STUDY OF SMALLHOLDER FARMS LIVESTOCK FEED SOURCING AND FEEDING STRATEGIES AND THEIR IMPLICATION ON LIVESTOCK WATER PRODUCTIVITY IN MIXED CROP-LIVESTOCK SYSTEMS IN THE HIGHLANDS OF THE BLUE NILE BASIN, ETHIOPIA

M.Sc. Thesis

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A Thesis Submitted to the School of Animal and Range Sciences, School of Graduate Studies
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In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN AGRICULTURE (RANGE ECOLOGY AND MANAGEMENT)

By

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As Thesis research advisors, we hereby certify that we have read and evaluated this Thesis, prepared under our guidance, by Bedasa Eba, entitled ''**Study of Smallholder Farms Livestock Feed Sourcing and Feeding Strategies and Their Implication on Livestock water productivity in Mixed-crop Livestock Systems in the Highlands of the Blue Nile Basin, Ethiopia**'' and recommend that it be submitted as fulfilling the Thesis requirement.

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As members of the Examining Board of the Final MSc. thesis Open Defense, we certify that we have read and evaluated the thesis prepared by **Bedasa Eba** and recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in Agriculture (Range Ecology and Management).

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DEDICATION

I dedicate this thesis manuscript to my father EBA TEBEJE, and my mother TARIKE AYANA, for nursing me with affection and love and for their committed partnership in the success of my life.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my genuine work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc. degree at Haramaya University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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LIST OF ABBERVIATIONS

ARDO	Agriculture and Rural Development Offices

BNB	Blue Nile Basin
BPS	Barley-Potato System
DM	Dry Matter
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nation
FWP	Feed Water Productivity
GLM	General Linear Model
ha	Hectare
Kc	Crop Coefficient
ILRI	International Livestock Research Institute
IVDMD	In vitro Dry Matter Digestibility
IWMI	International Water Management Institute
LGP	Length of Growing Period
LSD	Least Significant Difference
LWP	Livestock Water Productivity
ME	Metabolisable Energy
MSS	Maize-Sorghum System
RPS	Rice-Pulses System
SAS	Statistical Analysis System
TLU	Tropical Livestock Unit
TMMS	Teff-Millet/Maize System
TMS	Teff-Millet System
TSS	Teff-Sorghum System
TWS	Teff-Wheat System

BIOGRAPHICAL SKETCH

The author was born in 1983 at Guduru Woreda, Horro-Guduru Wollega zone, Oromia regional state, Ethiopia. He attended elementary, junior secondary and high school education in Loyakidame, Fincha, and Shambu Schools, respectively.

The author joined Mekelle University in September 2002 and graduated with BSc degree in Animal, Range and Wild life Sciences on 16 July 2006. He worked in Agriculture and Rural Developments Office of the Abay Choman Woreda, Horro-Guduru Wollega zone as a feed resource expert from August 2006 up to April 2007. He also worked as instructor in Kombolcha Agriculture Technical and Vocational Education Training (ATVET) College, East Hararge from May 2007 up to April 2008. He has served as junior researcher in Oromia Agriculture Research Institute at Yabello Pastoral and Dry Land Agriculture Research Center, since September 2010. Then in October 2010 he joined the School of Graduate Studies at Haramaya University to pursue his MSc study in Range Ecology and Management.

