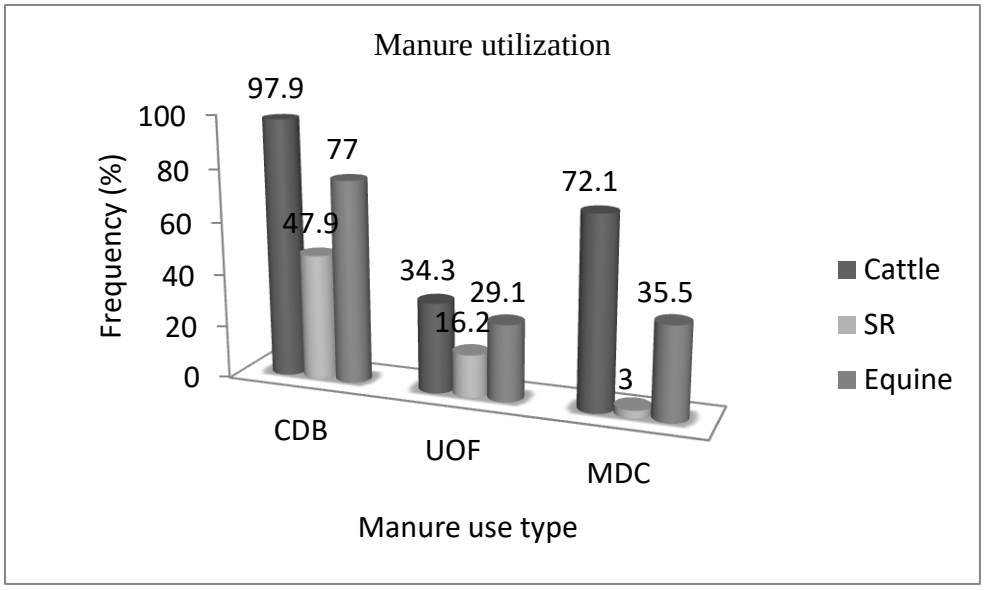
ab= means within the same row with different superscripts are significantly different

4.2. **Manure Utilization**

Homestead manure management was collected, store and distributed the place they wanted. The collecting system picks the animal manure drops from the place where the animal drops them (more often kraal), and family houses and gardens at night can be used either for dung cake (fuel) and/or organic fertilizer (Figure 2; Appendix Figure 1). The numbers of cattle manure collected was 97.9%, while that of equine manure was 77%. However, there were differences in that of manure made into dung cake from cattle (72.1 %) and equines (35.5%). Manure collected from different species of livestock (cattle, goats, sheep and equines) was 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 was rarely used for dung cake. Refused forages and bedding materials, which are hardly available, were deliberately mixed with manure during storage and preparation of dung cakes (see Appendix Figure 1).

The manure used for organic fertilizer from cattle (34.3%), equines (29.1%) and small ruminants (16.2%) was shown in Figure 2. Generally, a sizable proportion of farmers used manure as organic fertilizer at least in their backyard and farm plots near the 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 to the field by direct spreading as it was collected or stored and after processing into compost.



CDB = Collected on daily basis; UOF = Use as organic fertilizer; MDC= Made into dung cake; SR= Small ruminants

Figure 2. Manure collection and utilization type at the household level in the MCL areas of the Arsi zone

4.3. **Livestock Feed Resources and Nutrient Contents**

4.3.1.Major feed categories and their biomass yield

The feed resource potential biomass DM yields from the land use types are summarized and indicated in (Table 12) below. Communal grazing land and stover crop DM yields were highly significantly higher (P<0.001) for the lowlands agro-ecology, while unconventional feed DM yields were significantly (P<0.01) different between the highland and other agro-ecologies. Similarly, fallow land DM yield was significantly (P<0.01) different between midland and the other agro-ecologies. The cereals straw DM yield was significantly (P<0.01) different between highland and midland agro-ecologies, and lowland agro-ecology. Road-side grazing DM yield was higher (P<0.05) for highland and lowland compared to midland agro-ecologies. Similarly forage land DM yield were higher (P<0.05) for highland and midland agro-ecologies than for lowland agro-ecology. In general, cereal straw accounted for the majority of the annual DM yield, whereas the amount of unconventional feeds available on the HHs feed supply was very low compared to that of the other poor-quality roughage feeds.

Table 12. Households' major feed resources and annual dry matter yield (tons) in the mixed crop livestock production area of the Arsi zone.

Feed Resources	Agro-ecology			Overall			
Categories	Lowland (30) Mean (SE)	Midland (60) Mean (SE)	Highland (60) Mean (SE)	mean (150) Mean (SE)	P Value	Total DM	% DM
Communal grazing	1.65(0.3)[a]	0.23(0.05)[b]	0.51(0.08)[b]	0.75 (0.1)	0.000		
Private grazing	0.38 (0.2)	1.12 (0.1)	1.06 (0.2)	1.04 (0.1)	0.35	7.66	11.48
Road side grazing	0.26 (0.06)[ab]	0.21(0.04)[b]	0.52 (0.1)[ab]	0.36 (0.05)	0.025		
Fallow land	0.31 (0.06)[b]	1.21(0.4)[a]	0.2 (0.04)[b]	0.48 (0.1)	0.002		
Cereals straws	5.14 (1)[b]	16.79 (1.7)[a]	21.74 (4.2)[a]	16.52 (1.9)	0.006	43.67	65.45
Stovers crops	5.14 (0.8)[a]	2.32 (0.3)[b]	1.48 (0.4)[b]	3.27 (0.4)	0.000	8.94	13.4
Pulse haulms	0.57 (0.08)	0.97 (0.2)	1.29 (0.2)	1.14 (0.1)	0.265	2.83	4.24
Oil Straws	0.38 (0.1)	0.54 (0.1)	0.48 (0.06)	0.49 (0.06)	0.676	1.4	2.1
Forage crops	0.38 (0.04)[b]	0.6 (0.04)[ab]	0.82(0.1)[ab]	0.7 (0.05)	0.033	1.74	2.61
Unconventional feeds	0.07(0.02)[b]	0.12 (0.03)[b]	0.29 (0.06)[a]	0.18 (0.03)	0.005	0.48	0.72
Total	14.28	24.05	28.39	24.93		66.72	100.0

A,b= means within the same row with different superscripts are significantly different

Overall, the contribution of crop residues to agro-ecology was inclined primarily by the crops grown and overcame cropping intensity. Cooperatively, straw (cereals and oil), haulms (pulse), stovers (maize and sorghum) and natural pasture DM yields contributed 96.67% to the total HHs annual feed supply.

4.3.2. Nutritional quality of major feed resources

The chemical composition and nutritive value of the major livestock feeds in the study area are shown in Table 13. The OM content of all feeds across agro-ecologies exceeded 90%. The CP content of the mixed pasture, straws, stovers, and haulms showed that there is variation between the agro-ecologies. Wheat straw had the lowest CP compared to the remaining straws, stovers and haulms (Table 12). The relatively high NDF content of mixed pasture from lowland agro-ecology may be due to the type of plants grown (species and maturity) faster than other agro-ecologies and other prevailing factors. The NDF contents of crop stovers, crop aftermath and cereal straws were high compared to those of pulse crop haulms, which were categorized as medium-quality roughages. The ADF content of crop aftermath was high compared to cereal straws, stovers and pulse haulms. The ADL content of roughage feeds ranged from 6.24% DM (sorghum stover) to 15.2% DM (pea haulm) across all agro-ecologies (Table 12). The IVDODM from the mixed pasture and pulse haulms were better than other roughage feeds (stovers and crop aftermath) followed by the straws across the agro-ecologies. The highest IVDODM % was recorded for pea haulm from midland agro-ecology, while the lowest IVDODM% was sorghum stover from lowland agro-ecology, which might be climate change, soil fertility and inputs given in the area.

Table 13. Chemical composition of major feeds in the study area at the household level

Agro-ecology	Feed type	DM%	%DM						
			OM	Ash	CP	NDF	ADF	ADL	IVDOMD
Lowland (30)	MP	93.42	90.03	9.97	5.81	70.52	39.23	8.51	53.7
	Maize st.	93.33	90.34	9.66	3.02	77.81	49.32	8.61	48.01
	Sorghum st.	94.35	88.64	11.36	2.82	73.74	48.93	9.42	47.1
	Teff S.	93.12	90.52	9.48	4.52	75.93	49.32	10.1	50.9
	CA	94.56	90.83	9.17	3.67	79.58	57.23	11.12	41.32
Midland (60)	MP	92.51	90.21	9.79	7.91	67.23	37.31	6.73	55.7
	Wheat S.	91.12	90.42	9.58	2.13	75.83	45.32	11.92	47.7
	Barley S.	93.31	92.01	7.99	3.71	79.84	42.11	10.32	49.01
	Teff S.	91.52	92.81	7.19	5.42	79.31	43.03	8.02	53.6
	Maize st.	92.01	93.23	6.77	5.81	74.63	42.84	7.53	52.1
	Sorghum st.	94.35	90.83	9.17	4.93	71.92	42.13	6.24	51.2
	Bean H.	93.83	92.31	7.69	5.12	67.83	47.21	11.71	53.2
	Pea H.	92.12	94.72	5.28	6.72	70.13	48.12	15.2	57
	CA	93.89	91.23	8.77	3.76	79.85	55.98	11.11	42.48
Highland (60)	MP	91.62	90.42	9.58	7.44	67.41	37.21	6.83	55.5
	Wheat S.	92.33	93.21	6.79	2.61	78.04	44.02	7.81	49.1
	Barley S.	92.43	93.12	6.88	3.03	76.11	44.21	7.72	49.6
	Bean H.	92.24	94.42	5.58	5.82	65.13	43.61	13.5	55.6
	Pea H.	93.2	93.7	6.3	4.74	66.33	45.61	14.5	52.6
	CA	93.68	91.23	8.77	3.66	78.87	55.98	11.1	42.51

MP=mixed pasture; St= stover; S=straw; H= haulms; CA= crop aftermath; DM=dry matter; OM=organic matter; CP=crude protein; NDF=neutral detergent fiber; ADF=acid detergent fiber; ADL=acid detergent lignin; IVDOMD=in vitro digestible organic matter in the dry matter

Feeding Trial

4.4. **Chemical Composition of the Treatment Feeds**

The chemical composition of the experimental diets is presented in Table 5. The DM content was low in *S. sesban* but high in natural grass hay and noug seed cake. The organic matter content was high in S. sesban and low in natural grass hay and noug seed cake. The CP content was high in *S. sesban* and noug seed cake but low in natural grass hay. The NDF, ADF and cellulose contents were high in *S. sesban* leaves and natural grass hay but low in noug seed cake. In contrary, ADL and ash content was high in noug seed cake and low in *S. sesban* leaves and natural grass hay. Hemi cellulose was higher in natural grass hay than noug seed cake and *S. sesban* leaves.

4.4.1.Dry matter and nutrient intake

The total daily DM intake of treatment two was significantly (P<0.001) different between treatment one and three (Table 14), and there was highly significantly (P<0.001) difference between treatment three and one. Similarly, there was a highly significantly (P<0.001) different between treatment two and three. This may be because of ant-nutritional compounds found in the *S. sesban* leaves. The intake of DM as a percent of BW was significantly (P<0.001) different between treatment two and other treatments and also between treatment one and three. The intake of OM, NDF, ADF and ME were significantly (P<0.001) different between the treatments. However, CP intake was significantly (P<0.05) different between treatment one and the other treatments in this feeding trial. However, there was no significantly (P<0.05) different between treatments two and three.

Table 14. Daily feed and nutrient intakes of Arsi-Bale sheep fed dried *S. sesban* leaves, and mixed different percentages of hay, *S. sesban* leaves and noug seed cake.

Parameters	Treatment feeds			SEM	P-value
	T_1	T_2	T_3		
Total DM intake (g d^-)	507.6^c	706.9^a	624.0^b	43.2	<0.0001
DM intake (% BW)	1.9^c	2.7^a	2.3^b	44.3	<0.0001
OM intake (g d^-)	480.9^c	671.4^a	582.7^b	47.3	<0.0001
CP intake (g d^-)	100.5^b	109.9^a	109.9^a	7.93	<0.021
NDF intake (g d^-)	213.3^c	318.0^a	278.2^b	64.3	<0.0001
ADF intake (g d^-)	161.3^b	196.5^a	151.3^b	32.4	<0.001
ME intake (MJ/kg DM)	8.5^b	10.1^a	9.7^a	26.65	<0.001

Means followed by different superscript letters within a row for each treatment feed are significantly different at P < 0.05; SEM = standard error of means; SSL; S. sesban leaf; Noug seed cake; DM =Dry matter; OM=Organic matter; CP = Crude protein; NDF= Neutral detergent fiber; ADF =Acid detergent fiber; ME= Metabolizable energy T_1 = S. sesban leaf; T_2 = 27.6% (hay: SSL): 44.8%NSC; T_3 = 38.6%hay: 61.4%NSC.