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ABSTRACT

This study was conducted to assess livestock feed sourcing and feeding strategies and their implications on livestock water productivity (LWP) in mixed crop-livestock production systems of the Blue Nile Basin (BNB) in Ethiopian Highlands. Three Woredas (Diga, Jeldu and Fogera) representing diverse agricultural farming systems were considered. One watershed in each Woreda, which is Dapo from Diga, Meja from Jeldu and Mizuwa from Fogera were selected. Each watershed further stratified to different farming systems depending on cropping pattern and landscape positions. Accordingly seven farming system has been identified. Diga has teff-millet and maize-sorghum farming systems; Jeldu has barley-potato, teff-wheat and teff-sorghum farming systems; and Fogera has teff-millet/maize and rice-pulses farming systems. A multi-stage stratified random sampling technique was employed to select farm households. A total of 220 household were selected: where 67 household from Diga, 91 household from Jeldu and 62 household from Fogera Woreda. A structured questionnaire, group discussions, plant biomass sampling, literature and survey were done to generate data on farmers feed sourcing and feeding strategies. To estimate livestock water productivity, water depleted (evapotranspired) for livestock feed was estimated using reference evapotranspiration and crop coefficient and then LWP was estimated as a ratio of livestock's beneficial outputs and services to depleted water. The results indicated that the major feed sources in the BNB were mainly from natural pasture and crop residues. Improved feed sources including those with denser metabolisable energy were not reported. The share of crop residues on dry matter basis was highest in all study sites. In the study farming system the contribution of crop residues to livestock feed sourcing varied *among farming systems and it ranged from 58.5% to 78.2%. Generally access to crop residues by the households is a function of crop composition and productivity at farm scale and thus varies across study systems. For example in Diga and Fogera, the dry matter of crop residues per household were greater for maize-sorghum and rice-pulses systems, respectively at $P<0.05$. Similarly dry matter from private grazing land showed significant differences among the farming systems in Jeldu and Fogera at $P<0.05$. The feed storage, feeding strategies and utilization techniques were relatively similar among the study farming systems but the magnitude varies in Woredas. In response to low biomass yield feed deficit in terms of metabolisable energy predominated in all farming systems, except maize-sorghum system of Diga. The water depleted for feed production ($m^3 ha^{-1}$) and feed water productivity (FWP) (kg m^{-3}) were greater for maize-sorghum and rice-pulses systems of Diga and Fogera Woreda, respectively at $P<0.05$. FWP for Jeldu systems was also differed ($P<0.05$). The productivity of livestock per TLU (US\$ TLU^{-1}) was greater only for maize-sorghum system in Diga at $P<0.05$. There was no significance difference ($P>0.05$) observed in LWP within all Woreda between the farming systems, and the value falls between 0.15-0.19 US\$ m^{-3}. However, when farm households clustered into wealth status difference of LWP was observed within all farming systems (ranges 0.08-0.24US\$ m^{-3}) and lower value of LWP general observed for the poor farm households. Such big gap of LWP for farm households operating in the same farming system suggests a potential for improvements. Such big differences of LWP values among farm household can be accounted for by the strategies farm households are following in feed sourcing and how water productive those feed sources are. Although divergences in feeding strategies and livestock beneficial outputs were not vivid, among the systems, empirical evidences suggests that these are also a good entry points to improve LWP. Hence, in the context of this work, options to improve LWP mainly involve sourcing water productive and higher quality feed.*

Key words: feed sourcing, farming system, Livestock water productivity, Dry matter, water depleted

1. INTRODUCTION

The Ethiopian Highlands, which cover major parts of the Blue Nile Basin (BNB), are highly populated by people and livestock (CSA, 2008). The density ranges from 37-120 person/km^2 and 27-130 TLU/km^2. This is one of the major reasons for severe degradation of the natural resources base in this part of the country. Approximately 88% of the human, 75% of the cattle, 75% of the sheep and 34% of the goat population in Ethiopia are found in the Highlands (CSA, 2008).

Livestock keeping is an intensive use of the earth's increasingly scarce water resources. Water productivity in agriculture highlights livestock as a key area for water productivity improvement (Molden, 2007). There are many ways in which livestock affect water productivity across a landscape, but the most important one is through the feed that they consume (Tilahun *et al.*, 2009) and therefore understanding the interactions between livestock and water is an important avenue in improving water productivity of livestock. Steinfeld *et al.* (2006) also indicated that significant volumes of water are withdrawn globally for the production of feed. The presence of heavy grazing also disturbs water cycles, reducing replenishment of below ground water resources, ultimately impacting sustainable livestock and crop production. In general, there is a growing concern that increased water scarcity and water competition among different uses and users can hinder meeting increasing food-feed demands (Benin *et al.*, 2006).

The BNB shares similar problems of unproductive and inefficient uses of water by the agricultural sector. Recent studies indicated that much rain water is lost as unproductive run off and evaporation and high volume of water is required to produce a liter of milk (Descheemaeker *et al*., 2010a). Although livestock benefits in mixed crop livestock systems are more than just milk production, the current situation affects sustainable use of the scarce water resource and the livelihoods of smallholder farmers. Amare *et al*. (2009) suggests that adequate feed supply largely determines livestock production while the ways feed is produced and supplied to the animal affect the water productivity of livestock and ecosystem services. Furthermore, the findings of Solomon *et al*. (2009) advocate some strategies and technological options such as improved feeds, better herd management (e.g., appropriate herd structure such as age and weight) that should be taken into account to enhance Livestock Water Productivity (LWP).