4.4.2. Dry matter and nutrient digestibility

The DM and OM digestibility were significantly (P<0.01) different between T_2 and T_1. Similarly, the digestibility of DM and OM was not significantly (P>0.05) different between T_1 and T_3, and between T_2 and T_3 (Table 15). The digestibility of CP was significantly (P<.01) different between T_2 and T_3 compared to T_1. Likewise, the

digestibility of CP was not significantly (P>0.05) different between T_2 and T_3. The digestibility of NDF was significantly (P<.05) different between T_2 and T_3 compared to T_1. Likewise, the digestibility of NDF was not significantly (P>0.05) different between T_2 and T_3.

Table 15. Dry matter and nutrient digestibility of Arsi-Bale sheep fed dried *S. sesban* leaves, and mixed different percentages of hay, *S. sesban* leaves and noug seed cake.

Digestibility (%)	Treatments			SEM	P-value
	T_1	T_2	T_3		
DM	61.3^{b}	78.6^{a}	70.3^{ab}	12.2	<0.008
OM	60.7^{b}	77.9^{a}	70.0^{ab}	11.8	<0.008
CP	72.3^{b}	84.0^{a}	79.9^{a}	12.2	<0.008
NDF	57.2^{b}	70.1^{a}	68.9^{a}	6.7	<0.029
ADF	51.0	65.6	63.8	5.2	<0.048

Means followed by different superscript letters within a row for each feed type are significantly different at P < 0.05; SEM = standard error of means; DM =Dry matter; OM=Organic matter; CP = Crude Protein; NDF= Neutral detergent fiber; ADF =Acid detergent fiber SSL= S. sesban leaf; NSC= Noug seed cake; T_1 = S. sesban leaf; T_2 = 27.6% (hay: SSL): 44.8% NSC; T_3 = 38.6% hay: 61.4% NSC.

4.4.3.Estimation of enteric methane emissions from feed trials

Table 16 presents enteric CH_4 emission factors and daily methane production of Arsi-Bale sheep fed different feed treatments in the study area. The GE, EF and DMP were significantly (P<0.001) different between the treatments. Treatment three was emitted more methane than treatment two and one and treatment one was the least emitter from the rest treatments. This is may be due to anti-nutritional factors contained in *S. sesban*.

Table 16. Gross energy intake and enteric methane emission factors for sheep fed dried *S. sesban* leaves, and mixed different percentages of hay, *S. sesban* leaves and noug seed cake.

Parameters	Treatments			Over all mean	SEM	P_value
	T_1	T_2	T_3			
GEI (MJ/day)	9.29^{c}	11.15^{b}	12.94^{a}	11.12	188.46	0.0001
EF (kg $CH_4 head^{-1} year^{-1}$)	3.96^{c}	4.75^{b}	5.495^{a}	4.73	192.72	0.0001
DMP (g $CH_4 head^{-1} day^{-1}$)	10.5^{c}	12.9^{b}	14.63^{a}	12.685	43.2	0.0001

Means followed by different superscript letters within a row for each parameters are significantly different at P < 0.01; SEM = standard error of means; DMP=Daily methane production; EF= Emission factor; GEI= Gross energy intake; T_1 = S. sesban leaf; T_2 = 27.6 %(hay: S. sesban leaf): 44.8% Noug seed cake; T_3 = 38.6 %hay: 61.4% Noug seed cake.

4.5. Estimated livestock GHG emission

4.5.1.Prediction of enteric methane emission

The enteric methane emission estimate of the cattle categories is given in Table 17. The estimated enteric methane EF of different age groups of cattle was significantly (P<0.001) different between the cattle subcategories. This may be due to the body size of the cattle. Similarly, the estimated enteric CH_4 EF of cattle was significantly (P<0.001) different between the lowland agro-ecology and other agro-ecologies, and there was no significant (P>0.05) difference between the midland and highland agro-ecologies. This may be due to the lower digestibility of feed in the lowland area than in the mid and high land areas because the feed in the lowland area grew quickly and was lignified early.

Table 17. Enteric methane emission factor of cattle under each subcategory and agro-ecology in the study area, (kg CH_4 $head^{-1}$ $year^{-1}$).

	Cattle subcategories	Agro-ecologies			Means	F value	Sig.
		Low land	Mid land	High land			
Cattle	Adult multipurpose cows >3 years	57.7^{bA}	56.6^{bB}	56.6^{bB}	57.0	26.83	<.0001
	Adult males used for draught (3-10 years)	57.1^{cA}	56.0^{cB}	56.0^{cB}	56.4		
	Adult males used for breeding & other purpose (>3-10 years)	61.9^{aA}	60.7^{aB}	60.7^{aB}	61.1		
	Growing females 1-<3 years	41.4^{eA}	40.5^{eB}	40.4^{eB}	40.8		
	Growing males 1–<3 years	53.9^{dA}	52.7^{dB}	52.7^{dB}	53.1		
	Calves < 6 months (male & female)	5.3^{gA}	5.2^{gB}	5.2^{gB}	5.2		
	Calves 6 m–<1 year (male & female)	14.8^{fA}	14.4^{fB}	14.4^{fB}	14.6		
	Means	41.7	40.9	40.9	41.2		
	F-value	24350.4					
	Sig.	<.0001					

a, b, c,d,e,f Means with different superscripts in a column are significantly different. A, B, C means with different superscripts in a row are significantly different

The enteric methane emission estimate of the sheep categories is given in Table 18. The estimated enteric CH_4 EFs of different age groups of sheep were significantly (P<0.001) different between the sheep subcategories. This may be due to the body size of the sheep. In addition, the enteric EFs of sheep were significantly (P<0.001) different between agro-ecologies. This may be due to the lower digestibility of feed in the lowland area than in the midland and highland areas because the feed in the lowland area matured early.

Table 18. Enteric methane emission factor of sheep and goats under each subcategory and agro-ecology in the study area, (kg CH_4 $head^{-1}$ $year^{-1}$).

Species	Sheep and goats subcategories	Agro-ecologies			Means	F-value	Sig.
		Lowland	Midland	Highland			
Sheep	Breeding ewes (>2 years)	6.8^{aA}	6.7^{aB}	6.6^{aC}	6.7	93.37	<.0001
	Mature male (>2years)	6.1^{dA}	$6.0d^{bB}$	5.9^{dC}	6.0		
	Female (1-2 years)	6.2^{cA}	6.1^{cB}	6.0^{cC}	6.1		
	Male (1-2 years)	6.4^{bA}	6.3^{bB}	6.2^{bC}	6.3		
	Intact male lambs (<1 year)	3.4^{eA}	3.3^{eB}	3.2^{eb}	3.3		
	Female lambs (<1 year)	3.1^{fA}	3.0^{fB}	2.9^{fC}	3.0		
	Means	5.3	5.2	5.1	5.2		
	F-value	14499.6					
	Sig.	<.0001					
Goats	Adult does (2+ years)	7.0^{aA}	6.9^{aB}	6.8^{aC}	6.9	32.3	<.0006
	Bucks (>2 years)	6.6^{bA}	6.5^{bB}	6.3^{bC}	6.5		
	Yearling (1-2 years)	6.6^{bA}	6.5^{bB}	6.3^{bC}	6.5		
	Kids (males & females, <1 year)	2.63^{cA}	2.587^{cB}	2.5^{cC}	2.6		
	Means	5.7	5.6	5.5	5.6		
	F-value	10880.6					
	Sig.	0.0001					

a, b, c,d,e,f Means with different superscripts in a column are significantly different. A, B, C means with different superscripts in a row are significantly different

The enteric methane emission estimate of the goat categories is given in Table 18.

As the estimated enteric CH_4 FE of different age groups of goats was significantly ($P<0.001$) different between the goat subcategories, but there was no significant ($P>0.05$) difference between bucks and yearlings. This may be due to the body size difference of the goats. Furthermore, the enteric CH_4 EF of goats was significantly ($P<0.001$) different between agro-ecologies. This may be due to the lower digestibility of feed in the lowland area than in the midland and highland areas because the feed in the lowland area affect digestibility due to the early lignified plants.

The total enteric CH_4 emissions from the different species of animals (cattle, sheep, goats, horses, donkeys and mules) were different (Table 19 and Figure 3). Among these species, cattle contributed 45.76%, followed by horses (20.01%), donkeys or mules (11.12%), goats (6.22%) and sheep (5.78%). From the total population point of view in the study area, cattle share (83.88%) the largest EF of CH_4, followed by donkeys (4.31%), goats (4.19%), sheep (4.11%) and horses (3.23%). Additionally, from agro-ecologies, the lowland area had the highest share (33.61%), followed by the midland (33.23%) and highland (33.16%) areas. Similarly, the shares of agro-ecologies per total population highland area (43.54%) were the largest, followed by midland (35.23%) and lowland (21.23%).

Table 19. Enteric methane emissions from the total livestock population and agro-ecologies in the study area

			Livestock species						Total EF AEZ	% Share AEZ	% Share of AEZ /P
			Cattle	Sheep	Goats	Horse	Donkey	Mules			
Agro-ecologies	Lowland	EF (kg CH4/H/Y)	41.7	5.3	5.7	18	10	10	90.7	33.61	
		Livestock (000H)	570	201	416	25	117	5			
		Subtotal EF (Mg/Y)	23.8	1.1	2.4	0.5	1.2	0.1	28.9		21.23
	Midland	EF (kg CH_4/H/Y)	40.9	5.2	5.6	18	10	10	89.7	33.23	
		Livestock (000H)	970	361	442	61	264	15			
		Subtotal EF (Mg/Y)	39.7	1.9	2.5	1.1	2.6	0.2	47.9		35.23
	Highland	EF (kg CH_4/H/Y)	40.9	5.1	5.5	18	10	10	89.5	33.16	
		Livestock (000H)	1238	518	155	158	205	19			
		Subtotal EF (Mg/Y)	50.6	2.6	0.9	2.8	2.1	0.2	59.2		43.54
Total EF Spp. (kgCH_4/Y)			123.5	15.6	16.8	54	30	30	269.9		
% Share species			45.76	5.78	6.22	20.01	11.12	11.12		100.0	
Total EF Spp./P (Mg CH_4/Y)			114.1	5.6	5.7	4.4	5.9	0.4	136.0		
% Share Spp. per P			83.88	4.11	4.19	3.23	4.31	0.29			100.0

AEZ=Agro-ecology; H=Head; P=Population; Spp=Species; Y=Year

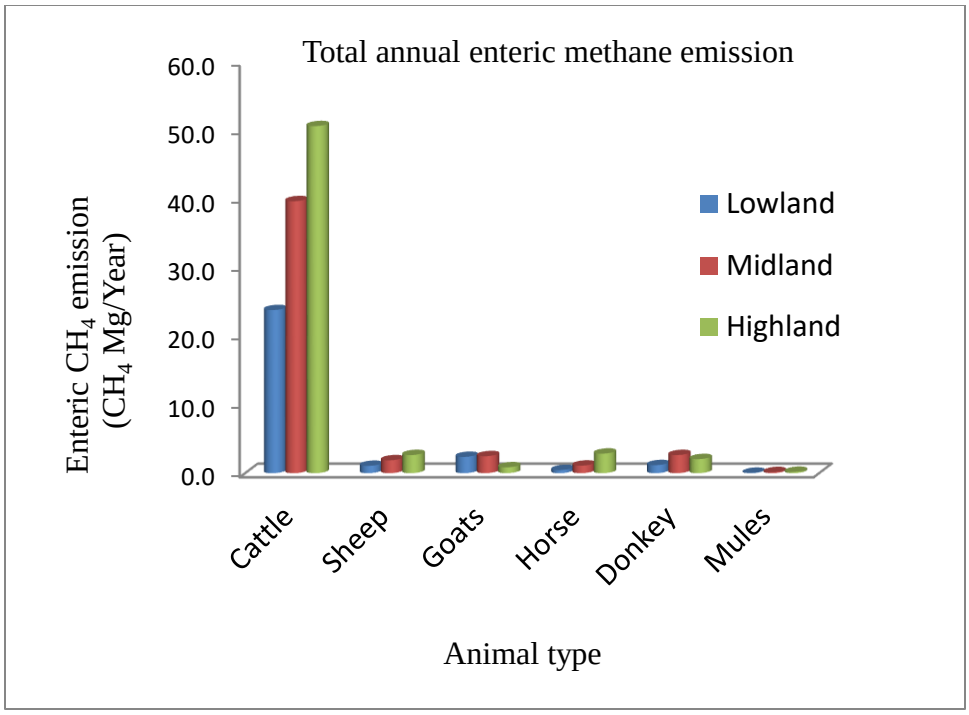


Figure 3. Contribution of livestock to total annual enteric methane emission (CH_4 kg/head/year) on estimated total population livestock in Arsi zone.

4.5.2.Prediction of methane emissions from manure

The estimated CH_4 emission factor for cattle from manure handling practices is presented in Table 20. The estimated CH_4 emissions from manure handling practices in the study area for the different age groups of cattle were significantly ($P<0.001$) different between the cattle subcategories. Likewise, the estimated CH_4 emissions from the manure of cattle were significantly ($P<0.001$) different between the lowland agro-ecology and other agro-ecologies, and there was no significant ($P>0.05$) difference between the midland and highland agro-ecology.

Table 20. Manure management methane emission factors for cattle subcategories and agro-ecologies in the study area (kg CH_4 $head^{-1}$ $year^{-1}$)

	Livestock subcategories	Agro-ecologies			Means	F-value	Sig.
		Low land	Mid land	High land			
Cattle	Adult multipurpose cows >3 years	4.32^{bA}	4.18^{bB}	4.18^{bB}	4.23	34.41	<.0001
	Adult males used for draught (3-10 years)	4.28^{bA}	4.14^{bB}	4.13^{bB}	4.18		
	Adult males used for breeding & other purpose (>3-10 years)	4.63^{aA}	4.48^{aB}	4.48^{aB}	4.53		
	Growing females 1-<3 years	3.1^{dA}	2.99^{dB}	2.99^{dB}	3.02		
	Growing males 1–<3 years	4.03^{cA}	3.9^{cB}	3.89^{cB}	3.94		
	Calves < 6 months (male & female)	0.761^{fA}	0.733^{fB}	0.732^{fB}	0.742		
	Calves 6 m–<1 year (male & female)	1.08^{eA}	1.04^{eB}	1.03^{eB}	1.05		
	Means	3.17	3.07	3.06	3.1		
	F-value	9415.32					
	Sig.	<.0001					

a, b, c,d,e,f Means with different superscripts in a column are significantly different. A, B, C means with different superscripts in a row are significantly different

The estimated CH_4 emission factor for sheep from manure handling practices is presented in Table 21. The methane emissions from the manure handling practices of different age groups of sheep were significant ($P<0.001$) different between the sheep subcategories, while there was no significant ($P>0.05$) different between breeding ewes and intact male lambs and among female lambs with female (1-2 year) and mature male. Similarly, the estimated CH_4 emissions from manure of different categories of sheep were significant ($P<0.001$) different between the agro-ecologies.

Table 21. Manure management methane emission factors for sheep and goats subcategories and agro-ecologies in the study area (kg CH_4 $head^{-1}$ $year^{-1}$)

Species	Sheep and goats subcategories	Agro-ecologies			Means	F-value	Sig.
		Low land	Mid land	High land			
Sheep	Breeding ewes (>2 years)	0.143^{aA}	0.142^{aB}	0.138^{aC}	0.141	124.93	<.0001
	Mature male (>2years)	0.13^{dA}	0.127^{dB}	0.123^{dC}	0.127		
	Female (1-2 years)	0.133^{cA}	0.13^{cB}	0.126^{cC}	0.13		
	Male (1-2 years)	0.137^{bA}	0.133^{bB}	0.129^{bC}	0.133		
	Intact male lambs (<1 year)	0.131^{dA}	0.128^{dB}	0.124^{dC}	0.128		
	Female lambs (<1 year)	0.119^{eA}	0.115^{eB}	0.111^{eC}	0.115		
	Means	0.132	0.129	0.125	0.129		
	F-value	169.9					
	Sig.	<.0001					
Goats	Adult does (2+ years)	0.182^{aA}	0.177^{aB}	0.172^{aC}	0.177	73.5	<.0001
	Bucks (>2 years)	0.171^{bA}	0.166^{bB}	0.161^{bC}	0.166		
	Yearling (1-2 years)	0.171^{bA}	0.166^{bB}	0.161^{bC}	0.166		
	Kids (males & females, <1 year)	0.093^{cA}	0.09^{cB}	0.087^{cC}	0.09		
	Means	0.154	0.15	0.145	0.15		
	F-value	4748.33					
	Sig.	<.0001					

a, b, c, d, e Means with different superscripts in a column are significantly different. A, B, C means with different superscripts in a row are significantly different

The estimated CH_4 emission factor for goats from manure handling practices is presented in Table 21. The methane emissions from the manure handling practices of different age groups of goats were significantly ($P<0.001$) different between the goat subcategories, but there was no significant difference ($P>0.05$) between the bucks and yearlings. Furthermore, the CH_4 emissions from the age group of goats were significantly ($P<0.001$) different among the three agro-ecologies.

Among the livestock species in the study area, cattle (76.13%) had the highest share, followed by horses (12.45%) and donkeys (8.95%). Under similar conditions, the highland area share (46.0%) was the largest, followed by the midland (34.7%) and lowland (19.3%) areas, when compared to the total population in the study area (see Table 22).

Table 22. Methane emissions from manure using Tier 1.

Livestock species	CH_4 from manure (kg/H/Y)	Agro-ecology						Total CH_4 Spp. (kg/ year)	Total emission (%)
		Lowland		Midland		Highland			
		Livestock (000H)	Total CH_4 (kg)	Livestock (000H)	Total CH_4	Livestock (000H)	Total CH_4		
Cattle	0.368	570	209.7	970	356.9	1238	455.5	1022.08	76.13
Sheep	0.013	201	2.6	361	4.7	518	6.8	14.08	1.05
Goats	0.011	416	4.6	442	4.9	155	1.7	11.24	0.84
Horse	0.685	25	17.1	61	41.8	158	108.2	167.11	12.45
Donkey	0.205	117	24.0	264	54.1	205	42.0	120.12	8.95
Mule	0.205	5	1.0	15	3.1	19	3.9	7.99	0.60
Total CH_4 AEZ (kg/year)			259.1		465.5		618.1	1342.63	
AEZ share (%)			19.3		34.7		46.0		100.00

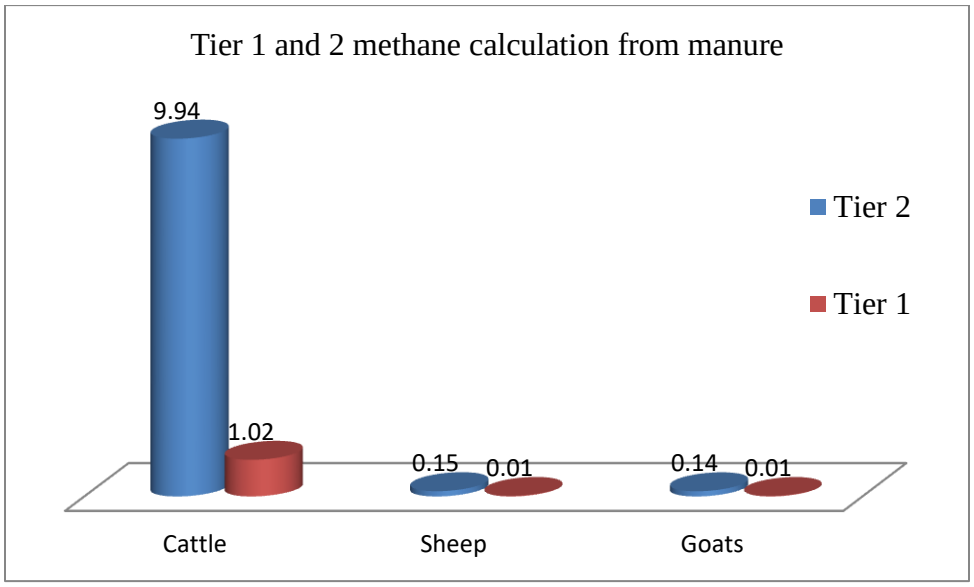


Figure 4. Methane calculation from manure using Tier 1 and Tier 2 from the total population in the study area (Mg CH_4/year)

4.5.3.Prediction of nitrous oxide emissions from manure

The nitrous oxide emission estimate of the cattle subcategories is given in Table 23. The estimated nitrous oxide of different age groups of cattle was significant (P<0.001) different between the cattle subcategories. Similarly, the estimated nitrous oxide of cattle was significant (P<0.001) different between the lowland agro-ecology and other agro-ecologies, while there was no significant (P>0.05) difference between the midland and highland agro-ecologies.

Table 23. Direct nitrous oxide emissions from manure management for cattle subcategories in the study area (gram N_2O/head/year)

Species	Livestock categories	Agro-ecologies			Means	F-value	Sig.
		Lowland	Midland	Highland			
Cattle	Adult multipurpose cows >3 years	10.1^{cA}	9.9^{cB}	9.9^{cB}	10	42	<.0001
	Adult males used for draught (3-10 years)	10.8^{bA}	10.6^{bB}	10.6^{bB}	10.1		
	Adult males used for breeding & other purpose (>3-10 years)	11.7^{aA}	11.4^{aB}	11.4^{aB}	10.2		
	Growing females 1-<3 years	7.3^{eA}	7.1^{eB}	7.1^{eB}	7.0		
	Growing males 1–<3 years	9.4^{dA}	9.2^{dB}	9.2^{dB}	9.0		
	Calves < 6 months (male & female)	1.1^{gA}	1^{gB}	1^{gB}	1.0		
	Calves 6 m–<1 year (male & female)	4.6^{fA}	4.5^{fB}	4.4^{fB}	4.0		
	Means	7.85	7.7	7.7	8.0		
	F-value	19175.25					
	Sig.	<.0001					

a, b, c, d, e, f Means with different superscripts in acolumn are significantly different. A, B, C means with different superscripts in a row are significantly different

The nitrous oxide emission estimate of the sheep categories is given in Table 24. The estimated nitrous oxide of different age groups of sheep was significant (P<0.001) different between the sheep subcategories, but, there was no significant (P<0.05) different between female (1-2 year) and female lambs. Likewise, the estimated nitrous oxide was significant (P<0.001) different between the three agro-ecologies.

The nitrous oxide emission estimates of the goat categories are given in Table 24. The estimated nitrous oxide of different age groups of goats was significant (P<0.001 different between the goat subcategories, But, there was not significant (P>0.05) different between bucks and yearlings. Additionally, the estimated nitrous oxide was significant (P<0.001) different between the three agro-ecologies.

Table 24. Direct nitrous oxide emissions from manure management for sheep and goats subcategories in the study area (gram N_2O /head/year)

Species	Sheep and goats categories	Agro-ecologies			Means	F-value	Sig.
		Lowland	Midland	Highland			
Sheep	Breeding ewes (>2 years)	1.34^{aA}	1.32^{aB}	1.23^{aC}	1.32	611.1	<.0001
	Mature male (>2years)	1.2^{dA}	1.18^{dB}	1.16^{dC}	1.18		
	Female (1-2 years)	1.16^{eA}	1.14^{eB}	1.12^{eC}	1.14		
	Male (1-2 years)	1.25^{cA}	1.23^{cB}	1.2^{cC}	1.23		
	Intact male lambs (<1 year)	1.28^{bA}	1.26^{bB}	1.23^{bC}	1.26		
	Female lambs (<1 year)	1.17^{eA}	1.14^{eB}	1.12^{eC}	1.14		
	Means	1.23	1.21	1.19	1.0		
	F-value	2947.67					
	Sig.	<.0001					
Goats	Adult does (2+ years)	1.63^{aA}	1.61^{aB}	1.58^{aC}	1.6	74.54	<.0001
	Bucks (>2 years)	1.54^{bA}	1.52^{bB}	1.49^{bC}	1.5		
	Yearling (1-2 years)	1.55^{bA}	1.52^{bB}	1.49^{bC}	1.5		
	Kids (males & females, <1 year)	0.86^{cA}	0.85^{cB}	0.83^{cC}	1.0		
	Means	1.4	1.37	1.35	1.37		
	F-value	12657.6					
	Sig.	<.0001					

a, b, c, d, e Means with different superscripts in a column are significantly different. A, B, C means with different superscripts in a row are significantly different

5. DISCUSSION

5.1. Household Demographic Characteristics

The study area overall mean household family size is higher than the 4.9 and 4.7 persons per HH reported by CSA, (2018) for the Oromia region and as the whole national average, respectively. The present study was lower than the 8.94 and 6.56 reported by Duguma & Janssens (2021) and Girma *et al.* (2016) in the mixed farming areas of the Jimma zone and Bale zone, respectively. A large family size was also considered very important for providing adequate labor for both crop and livestock farming, which requires higher labor inputs. Depending on the socioeconomic setup of the community, family size is considered an asset and a factor that guarantees social security at the household level Fekede *et al.* (2013). The average age of the HHs found in the study area was within the standard productive age range (15-64 years) of the country, which is considered a possible workforce (Table 8). In addition, the majority of sampled HHs attended formal education. In fact, the educational level of farmers is assumed to increase the ability to understand processes and use agriculture-related information and adopt technologies in a better way. Generally, in the study area, the education level of sampled HHs was similar to the finding of Girma *et al.* (2018) and Kochare *et al. (*2018). Duguma & Janssens, (2021) reported that the level of education correlates to knowledge and making positive farm decisions. Better education level and farm experience improve productivity and farmers' perceptions of climate situations Girma *et al.*(2018). In general, farm workforce age, family size and education have future implications for resource use to achieve optimum productivity. The majority of the respondents in the present study had formal education, and it is important to understand extension messages and to realize the importance of new technologies within a short time. Education plays a vital role adopting and promoting new technologies. Moreover, it was explicitly indicated that farmers with high educational levels adopt new technologies more rapidly than farmers with lower levels of education Ofuoku *et al.* (2008).

5.2. Landholdings and Land Utilization

The overall mean ± SE of the total land holdings per HHs of the studied area was 3.24±0.2 ha, and the cultivable land per HHs was 2.3 ±0.1 ha. This value was slightly lower than the average cultivable land holding per HHs (3.13±0.08 ha) reported by Girma *et al.*(2018). The studied area was a mixed farming system with crop and livestock production, which is the pillar for the livelihood of the community. However, a major area of the land in the midland agro-ecology was used for cultivation, and extensive cultivation affects animal production and feed sources due to grazing land shrinkage (Table 10). The variation was attributed to population growth, which diminishes the size of the cropping land from time to time through inheritance. The land covers were dominated in the lowland area by maize, in the midland by wheat and in the highland by barley, which are suitable agro-ecologies. In Adami Tulu district, central Ethiopia, approximately 69.35% of the land is allocated for crop cultivation, although the rest is allocated for private grazing land, homestead land and enclosed plantation/wood land Dawit *et al.* (2013). The average crop land landholding owned per household in the midland area was significantly higher. This might be due to the shrinkage of grazing land and the increase in cultivated land in the area. The overall average landholding per HHs (3.24 ha) in the current study was higher than that reported by Kedida Gamela Distric (0.69 ha) of the SNNPR of Ethiopia Habte *et al.*(2019) and Mengistu *et al.*(2016). However, the grazing lands that have been serving as a source of natural pasture for livestock in the highlands of Ethiopia are continuously shrinking due to high population pressure, land degradation, frequent occurrence of drought and conversion of grazing lands into arable lands Shimelis & Alene (2016).

5.3. Major Crops Grown and Land Allocated to each Crop

Information regarding the major crops grown, land area allocated to each crop and productivity of the different crops is needed for estimating the quantities of crop residues produced per household and their relative contribution to livestock feed supply. The different crops grown and the land area allocated to each crop per household in the study areas are shown in Table 10.

Wheat, barley, teff (*Eragrostis teff*), maize, sorghum and oats were reported to be the major cereals, while faba bean and field pea were the important pulse crops grown in the areas. In addition, oil crops and vegetable crops were grown in the area. In terms of the proportion of producing households and land allocation, wheat was the dominant cereal crop followed by barley in both midland and highland agro-ecology and maize dominant crop in lowland agro-ecology. The higher grain productivity of the crops in the study area indicates the better potential of crop residue production as an important source of feed in the area. Land allocation for crops showed a reduced trend from year to year due to increased human population and the consequent reduction in landholdings per household. Land allocation for feed production had also been diminishing in size due to population growth, which resulted in the use of grazing lands for crop production.

5.4. Livestock Holding and Compositions

Households in the study area keep a mix of cattle, sheep, goats, equines and chicken. The average livestock ownership in terms of Tropical Livestock Unit (TLU) was significantly different ($P<0.01$) across all three agro-ecologies, which agreed with reports by (Girma *et al.*, 2018; Tibebu and Berhan, 2018). Most HHs in the study area owned local breeds and crossbred animals. The overall average cattle herd size per HHs was 7.48 TLU. Cattle were the dominant stock, while the number of oxen was pronounced within the herd across the agro-ecologies (Table 10). The average cattle population per HHs in the study areas were higher than the 6.73 TLU reported by Habte *et al.*, (2019) in the western showa zone. This is because cattle were primarily used for draught power in the area, as in the other mixed farming areas of the country Girma *et al.* (2018). Cattle constitute the largest share of the households' TLU holdings, which was in line with the findings of Fekede *et al.* (2013), who concluded that cattle are both numerically and functionally the dominant livestock species in the country.

5.5. The Chemical Composition of the Experimental Feeds

Natural grass hay has been used as a vital feed for livestock in the tropics. In this study, the CP content of the natural grass hay was slightly below the maintenance requirement (7%) for ruminants needed for microbial protein synthesis in the rumen, which is in line with the result of Daniel *et al.* (2014) and Melesse *et al.* (2017) and higher than the CP

content reported by Getahun *et al.* (2020), Melesse *et al.* (2015) and Solomon & Tsadkan (2018). In general, the nutrient compositions of the experimental feeds were within the range of Ethiopian feeds Seyoum *et al. (*2007). The CP content of *S. sesban* leaves recorded in this study was lower than that reported by (Solomon *et al.*, 2005) for the *S. sesban* 15019 accessions, Mekoya *et al.* (2008), Wondwosen *et al.* (2013) and Solomon & Tsadkan (2018). The OM, NDF, ADF and ADL obtained in this study were higher than the values reported for *S. sesban* leaves Mekoya *et al.*(2008), Solomon *et al.* (2005) and Wondwosen *et al.* (2013). The OM content of *S. sesban* leaves in this study were similar to those reported by Solomon & Tsadkan (2018), but the NDF and ADF contents of *S.sesban* were lower than those reported by the same authors.

The CP content of NSC in the present study was lower than that reported by Abebaw & Melaku (2009), Fentie & Melaku (2008), Tesfay & Melaku (2009) and Zinash *et al.* (2017) but higher than that reported by Jemberu *et al.* (2009). NDF, ADF, ADL and cellulose content of NSC in the present study were lower than the report by Abebaw & Melaku (2009) and Jemberu *et al.* (2009) but higher for the content of OM and hemicellulose by the same authors.

5.5.1.Dry matter and nutrient intake

Total daily DM intake was higher ($P<0.001$) for sheep in mixed treatments than for the *S.sesban* leave (Table 14). The low intake in *S. sesban* leaf may be because *S. sesban* contains a substantial amount of anti-nutritional factors, such as condensed tannins, which might have limited complete consumption of the same feed at a higher level of inclusion Frutos *et al.*(2004).

Similarly, with the current finding, Solomon *et al.* (2004a, 2004b, 2004c) stated variable quantities of refusals from feeding *S. sesban* to ewes and concluded that anti-nutritional factors in the same feed limit palatability and intake at a higher level of offer. It has been documented by Frutos *et al*. (2004) that most browse species, including *S. sesban*, contain phenolic compounds that reduce voluntary feed intake, and tannins are considered anti-nutritional and/or toxic compounds when present in feeds due to their decreasing intake Mueller-Harvey (2006). Mcdonald *et al.*, (2002) stated that tannins

reduce the palatability of the browses and make them less preferred by animals. Other studies Bitende & Ledin (1996) and Tibebu *et al.* (2009) also showed that supplementation of *Sesbania* to grass or straw based diets fed to different ruminant animal species increased the DM, OM and CP intakes. According to (Ranjhan (1977), the ME requirement for sheep weighing 20-30 kg ranged between 5.86 and 8.37 MJ, and in the current study, all the treatments satisfied the ME requirements.

5.5.2.Dry matter and nutrient digestibility

Dry matter and nutrient digestibility values are given in Table 15. The lower DM and nutrient digestibility in the *S. sesban* leaves indicated that *S. sesban* leaves might not be used solely as a supplement to sheep in such a basal diet. Multipurpose trees are seldom fed to ruminants as a sole source of feed, and therefore, their important attributes are their ability to improve the digestibility and utilization of fibrous feeds when used as a supplement Solomon (2001). The different effects of *S. sesban* supplementation on the total DMI may be attributed to its palatability, anti-nutritional content, stage of maturity, means of supplementation, and amounts added Solomon & Tsadkan (2018). Furthermore, it was apparent that nutrient digestibility showed a decreasing trend as the level of inclusion of *S. sesban* in the supplement increased. Khalili & Varvikko (1992) stated that dietary crude protein digestibility decreases with increasing *S. sesban* supplementation compared to concentrate supplementation. This could be attributed to anti-nutritional factors contained in *S. sesban*. The deleterious effect of secondary plant metabolites such as tannins on nutrient digestibility has been well documented Solomon *et al.* (2004a, 2004b). Tannins are considered as anti-nutritional and/or toxic compounds when present in feeds due to their decreasing digestion of MPT Mueller-Harvey (2006). Similarly, Tannin reacts with protein and forms a tannin–protein complex, which reduces rumen fermentation and eventually depresses nutrient digestibility and voluntary feed intake Frutos *et al.*(2004). In addition, Woldemeskel *et al.*(2001) reported that the adverse effect on rumen metabolism and diminished digestibility due to tannins and diarrhea induced by saponins may reduce the absorption and availability of ingredients at high levels of *S. sesban* (400 g), resulting in more adverse effects than at low levels (200 g).

5.5.3.Estimation of enteric methane emissions from feed trials

The quantification of methane emissions from livestock on a global scale relies on prediction models because measurements require specialized equipment and may be expensive Moraes *et al.* (2014). The average EFs in the present study are similar for sheep Nandi and Bomet (4.6 and 4.8 kg CH_4 per head per year) in Kenya Goopy *et al.*(2021). However, the emission factor of South African sheep (6.3 kg/CH_4 per head per year) was higher than that in the present study, as shown in Table 16 above. Methane production from ruminants in small ruminants varies with diet, which could be affected by factors such as DM intake, diet composition and digestibility. Because enteric CH_4 emissions are strongly related to feed intake, all models include a measure of intake, such as DMI, gross energy (GE) intake (GEI), ME intake, or NDFI. The reduction in CH_4 production in SSL in the current study may be associated with the DMI, GEI, NDFI Hristov *et al.*(2018) and fractions of tannin phenols and condensed tannins, which have the potential to modify rumen fermentation to reduce CH_4 production that why *s. sasben* leaves fed sheep reduce the methane emission Patra & Saxena (2011). High-quality forage, e.g., young plants, can reduce CH_4 production by altering the fermentation pathway because this forage contains higher amounts of easily fermentable carbohydrates and less NDF, leading to a higher digestibility and passage rate Beever *et al.* (1986). In contrast, more mature forage induces a higher CH_4 yield mainly due to an increased C:N ratio, which decreases digestibility Milich (1999). Different types of forage can also affect CH_4 emissions due to differences in their chemical composition Benchaar *et al.*(2011). Conversely, a roughage-based diet will favor acetate production and increase CH_4 production per unit of fermentable organic matter in ruminants Johnson & Johnson (1995). The reduction in CH_4 output by shifting H_2 flow toward alternative electron acceptors such as propionate significantly enhances the utilization of feeds and animal performance.

5.6. Greenhouse Gas (GHG) Emissions from Livestock

The mean kg GHG emission factors of the present study were similar to those in a previous report Wilkes *et al.*(2020) and higher than those in reports Million *et al.* (2022) that estimated (32.48-12.6 kg CH_4/head/year) enteric methane emissions from indigenous cattle subcategories. The IPCC Tier 2 approach is better able to reflect changes in both the structure of livestock populations and animal management and performance. The Tier 2 approach can therefore improve the quality of estimates of GHG emissions and emission reductions in line with Ethiopia's CRGE Strategy and its commitments in the NDC FDRE-CRGE (2011) and Wilkes *et al.*(2020). The livestock emissions trend for the principal GHGs directly produced by livestock (CH_4 and N_2O) in different emissions categories (enteric fermentation, manure management, manure left on pasture) in both developed and developing countries Caro *et al.*(2014). In tropical and subtropical agricultural production systems, the climate is generally warmer than that in temperate systems, which could result in greater N_2O and CH_4 emissions from excreta because emissions are often positively correlated with temperature Rochette *et al.*(2014). Savanna ecosystems cover approximately 65% of the African continent Brümmer *et al.* (2008), with much of this area being used by livestock farmers. In much of the arid and semiarid regions in sub-Saharan Africa (SSA), livestock production generally relies on the grazing of native pasture Thornton & Herrero (2014) with a long free grazing time, which leads to more than 40% of total excreta being deposited on rangelands without further use or management Rufino *et al.*(2006). Of the 3.3 Gt of direct cattle GHG emissions, CH_4 from enteric fermentation is the largest source, accounting for 71%. Manure N_2O, particularly from deposition on pasture, accounts for the next largest share (25%), whereas the remaining 4% is from manure CH_4 Opio *et al.*(2013).

5.6.1.Estimation of enteric methane emissions

The emission factors obtained from the mixed crop livestock production system and the cattle subcategories in the present study (5.2-61.1 kg CH_4 head/year) were close to the Tier 1 default emission factor of 52 kg CH_4 herd/year for other cattle in Africa (IPCC, 2019). However, the results obtained using the Tier 2 methodology were 54-61% higher than the default value of 31 kg CH_4 herd/year for Africa and the Middle East IPCC

(2006a) and lower the reports of Million & Getahun (2021) having the range of 11-66 $kgCH_4head^{-1}year^{-1}$. Compared with IPCC, (2006) default emission factors for Africa, higher Tier 2 emission factors were also reported for Benin (40 kg CH_4 herd/year) Kouazounde *et al.* (2015), which is in agreement with the present result. However, lower CH_4 emission factors of 31 and 16 kg CH_4 herd/year were reported for lactating and other cattle (Ndama breed) in Senegal Ndao *et al.* (2019). These comparisons highlight the necessity for developing country specific emission factors that reflect the national circumstances and actual animal management and performance in different production systems. The variation in emission factors estimated in the present study from literature reports was attributed to the difference in feed types Frank *et al.*(2000) and Moss *et al.*(2000), animal management, and body size Frank *et al.* (2000) and IPCC (2006). Emission factors for small ruminants in Sub-Saharan Africa have been estimated by Du Toit *et al.*(2013) and Ndao *et al.*(2019). Du Toit *et al.*(2013) estimated averages of 8.5 and 6.1 kg CH_4/head/year for sheep in commercial and communal production systems in South Africa, assuming average LWs of 59 kg for commercial and 44.5 kg in communal production systems. They also estimated emission factors of 10.1 and 6.3 kg CH_4/head/year for goats in commercial and communal production systems, respectively. Ndao *et al.*(2019) estimated mean emission factors in Senegal of 2.3 kg CH_4 /head/year for sheep and 2.0 kg CH_4/head/year for goats. However, the LWs in Senegal are lower than those estimated in this inventory.

Different studies indicate that the CH_4 conversion rate as a loss of energy from cattle ranged from 2 to 12% of GE intake from tropical cattle because of feed's higher fiber content Chuntrakort *et al.*(2014) and Tangjitwattanachai *et al.*(2015), which is in agreement with the present result. Thus, increasing roughage feed digestibility was an expedient way to reduce enteric CH_4 emissions accompanied by a minimized animal number and increased productivity. In general, CH_4 emissions from livestock are influenced by husbandry practices, feed intake, diet composition, feed digestibility and differences between animals Scholtz *et al.*(2012).

Methane emission from the enteric fermentation of ruminant livestock is a main source of GHG emission, which is a major concern for global warning. The mean enteric CH_4

emissions factors (EFs) per head per year for the cattle, sheep and goats categories were in close agreement with reports similar to the inventory of GHG emissions from cattle, sheep and goats in Ethiopia Wilkes *et al.*(2020) and lower than the reports Million & Getahun (2021) for cattle subcategories. However, the EF from cattle was higher than the IPCC values from developing countries (African regions) livestock EFs under similar production systems and animal functions Goopy *et al.*(2021), Herrero *et al.*(2008), IPCC (2006, 2019) and Kouazounde *et al.*(2015). The study revealed that enteric CH_4 emissions from cattle categories were high (45.76%) compared to small ruminants and equines, which was attributed to the greater number of cattle herds at the zone level being comparable to the 84% livestock emissions from cattle reported by FDRE-CRGE (2011) and Wilkes *et al.* (2020) (refer to Table 20 and Figure 3). The differences in EFs may be due to differences in live weights of all the animal subcategories and digestibility of the feed Girma *et al.* (2016) and Wanjugu *et al.*(2021).

Methane from enteric fermentation is the major contributor to total GHG emissions and is directly related to the nutritional and energetic efficiency of the animal Gerber *et al.*(2010) and Thornton & Herrero (2010). Enteric CH_4 emissions in the lowland area were higher than those in the highland area in a similar report Annastacia *et al.* (2022). This is an important point to note in the results because feeds in a highland area differ nutritionally from feeds in lowland areas with low agricultural potential. Feeds in the rangelands deposit more structural tissue that is more fibrous and less digestible Wilson *et al.*(1991). The (weighted mean) DE of feed baskets in the present study was in the range of the IPCC default estimates (of 50-55%) for African forages IPCC (2006). The differences in DE among AEZs, with the difference in a range of 53-55% (Appendix table 4), are likely to have influenced the estimates of EFs, which is similar to the reports of Ndung'U *et al.*, (2019) in Kenya. On the other hand, increasing roughage feed digestibility was a convenient way to reduce enteric CH_4 emissions while minimizing animal numbers and increasing productivity. Therefore, the present report of enteric CH_4 production of the existing livestock herd categories of the prevailing feeding regime presents ample scopes to decrease CH_4 emission through appropriate feeding interventions Defar *et al.*(2018).

Increased CH_4 yield in withers grazing late summer season pastures is attributed to the quality deterioration (poor dry matter digestibility, lower protein and soluble carbohydrate content and increased cell wall content) of the pastures during the summer season Ulyatt *et al.*(2005). The amount of enteric CH_4 is mainly linked to the type, quality and quantity of feed Shibata & Terada (2010). Methane production was positively correlated with NDF, ADF, cellulose and hemicellulose whereas CP, ash, EE (ether extract) and NFC (non-fiber carbohydrates) negatively correlated (Gemeda & Hassen, 2014). Gross energy (GE) is negatively related to feeding level and dietary fat composition and positively related to diet digestibility, whereas dietary carbohydrate composition has only minor effects. As the daily feed intake increases, CH_4 production also generally increases Shibata & Terada (2010). Amazingly, there were no clear seasonal trends in the nutritional value (i.e., digestibility) of pasture, most likely because the samples as harvested showed the effects of early-mature stages of growth and the climatic effects of more than a single season. Similarly, there were no uniform changes in cattle LW by landscape position or season, which was also not expected -LW losses for some individuals occurred in all landscape positions in all seasons Goopy *et al.*(2018). Local weather conditions and individual husbandry decisions most likely also played a role in the observed variability in cattle LW fluctuation and indicated the overall heterogeneity of smallholder farming systems Goopy *et al.*(2018). In another direction, feeding strategies that increase voluntary feed intake and limit ruminal fermentation, such as the utilization of less ruminal degradable starch, are likely to increase the extent of post-ruminal digestion and decrease CH_4 emissions Marino *et al.*(2016).

The quality of forages may be affected by increased temperature and dry conditions due to variations in the concentrations of water-soluble carbohydrates and nitrogen. Temperature increases may increase lignin and cell wall components in plants (Polley *et al.*, 2013), which reduce digestibility and degradation rates IFAD.(2010) and Polley *et al.*(2013), leading to a decrease in nutrient availability for animals (Thornton *et al.*, 2009). In general, the impacts of climate change on forage quantity and quality depend on the region and length of the growing season Polley *et al.*(2013) and Thornton *et al.*(2009). A temperature increase leads to a decrease in forage quality and can increase methane emissions per unit of gross energy consumed Benchaar *et al.* (2001).

5.6.2.Methane from manure

Livestock manure (including dung and urine) is composed of mostly organic material and water. Anaerobic and facultative bacteria decompose organic material under anaerobic conditions Bouwman (1996) and produce CH_4. The current finding agrees with *Wilkes, et al*., (2020) on cattle having the result of 3.075kg CH4/head /year. The emissions from manure depend on the animal category, the amount of manure per animal and the manure management system. In the mixed farming areas of Ethiopia, manure has been used for fuel and sometimes as organic fertilizer on farmlands, which is a similar practice to the study area. In tropical and subtropical agricultural production systems, the climate is generally warmer than that in temperate systems, which could result in CH_4 emissions from excreta because emissions are often positively correlated with temperature Rochette *et al.*(2014). However, the types of management systems used, the quality of the feeds, and the species of cattle raised may also affect emissions. When CH_4 is reduced by increasing the time of cattle on pasture, pollution swapping occurs because more N_2O will be produced (0.2 Tg CO_2 eq.). Livestock manure is primarily composed of organic material and water. Under anaerobic conditions, anaerobic and facultative bacteria decompose the organic matter of livestock waste.

The feed and feeding habits of animals could influence ruminants' emissions of CH_4 in farmhouses and fecal decomposition sites Henry *et al.*(2011). The higher values for mature draught oxen and lactating cows are attributed to the higher volatile solid content of the manure compared to other subcategories. The manure management CH_4 emission factor in the present study is greater than the manure management CH_4 emission factor of 2.5 kg per head per year reported for Canadian beef cattle Kebreab *et al.*(2011). The higher value for Ethiopian cattle breeds compared with Canadian beef cattle is attributed to differences in manure management systems/practices, differences in the volatile solid content of manure/excreta and differences in the digestibility of feed. GHG emissions of cattle excreta vary by diet, breed and type of manure management practice used Hristov *et al.*(2019). The lower digestibility of feed (an average 54.35%) in the present study resulted in increased VS content of manure and hence CH_4 emission from manure. In the present study, due to the lack of country-specific Bo values, we used IPCC default values

of 0.1 for the Africa region IPCC (2006a). CH_4 emissions in the present study using tier 2 methodologies were higher than the IPCC default manure management emission factor (1 kg/head/year) for other cattle IPCC (2006a). The higher value for tier 2 is attributed to higher VS contents of manure.

5.6.3. Nitrous oxide

According to the Intergovernmental Panel on Climate Change (IPCC) guidelines, it is estimated that the generation of N_2O by manure deposited in grasslands corresponds to 2% of the total excreted N IPCC (2006a). Similarly, according to Tier 1 IPCC (2006a), direct N_2O emissions depend on the total amount of N excretion from all livestock species/categories in each type of manure management system in combination with the IPCC default factor for that type of manure management system. Dietary protein content, feed digestibility, and sugar content are known to influence the amounts and types of N and C voided in cattle excreta Bannink *et al.*(2011). Therefore, lower-quality feeds likely result in excreta with reduced N concentrations and higher C/N ratios because the C/N ratio is negatively correlated with N and N_2O Pelster *et al.*(2016). Manure management contributes to adverse environmental impacts through losses of nitrogen (N) De Vries *et al.*(2015). The low N_2O emissions are more likely related to the low N concentration and high C/N ratio typical of tropical cattle manure Rufino *et al.*(2006), which was related to the poor-quality fodder Korir *et al.*(2016).

Ruminants are poor nitrogen converters, because only 5-30% of ingested nitrogen is up taken by the animal, and the remaining 70–95% is excreted via feces and urine Luo *et al.*(2010). Therefore, nitrogen loads in animal excreta often exceed plant demands and are vulnerable to losses via gaseous emissions and leaching Selbie *et al.*(2015). Likewise, Rivera *et al.*(2019) found that cows excreted 72% of ingested nitrogen in tropical dairy systems, generating the deposition of 46.8 kg N/animal/year from manure and 42.9 kg from urine when the diet had on average 14% crude protein (CP). For this reason, improving the efficiency in the use of this nutrient by ruminants may be a viable alternative not only to increase animal productivity but also to reduce GHG emissions by reducing N excretion. Grazed pastures are systems with a wide range of environmental

and management conditions that can result in the emission of N_2O Roswitha (2021). The majority of African ruminants graze for much of their life Schlecht *et al.* (2006), which results in over 40% of excreta being deposited on rangelands and pastures Rufino *et al.*(2006), much more than in temperate regions. Thus, approximately 80% of the emissions associated with excreta deposited on rangelands and pasture occur in developing countries Smith *et al.*(2014). The diet of African ruminants tends to be based on grasses and crop residues that are more fibrous than their counterparts from temperate regions, with lower digestibility and protein content Schlecht *et al.*(2006). Dietary protein content, feed digestibility, and sugar content are known to influence the amounts and types of N and C voided in cattle excreta Bannink *et al.*(2011). Therefore, lower-quality feeds likely result in excreta with reduced N concentrations and higher C/N ratios because the C/N ratio is negatively correlated with N and N_2O Pelster *et al.*(2016).

Nitrous oxide can also be produced from the microbial decomposition of organic nitrogen compounds in manure. The production and emissions of N_2O are closely linked to the efficiency of nitrogen (N) transfer between the major components of a livestock system, that is, animal manure Schils *et al.*(2013).

Dung is an undigested feed component, including nutrients, and causes endogenous digestive losses. Urine contains inevitable losses, waste products of metabolic processes and surplus nutrients. The amount of dung and urine produced by animals is very variable due to differences in feed and water intake, which are strongly related to body weight and production intensity. Dung is an undigested feed component, including many nutrients, as well as endogenous losses. Urine contains inevitable losses, waste products of metabolic processes and surplus nutrients. The quantity of nutrients excreted depends on the nutrient intake level, the efficiency with which the nutrients are utilized by the animal for growth (meat), maintenance and other functions (e.g., milk, eggs) and the amount of normal metabolic losses (endogenous).

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

In this study we conclude that the numerical contribution of species in the mix of livestock varied along with agro-ecologies of the households. Cultivated croplands and grazing lands are the major agricultural land use types on which livestock feeds are sourced. The area of grazing lands revealed a decreasing trend as the result of conversion into cultivated cropland. The prevailing cropping pattern, plot of land allocated per crop type and level of input utilization at the farm level determine the seasonal quantity and quality of livestock feed resources from crop production among the agro-ecologies of farmers.

Livestock sector response to the challenges of environmental change except needs formulation of appropriate adaptation and mitigation options. The projected trend of population growth indicates that the livestock population will increase substantially over the years and may create conducive areas for further increases in greenhouse gas emissions.

The combination of feed fed to Arsi-Bale sheep with different proportions of noug seed cake, hay and *S. sesban* leaves improved feed intake and digestibility compared to the *S.sesban* leaves alone. Moreover, the methane emission of *S.sesban* leaves fed was less emitter than the rest of treatments because forage trees were decrease methane emission due to the presence of tannin.

Cattle were the largest producer of methane and nitrous oxide through the agro-ecology and among the specie of the rest of the livestock. Among the sub categories of the species, the aged animals were more emitter than the young animal. Lowland area was emitted more methane and nitrous oxide than midland and highland areas. Nitrous oxide emissions for goats in the lowland were lower than midland and highland, because the digestibility of acacia trees high per animal but increase per population.

6.2. Recommendation

Based on the current study findings, some points were considered very important to give due attention to improving livestock production in the study area. The following are some of them:

- Assessing the availability, management and utilization of various feed resources for feeding livestock under different production systems and agro-ecology.
- Providing opportunities to focus attention on increasing productivity per animal, thus reducing negative environmental impacts.
- Forthcoming planning of smallholder livestock projects should be inclusive of climate change and greenhouse gas emission mitigation strategies while responding to the growing demand for livestock products.
- The largest emissions from CH_4 and N_2O indicated the need to improve livestock and manure management systems under smallholder agriculture. Existing mitigation strategies for CH_4 emissions for livestock, which include the use of high quality forages, are recommended management practices.
- Improve the management and utilization of livestock manure. Evaluate the current storage and handling practices to preserve manure nutrients.

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8. APPENDICES

8.1. Tables in the Appendices

Appendix Table 1: Arsi zone mixed farming livestock population in the three agro-ecologies

Species	Livestock categories	Agro-ecology		
		Lowland	Midland	Highland
Cattle	Adult multipurpose cows >3 years	160521	287600	426384
	Adult males used for draught (3-10 years)	208035	297869	364062
	Adult males used for breeding & other purpose (>3-10 years)	22604	55882	62160
	Growing females 1-<3 years	40528	94921	111986
	Growing males 1–<3 years	44813	70143	93523
	Calves < 6 months (male & female)	47147	76411	82914
	Calves 6 m–<1 year (male & female)	46224	87495	97401
Sheep	Breeding ewes (>2 years)	66262	170072	192159
	Mature male (>2years)	19246	33680	81793
	Female (1-2 years)	11780	14137	43352
	Male (1-2 years)	11032	17821	18670
	Intact male lambs (<1 year)	42840	64260	81170
	Female lambs (<1 year)	49464	60551	100634
Goat	Adult does (2+ years)	119149	155500	90876
	Bucks (>2 years)	76811	24778	17344
	Yearling (1-2 years)	64442	90219	7365
	Kids (males & females, <1 year)	155893	171301	39880
Equine	Horse	24568	61420	157645
	Donkey	117150	263588	205013
	Mule	4859	14577	19436

Source: CSA (2020/21)

Appendix Table 2: Feed sources DM (ton per hectare) yield conversion factors

Sources of crop types	Conversion factor *
Communal grazing	2
Private grazing	2
Road side grazing	2
Fallow land	1.8
Cereals straws	1.5
Stovers crops	2
Pulse haulms	1.2
Oil Straws	4
Forage crops	6.0-8.0
Unconventional feeds	0.3

Source: FAO (1987); Mengistu (2006)

Appendix Table 3: Conversion factors of the livestock to tropical livestock unit (TLU)

Livestock type	Tropical livestock unit (TLU)
Cows	0.8
Oxen/bulls	1.1
Steers	0.6
Heifers	0.5
Calves	0.2
Sheep	0.1
Goats	0.1
Horses	0.8
Donkey	0.5
Mules	0.7
Chicken	0.01

Source: Gryseels (1988)); Jahnke (1982

Appendix Table 4: Percentage of digestibility of feed in the agro-ecologies used for livestock

Species	Agro-ecology		
	Lowland	Midland	Highland
	DE (%)		
Cattle	53.93	54.54	54.57
Sheep	53.534	54.026	54.576
Goats	53.534	54.026	54.576

Appendix Table 5: ANOVA table of household characteristics in the mixed farming areas of the three agro-ecologies of Arsi zone

Source of variation		Sum of squares	df	Mean square	F value	Sig.
Household total family size	Between groups	16.16	2	8.08	1.563	0.213
	Within groups	759.733	147	5.168		
	Total	775.893	149			
Respondent age	Between groups	2398.410	2	1199.205	8.399	0.000
	Within groups	20989.38	147	142.785		
	Total	23387.79	149			
Productive age	Between groups	1.485	2	.743	.211	0.81
	Within groups	488.972	139	3.518		
	Total	490.458	141			
Unproductive age	Between groups	4.722	2	2.361	1.197	0.305
	Within groups	266.358	135	1.973		
	Total	271.080	137			
Farm experience	Between groups	2430.033	2	1215.017	8.487	0.000
	Within groups	21045.967	147	143.170		
	Total	23476.00	149			

Appendix Table 6: ANOVA table of household land holding, land use types and cropping pattern (ha HH^{-1}) in the mixed farming areas in the three agro-ecologies Arsi zone

Source of variation		Sum of squares	df	Mean square	F value	Sig.
Land use type						
Grazing land	Between groups	1.736	2	0.868	0.947	0.391
	Within groups	115.549	126	0.917		
	Total	117.286	128			
Crop land	Between groups	13.226	2	6.613	3.973	0.021
	Within groups	244.658	147	1.664		
	Total	257.884	149			
Fallow land	Between groups	1.275	2	0.638	7.562	0.003
	Within groups	1.771	21	0.084		
	Total	3.046	23			
Forage crops land	Between groups	0.025	2	0.012	3.587	0.033
	Within groups	0.223	64	0.003		
	Total	0.248	66			
Forest land	Between groups	0.08	2	0.04	4.874	0.026
	Within groups	0.107	13	0.008		
	Total	0.187	15			
Rented in/out cropland	Between groups	0.048	2	0.024	0.812	0.451
	Within groups	1.239	42	0.029		
	Total	1.287	44			
Total land holding	Between groups	4.865	2	2.433	0.618	0.54
	Within groups	578.388	147	3.935		
	Total	583.253	149			
Cropping pattern						
Wheat	Between groups	6.706	2	3.353	10.03	0.000
	Within groups	45.461	136	0.334		
	Total	52.167	138			
Barley	Between groups	7.362	1	7.362	17.238	0.000
	Within groups	43.565	102	0.427		
	Total	50.927	103			
Teff	Between groups	1.637	2	0.818	3.816	0.027
	Within groups	13.508	63	0.214		
	Total	15.144	65			
Oats	Between groups	0.000	1	0.000	0.5	0.487
	Within groups	0.015	21	0.001		
	Total	0.015	22			
Maize	Between groups	0.231	2	0.115	2.233	0.117

	Within groups	2.948	57	0.052		
	Total	3.179	59			
Sorghum	Between groups	0.012	1	0.012	0.187	0.67
	Within groups	1.39	22	0.063		
	Total	1.402	23			
Pulse crops	Between groups	0.127	2	0.063	1.529	0.226
	Within groups	2.321	56	0.041		
	Total	2.448	58			
Oilseed crops	Between groups	0.007	2	0.004	0.877	0.424
	Within groups	0.152	38	0.004		
	Total	0.159	40			
Vegetable crops	Between groups	0.089	1	0.089	2.603	0.119
	Within groups	0.859	25	0.034		
	Total	0.949	26			

Appendix Table 7: ANOVA table of household level livestock category and herd structure (TLU) in the mixed farming areas in the three agro-ecologies Arsi zone

Source of variation		Sum of squares	df	Mean square	F value	Sig.
Total cattle	Between groups	111.806	2	55.903	7.037	0.001
	Within groups	1167.72	147	7.944		
	Total	1279.526	149			
Cow	Between groups	38.714	2	19.357	8.567	0.000
	Within groups	332.149	147	2.26		
	Total	370.863	149			
Ox/bull	Between groups	7.805	2	3.902	1.793	0.17
	Within groups	319.904	147	2.176		
	Total	327.708	149			
Heifer	Between groups	0.177	2	0.088	0.348	0.707
	Within groups	29.69	117	0.254		
	Total	29.867	119			
Steer	Between groups	0.249	2	0.125	1.414	0.255
	Within groups	3.613	41	0.088		
	Total	3.862	43			
Calves	Between groups	0.108	2	0.054	1.643	0.197
	Within groups	4.249	129	0.033		
	Total	4.357	131			
Total sheep	Between groups	0.411	2	0.206	1.442	0.241
	Within groups	14.978	105	0.143		
	Total	15.389	107			
Mature	Between groups	0.133	2	0.066	1.18	0.312

	Within groups	5.297	94	0.056		
	Total	5.43	96			
Yearling	Between groups	0.319	2	0.159	2.962	0.056
	Within groups	5.593	104	0.054		
	Total	5.912	106			
Total goats	Between groups	10.832	2	5.416	5.84	0.004
	Within groups	79.747	86	0.927		
	Total	90.578	88			
Mature	Between groups	1.934	2	0.967	6..001	0.004
	Within groups	13.375	83	0.161		
	Total	15.309	85			
Yearling	Between groups	3.588	2	1.794	5.019	0.009
	Within groups	28.595	80	0.357		
	Total	32.183	82			
Total equine	Between groups	12.827	2	6.413	7.002	0.001
	Within groups	98.003	107	0.916		
	Total	110.83	109			
Horse	Between groups	2.685	2	1.343	2.718	0.074
	Within groups	30.634	62	0.494		
	Total	33.319	64			
Mule	Between groups	0.232	2	0.112	1.592	0.215
	Within groups	3.015	43	0.07		
	Total	3.238	45			
Donkey	Between groups	0.778	2	0.389	2.061	0.135
	Within groups	13.215	70	0.189		
	Total	13.993	72			
Chicken	Between groups	0.088	2	0.044	4.303	0.016
	Within groups	1.217	119	0.01		
	Total	1.305	121			

Appendix Table 8: ANOVA table of household major feed resources and annual dry matter yield (tons) in the mixed farming areas in the three agro-ecologies of Arsi zone

Source of variation		Sum of squares	df	Mean square	F value	Sig.
Communal grazing	Between groups	25.484	2	12.742	24.63	0.000
	Within groups	39.835	77	0.517		
	Total	65.319	79			
Private grazing	Between groups	3.833	2	1.916	1.06	0.35
	Within groups	200.617	111	1.807		
	Total	204.449	113			
Road side grazing	Between groups	1.519	2	0.759	3.907	0.025
	Within groups	13.219	68	0.194		
	Total	14.737	70			
Fallow land	Between groups	4.328	2	2.164	8.234	0.002
	Within groups	5.782	22	0.263		
	Total	10.111	24			
Cereals straws	Between groups	5390.779	2	2695.39	5.372	0.006
	Within groups	73249.08	146	501.706		
	Total	78639.86	148			
Stovers crops	Between groups	130.434	2	65.217	9.037	0.000
	Within groups	433.015	60	7.217		
	Total	563.449	62			
Pulse haulms	Between groups	2.11	2	1.055	1.361	0.265
	Within groups	43.41	56	0.775		
	Total	45.52	58			
Oil crops	Between groups	0.145	2	0.073	0.396	0.676
	Within groups	6.972	38	0.183		
	Total	7.117	40			
Forage crops	Between groups	1.225	2	0.613	3.593	0.033
	Within groups	10.913	64	0.171		
	Total	12.138	66			
Unconventional feeds	Between groups	0.578	2	0.289	5.723	0.005
	Within groups	3.231	64	0.05		
	Total	3.808	66			

Appendix Table 9: Summary of ANOVA for dry matter and nutrient intake of Arsi-Bale sheep fed dried *S. sesban* leaves, and mixed different percentage of hay, *S. sesban* leaves and noug seed cake.

Source of variation		Sum of squares	df	Mean square	F value	Sig.
Total DMI	Between groups	60193.32	2	30096.658	43.209	0.000
	Within groups	4179.253	6	696.542		
	Total	64372.57	8			
DMI (%BW)	Between groups	0.874	2	0.437	44.338	0.000
	Within groups	0.059	6	0.01		
	Total	0.933	8			
OMI	Between groups	54548.46	2	27274.231	47.335	0.000
	Within groups	3457.194	6	576.199		
	Total	58005.66	8			
CPI	Between groups	175.408	2	87.704	7.932	0.021
	Within groups	66.344	6	11.057		
	Total	241.753	8			
NDFI	Between groups	16752.07	2	8376.036	64.278	0.000
	Within groups	781.859	6	130.31		
	Total	17533.93	8			
ADFI	Between groups	3374.852	2	1687.426	32.385	0.001
	Within groups	312.633	6	52.385		
	Total	3687.485	8			
ME	Between groups	4.163	2	2.081	26.645	0.001
	Within groups	0.469	6	0.078		
	Total	4.631	8			

Appendix Table 10. Summary of ANOVA on dry matter digestibility and nutrient utilization response of Arsi-Bale sheep fed dried *S. sesban* leave, and mixed different percentage of hay, *S. sesban* leave and noug seed cake.

Source of variation		Sum of squares	df	Mean square	F value	Sig.
DMD	Between groups	0.044	2	0.022	11.785	0.008
	Within groups	0.011	6	0.002		
	Total	0.056	8			
OMD	Between groups	0.045	2	0.022	12.2	0.008
	Within groups	0.011	6	0.002		
	Total	0.056	8			
CPD	Between groups	0.021	2	0.011	12.17	0.008
	Within groups	0.005	6	0.001		
	Total	0.027	8			
NDFD	Between groups	0.034	2	0.017	6.723	0.029
	Within groups	0.015	6	0.002		
	Total	0.049	8			
ADFD	Between groups	0.038	2	0.019	5.237	0.048
	Within groups	0.022	6	0.004		
	Total	0.06	8			

Appendix Table 11. Summary of ANOVA on gross energy intake and enteric methane emission factors for sheep fed dried S. sesban leave, and mixed different percentage of hay, S. sesban leave and noug seed cake.

Source of variation		Sum of squares	df	Mean square	F value	Sig.
GEI	Between groups	19.483	2	9.741	188.46	0.000
	Within groups	0.31	6	0.052		
	Total	19.793	8			
EF	Between groups	3.552	2	1.776	192.72	0.000
	Within groups	0.055	6	0.009		
	Total	3.607	8			
DMP	Between groups	25.792	2	12.896	43.209	0.000
	Within groups	1.791	6	0.298		
	Total	27.583	8			

Appendix Table 12. Live weight and weight gain (kg) of cattle, sheep, and goats in the mixed crop-livestock production system

Species	Livestock categories	Live weight (kg)	ADW gain (kgday-1)	Initial body weight (kg)	Final body weight (kg)	Wgwean (kg)*
Cattle	Adult multipurpose cows >3 years	285.8	0			
	Adult males used for draught (3-10 years)	342.8	0			
	Adult males used for breeding & other purpose (>3-10 years)	342.8	0			
	Growing females 1-<3 years	181.4	0.149			
	Growing males 1–<3 years	226.9	0.202			
	Calves < 6 months (male & female)	53.8	0.362			
	Calves 6 m–<1 year (male & female)	105.5	0.213			
Sheep	Breeding ewes (>2 years)	27.95	0	27.95	27.95	8.65
	Mature male (>2years)	28.81	0	28.81	28.81	
	Female (1-2 years)	24.89	6.69	22.12	27.95	
	Male (1-2 years)	25.47	6.69	21.82	28.81	
	Intact male lambs (<1 year)	17.89	10.77	11.35	22.12	
	Female lambs (<1 year)	17.46	9.97	10.99	20.96	
Goat	Adult does (2+ years)	26.72	0	26.72	26.72	6.38
	Bucks (>2 years)	27.9	0	27.9	27.9	
	Yearling (1-2 years)	20.95	13.81	14.04	27.85	
	Kids (males & females, <1 year)	10.5	5.38	8.68	14.04	

Sources: (Wilkes *et al.*, 2020)

Appendix Table 13: Coefficients used to calculate associated energy requirement

Livestock categories	Coefficients considered				
	Cfi (MJ/kg day) to calculate NEm	Ca (activity coefficient, dimensionless)	Cg (coefficient for growth)	$C_{pregnancy}$	Work (hours)
Adult multipurpose cows >3 years	0.346	0.17	0	0.1	0.55
Adult males used for draught (3-10 years)	0.322	0.17	0		1.28
Adult males used for breeding & other purpose (>3-10 years)	0.37	0.17	0		0.75
Growing females 1-<3 years	0.322	0.17	0.8		0.55
Growing males 1–<3 years	0.37	0.17	1.2		0.55
Calves < 6 months (male & female)	0.345	0.17	0.97		
Calves 6 m–<1 year (male & female)	0.345	0.17	0.97		
Breeding ewes (>2 years)	0.217	0.024	0	0.077	
Mature male (>2years)	0.22	0.024	0		
Female (1-2 years)	0.217	0.024	a=1.2; b=0.45		
Male (1-2 years)	0.22	0.024	A=4.4;b=0.32		
Intact male lambs (<1 year)	0.2714	0.024	a=2.5; b=0.35		
Female lambs (<1 year)	0.236	0.024	a=1.2; b=0.45		
Adult does (2+ years)	0.315	0.024	0	0.077	
Bucks (>2 years)	0.315	0.024	0		
Yearling (1-2 years)	0.315	0.024	a=5;b=0.33		
Kids (males & females, <1 year)	0.315	0.024	a=5;b=0.33		

(IPCC, 2006a, 2019; Wilkes *et al.*, 2020)

Appendix Table14. Models (formulae) used to estimate different forms of net energy required by the cattle in the agro-ecology

Highland								
SN	Type of energy	Model used	calculated values for cattle					
			Cow	Adult male	Breeding Male	Female	Male	Calves (6m-12y	Calves (<6m)
1	Net energy for maintenance	$NEm=cf1*(weight)^{0.75}$	24.05	25.65	29.48	15.92	21.63	11.39	6.87
2	Net energy for activity	NEa=Ca*NEm	4.088	4.36	5.01	2.706	3.677	1.936	1.168
3	Net energy for growth	$NEg=22.02*(BW/C*MW)^{0.75}*WG^{1.097}$				2.293	2.438	1.865	2.0135
4	Net energy for lactation	NEl=milk*(1.47+0.4*fat)	1.6346						
5	Net energy for work	$NE_{work}=0.1*Ne_m*hours$	1.7076	3.514	1.8276	1.05	1.406		
6	Net energy for pregnancy	$NE_p=C_{pregnancy}*NE_m$	1.405						
7	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.46777	0.46777333	0.46777333	0.468	0.468	0.46777333	0.46777333
8	REG	$REG=(1.164-(5.16*10^{-3}*DE)+(1.308*10^{-5}*(DE)^2)-(37.4/DE))$	0.23601	0.23601128	0.23601127	0.236	0.236	0.23601127	0.23601127
Midland									
1	Net energy for maintenan	$NEm=cf1*(weight)^{0.75}$	24.05	25.65	29.48	15.92	21.63	11.39	6.87

	ce								
2	Net energy for activity	NEa=Ca*NEm	4.088	4.36	5.01	2.706	3.677	1.936	1.168
3	Net energy for growth	$NEg=22.02*(BW/C*MW)^{0.75}*WG^{1.097}$				2.293	2.438	1.865	2.0135
4	Net energy for lactation	NEl=milk*(1.47+0.4*fat)	1.6346						
5	Net energy for work	$NE_{work}=0.1*Ne_m*hours$	1.7076	3.514	1.8276	1.05	1.406		
6	Net energy for pregnancy	$NE_p=C_{pregnancy}*NE_m$	1.405						
7	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.4676	0.46760321	0.467603209	0.4676	0.468	0.467603209	0.467603209
8	REG	$REG=(1.164-(5.16*10^{-3}*DE)+(1.308*10^{-5}*(DE)^2)-(37.4/DE))$	0.23575	0.23574628	0.23574628	0.2357	0.236	0.23574628	0.23574628
Lowland									
1	Net energy for maintenance	$NEm=cf1*(weight)^{0.75}$	24.05	25.65	29.48	15.92	21.63	11.39	6.87
2	Net energy for activity	NEa=Ca*NEm	4.088	4.36	5.01	2.706	3.677	1.936	1.168
3	Net energy for growth	$NEg=22.02*(BW/C*MW)^{0.75}*WG^{1.097}$				2.293	2.438	1.865	2.0135
4	Net energy for lactation	NEl=milk*(1.47+0.4*fat)	1.6346						
5	Net energy for work	$NE_{work}=0.1*Ne_m*hours$	1.7076	3.514	1.8276	1.05	1.406		
6	Net energy for pregnancy	$NE_p=C_{pregnancy}*NE_m$	1.405						

7	REM	REM=(1.123-(4.092* 10^{-3}*DE)+(1.126* 10^{-5}* (DE)^2)-(25.4/DE))	0.46409	0.4640863	0.464086628	0.4641	0.464	0.464086628	0.464086628
8	REG	REG= (1.164 -(5.16 *10^{-3}*DE) + (1.308 *10^{-5}*(DE)^2) -(37.4/DE))	0.23027	0.2302721	0.230272096	0.2303	0.23	0.230272096	0.230272096

(IPCC, 2006, 2019; Wilkes *et al.*, 2020)

Appendix Table 15. Models (formulae) used to estimate different forms of net energy required by the sheep in the agro-ecology

SN	Type of energy	Models used	Calculated values for sheep					
			Breeding ewes	Mature male	Female	Male	Intact male lamb	Female lamb
1	Net energy maintenance	$NEm=cf1*(weight)^{0.75}$	2.6378	2.7389	2.4181	2.4972	2.3608	2.0158
2	Net energy for activity	NEa=Ca*(weight)	0.6708	0.69144	0.59736	0.61128	0.42936	0.41904
3	Net energy for growth	NEg={WGlambs*(a+0.5b(BWi+BWf))}/365			0.24498	0.239399	0.50004	0.514493
4	Net energy for lactation	$NEl=\{(5*Wg_{wean})/365\}*Ev_{milk}$	0.32495					
5	Net energy pregnancy	$Nep=C_{pregnancy}*NE_m$	0.203112578					
6	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.467807327	0.467807	0.467807	0.467807	0.467807	0.467807
7	REG	$REG=(1.164-(5.16*10^{-3}*DE)+(1.308*10^{-5}*(DE)^2)-(37.4/DE))$	0.236064232	0.236064	0.236064	0.236064	0.236064	0.236064
	Midland							
1	Net energy maintenance	$NEm=cf1*(weight)^{0.75}$	2.6378	2.7389	2.4181	2.4972	2.3608	2.0158
2	Net energy for activity	NEa=Ca*NEm	0.6708	0.69144	0.59736	0.61128	0.42936	0.41904
3	Net energy for growth	NEg={WGlambs/kids*(a+0.5b(BWi+BWf))}/365			0.24498	0.239399	0.50004	0.514493
4	Net energy for	$NEl=\{(5*Wg_{wean})/365\}*Ev_{milk}$	0.32495					

	lactation							
5	Net energy pregnancy	$Nep=C_{pregnancy}*NE_m$	0.203112578					
6	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.464647389	0.46464 7	0.46464 7	0.46464 7	0.46464 7	0.46464 7
7	REG	$REG= (1.164 -(5.16 *10^{-3}*DE) + (1.308 *10^{-5}*(DE)^2) -(37.4/DE))$	0.231144575	0.23114 5	0.23114 5	0.23114 5	0.23114 5	0.23114 5
	Lowland							
1	Net energy maintenance	$NEm=cf1*(weight)^{0.75}$	2.6378	2.7389	2.4181	2.4972	2.3608	2.0158
2	Net energy for activity	NEa=Ca*NEm	0.6708	0.69144	0.59736	0.61128	0.42936	0.41904
3	Net energy for growth	NEg={WGlambs/kids*(a+0.5b(BWi+BWf))}/ 365			0.24498	0.23939	0.50004	0.51449
4	Net energy for lactation	$NEl={(5*Wg_{wean})/365}*Ev_{milk}$	0.32495					
5	Net energy pregnancy	$Nep=C_{pregnancy}*NE_m$	0.203112578					
6	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.461743958	0.46174 4	0.46174 4	0.46174 4	0.46174 4	0.46174 4
7	REG	$REG= (1.164 -(5.16 *10^{-3}*DE) + (1.308 *10^{-5}*(DE)^2) -(37.4/DE))$	0.226628953	0.22662 9	0.22662 9	0.22662 9	0.22662 9	0.22662 9

(IPCC, 2006, 2019; Wilkes *et al.*, 2020)

Appendix Table 16. Models (formulae) used to estimate different forms of net energy required by the goats in the agro-ecology

SN	Type of energy	Models used	Calculated values for goats			
			Adult does	Buck	Yearling	Kids
	Highland					
1	Net energy for maintenance	$NEm=cf1*(weight)^{0.75}$	3.702	3.82396	3.084598	1.84
2	Net energy for activity	NEa=Ca*(weight)	0.64128	0.6696	0.5028	0.25248
3	Net energy for growth	NEg={WGlambs*(a+0.5b(BWi+BWf))}/365			0.45069	0.169725
4	Net energy for lactation	$NEl=\{(5*Wg_{wean})/365\}*Ev_{milk}$	0.166016			
5	Net energy for pregnancy	$Nep=C_{pregnancy}*NE_m$	0.28505497			
6	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.467807327	0.467807	0.467807	0.467807
7	REG	$REG=(1.164-(5.16*10^{-3}*DE)+(1.308*10^{-5}*(DE)^2)-(37.4/DE))$	0.236064232	0.236064	0.236064	0.236064
	Midland					
1	Net energy for maintenance	$NEm=cf1*(weight)^{0.75}$	3.702	3.82396	3.084598	1.84
2	Net energy for activity	NEa=Ca*NEm	0.64128	0.6696	0.5028	0.25248
3	Net energy for growth	NEg={WGlambs/kids*(a+0.5b(BWi+BWf))}/365			0.45069	0.169725
4	Net energy for lactation	$NEl=\{(5*Wg_{wean})/365\}*Ev_{milk}$	0.166016			
5	Net energy for pregnancy	$Nep=C_{pregnancy}*NE_m$	0.28505497			
6	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.464647389	0.464647	0.464647	0.464647
7	REG	$REG=(1.164-(5.16*10^{-3}*DE)+(1.308*10^{-5}*(DE)^2)-(37.4/DE))$	0.231144575	0.231145	0.231145	0.231145
	Lowland					
1	Net energy for maintenance	$NEm=cf1*(weight)^{0.75}$	3.702	3.82396	3.084598	1.84

2	Net energy for activity	NEa=Ca*NEm	0.64128	0.6696	0.5028	0.25248
3	Net energy for growth	NEg={WGlambs/kids*(a+0.5b(BWi+BWf))}/365			0.45069	0.169725
4	Net energy for lactation	$NEl=\{(5*Wg_{wean})/365\}*Ev_{milk}$	0.166016			
5	Net energy for pregnancy	$Nep=C_{pregnancy}*NE_m$	0.28505497			
6	REM	$REM=(1.123-(4.092*10^{-3}*DE)+(1.126*10^{-5}*(DE)^2)-(25.4/DE))$	0.461743958	0.461744	0.461744	0.461744
7	REG	$REG=(1.164-(5.16*10^{-3}*DE)+(1.308*10^{-5}*(DE)^2)-(37.4/DE))$	0.226628953	0.226629	0.226629	0.226629

(IPCC, 2006, 2019; Wilkes *et al.*, 2020)

Appendix Table 17. ANOVA table of cattle, sheep and goats estimated enteric CH_4 (kg/year), Methane (kg/year), nitrogen excretion (kg/year) and nitrous oxide (g/year) emissions from manure in the mixed farming areas of Arsi zone

Parameter	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Enteric methane emission						
Cattle	Model	8	9067.5738	1133.44672	18269.5	<.0001
	Error	12	0.744484	0.06204		
	C. total	20	9068.3182			
Sheep	Model	7	40.172372	5.73891028	10383.5	<.0001
	Error	10	0.0055269	0.00055269		
	C. total	17	40.177899			
Goat	Model	5	36.677926	7.3355852	6541.28	<.0001
	Error	6	0.0067286	0.00112143		
	C. total	11	36.684655			
Methane from manure emission						
Cattle	Model	8	44.933925	5.61674065	7070.1	<.0001
	Error	12	0.0095332	0.00079444		
	C. total	20	44.943458			
Sheep	Model	7	0.0007171	0.00010245	157.05	<.0001
	Error	10	6.52E-06	0.00000065		
	C. total	17	0.0007237			
Goat	Model	5	0.0147042	0.00294084	2878.4	<.0001
	Error	6	6.13E-06	0.00000102		
	C. total	11	0.0147103			
Nitrous oxide emission						
Cattle	Model	8	0.25567	0.03195875	19175.25	<.0001
	Error	12	0.00002	1.66667E-06		
	C. total	20	0.25568			
Sheep	Model	7	8.04E-05	1.15E-05	2280.09	<.0001
	Error	10	5.04E-08	5.04E-09		
	C. total	17	8.04E-05			
Goat	Model	5	1.12E-03	2.25E-04	7624.36	<.0001
	Error	6	1.77E-07	2.95E-08		
	C. total	11	1.12E-03			

Appendix Table 18. Input data on MMS, fraction of manure managed in MMS and manure management CH_4 conversion factors.

	Liquid system		Solid storage		Dry lot		Pasture (range)		Burn for fuel		EF3	
Sub-categories of species	MS, %	MCF, %	MS, %	MCF, %	MS, %	MCF, %	MS, %	MCF, %	MS, %	MCF, %	Dry lot	Solid storage
Adult multipurpose cows >3 years	0.05	27.18	0.1	5	0.13	2	1.5	0.47	0.24	10	0.02	0.005
Adult males used for draught (3-10 years)	0.05	27.18	0.1	5	0.13	2	1.5	0.47	0.24	10	0.02	0.005
Adult males used for breeding & other purpose (>3-10 years)	0.05	27.18	0.1	5	0.13	2	1.5	0.47	0.24	10	0.02	0.005
Growing females 1-<3 years	0.05	27.18	0.1	5	0.13	2	1.5	0.47	0.24	10	0.02	0.005
Growing males 1–<3 years	0.05	27.18	0.1	5	0.13	2	1.5	0.47	0.24	10	0.02	0.005
Calves < 6 months (male & female)	0.05	27.18	0.1	5	0.13	2	1.5	0.47	0.24	10	0.02	0.005
Calves 6 m–<1 year (male & female)	0.05	27.18	0.1	5	0.13	2	1.5	0.47	0.24	10	0.02	0.005
Breeding ewes (>2 years)			17	5	3	2	80	0.47			0.02	0.005
Mature male (>2years)			17	5	3	2	80	0.47			0.02	0.005
Female (1-2 years)			17	5	3	2	80	0.47			0.02	0.005
Male (1-2 years)			17	5	3	2	80	0.47			0.02	0.005
Intact male lambs (<1 year)			17	5	3	2	80	0.47			0.02	0.005
Female lambs (<1 year)			17	5	3	2	80	0.47			0.02	0.005

Adult does (2+ years)			17	5	3	2	80	0.47			0.02	0.005
Bucks (>2 years)			17	5	3	2	80	0.47			0.02	0.005
Yearling (1-2 years)			17	5	3	2	80	0.47			0.02	0.005
Kids (males & females, <1 year)			17	5	3	2	80	0.47			0.02	0.005

Source. (IPCC, 2006a, 2019)

8.2. **Figures in the Appendices**

Dung left on pasture

Dung cake

Appendix Figure 1. Manure management and utilization types in the mixed farming areas of Arsi zone

8.3. **Published Articles**

1. Feed Resources Potential and Nutritional Quality of Major Feed Stuffs in the Three Agro-Ecological Zone of Mixed Farming System in Arsi Zone, Ethiopia.

Birhanu Mamo, Ashenafi Mengistu and Belete Shenkute

Published on Asian Journal of Research in Animal and Veterinary Sciences, 6(3), pp. 241-252, 2023; DOI: 0.9734/AJRAVS/2023/v6i3251

https://www.sdiarticle5.com/review-history/101327

2. Supplementary effects of Noug Seed (*Guizotia abyssinica*) Cake with Sesbania (*Sesbania sesban*) Leaves on Feed Intake, Digestibility and Enteric Methane Emission in Arsi-Bale Sheep.

   Birhanu Mamo, Ashenafi Mengistu and Belete Shenkute

Published on Journal of Agricultural Research. 8(3) 000316, 2023, DOI: 10.23880/oajar-16000316.

Questionnaires Used for the Study

Primary data collection format

Part-I: General information on household characteristics and resource holding

Section A: household characteristics

1. Household Head Name: _____

   Sex: _____ Age: _____ *Kebele* _____ HH mobile: _____.

2. Marital status: 1) Single 2) Married 3) Divorced 4) widowed
3. Total number of family members' _____ (Male_____

   Female_____)

3. Age category of the family members:

	Children (≤14 years)	Adult (≥15- 65 years)	Dependents (>65 years)
Total family members			

4. Education level of the respondent: Tick (X)

Illiterate	Read & write	Primary (1- 6)	Secondary (grade 7- 10)	Preparatory & above

Section B: ***Farming activities and resource holding***

1. How many years you have been in crop-livestock farming? _____.

2. Land holding and land used for different agricultural activity (timad):

	Grazing	Crop	Fallow	Forage crops	Forest	Rented in/out cropland	Total land
Timad							

3. Fill the table below with the proportion of shared grain and crop residues:

Grain %	Residue %

4. What is the area of land (*timad)* utilized for major food crops you grown in the current year?

	Main rainy season	Short rainy season	Irrigation
Wheat			
Barley			
Teff			
Oats/'Aja'			
Maize			
Finger Millet			
Sorghum			
Pulse			
Oil crops			
Vegetable			
Total land			

5. Amount of grain yield (*quintal*) and residue obtained from major crops of the current year:

	Main rainy season	Short rainy season	Irrigation	Residue (ton)
Wheat				
Barley				
Teff				
Oats/'Aja'				
Maize				
Finger millet				
Sorghum				
H. bean				
Field pea				
Oil crops				
Vegetable				
Total land				

6. Cattle owned and the herd structure (number):

	Lactating cow	Dry cow	Oxen/bull	Heifers	Steers	Calves	Remark
Number							Indigenous
Number							Exotic
Number							Cross breed

7. Sheep and goat owned and the herd structure (number):

		< 6 Months	6 Mo < 1yr	1yr - <2 yrs	2 yrs &Over
Sheep	Male				
	Female				
Goats	Male				
	Female				

8. Equines and camels owned (number):

	Horses		Mules		Donkeys		Camels	
Number	Male	female	Male	Female	Male	Female	Male	Female
< 3 Years								
3 Years & more								
Under 4 Years	[redacted]							
4 years and older								

9. Chicken

	Chicken					
	Cocks	Cockerels	Pullets	Non-Laying Hens	Chicks	Laying Hens

Part II. Livestock manure management

Section A. Livestock manure management and use type

1. Ways of livestock manure management and use type? (Tick X)

	Collected & managed	Left in the kraal	Made to dung cake	Discarded	Used as fertilize	Other purpose
Cattle						
Equines						
Shoats						
Chicken						