It is necessary to understand scientific links among LWP, feeding and feed sourcing strategies and selecting best practices that fit different farming systems and landscapes in the mixed crop livestock systems. In this respect Amare *et al.* (2009) suggested that in addition to feed sourcing, dry matter (DM) productivity and feed quality are important factors influencing the volume of water needed to support animal production. For example, the lower the DM productivity the more land is required to produce sufficient quantity of feed to satisfy the metabolisable energy (ME) and protein requirements of livestock. In terms of quality of feed, a recent study in Indo-Ganga Basin (Amare *et al*., 2011a) suggested that the total DM requirement of livestock to meet certain production targets can be reduced by improving feed quality. For example, by changing feed quality from 7 MJ kg^{-1} to 8.5 MJ kg^{-1} as much as 120 m^3 of water can be saved per cow per year. The saved water can be used for ecosystem services or alternative livelihood activities (e.g., supplemental irrigation for crops or additional milk production). The same study further elaborated that not only the feed quality, quantity and productivity that matters but also contact between livestock and the environment. For example, feeding strategies such as cut and carry systems, and tethering can mitigate livestock's impact on nutrient fluxes between and within systems (e.g., erosion), and through such practices considerable amount of energy can be saved which otherwise will be spent in walking in search of feed (Descheemaeker *et al*., 2010a). This has strong implication for LWP. Feeding strategy also includes how we synchronize temporal and spatial availability of feed and water resources to enhance efficient use of feed resources and also mitigate over grazing of areas around limited watering points.

Peden *et al*. (2006) and Amare *et al*. (2009) pointed out that the management of different species and breeds of domestic animals and their interaction with water vary in different farming systems due to farmers' diverse livelihood strategies (i.e., livestock or crop focused livelihood) and the resources base. Understanding spatial and temporal variability of these interactions and circumstances that result in unproductive water use is important to enhance

LWP (Peden *et al*., 2007; Peden *et al*., 2009). Therefore, it is important to understand the farming systems and landscape feed sourcing and feeding strategies in the Highlands of BNB. Thus, generating baseline information in this area will serve as a reference point to explore different water efficient feed sourcing and feeding practices. Furthermore, most of the research works related to livestock feed resources in different parts of the country, focused on feed demand and supply analysis and the feed rationing exercises. Most often they also consider parameters such as feed cost and feed quality. This thesis argues that an insight of the water productivity of feeds and efficient uses of water productive feeds is equally important. Therefore the objectives of this study were:

- To identify the different livestock feed sourcing and feeding strategies and their dynamics across different landscapes and farm typologies in mixed crop livestock systems of the BNB
- To assess the dry matter productivity and implications for feed demand-supply and farmers coping mechanisms in time of feed shortage in mixed crop livestock systems of the BNB
- To assess the effects of current feeding strategies on livestock water productivity
- To propose alternative livestock feed management practices that make water more productive, enhance ecosystem services and improve livelihoods of the smallholders

2. LITERATURE REVIEW

2.1. Feed Resources in the Ethiopian Highlands

In the Highlands of Ethiopia (including major parts of the Blue Nile Basin), livestock feed resources are mainly from natural pasture, crops residues and stubble grazing. The contributions of these ingredients to the total feed resource base vary across systems, seasons of the year and farm typology (Seyoum *et al.,* 2001). Temporal and spatial variation of the feed resources in terms of access and availability and quality is a major concern. In general feed resources availability depends on the intensity of crop production and amount and distribution of the rain fall (Mohammed and Abate, 1995). Seyoum *et al*. (2001) noted that pasture growth is a reflection of the annual rainfall distribution pattern. Despite the good rain fall in major parts of the BNB, decline in the size and productivity of grazing land is a growing concern. Numbers of scholars ascribe this to overgrazing and the expansion of arable cropping. As coping mechanism, farmers in different mixed-crop livestock production systems are increasingly feeding agricultural by-products to their livestock (Alemu *et al*., 1991; Abate *et al*., 1993; Getinet, 1999; Alemayehu, 2004). The potential use of crop residues as livestock feed is greatest in mixed crop-livestock farming systems (Kossila, 1988; Getachew, 2002; Lemma, 2002). Crop residues are required by animals to supply feeds during the dry season and yet trade off with soil fertility management and crop residue's poor feed quality are some of the major challenges.

2.1.1. Natural pasture

Natural grassland consists of the main Highlands pastures of Ethiopia and the grassland of Ethiopia accounts for about 30.5% of the area of the country (Alemayehu, 2004). The change of species composition in the grassland vegetation naturally depends upon a number of factors. From ecological point of view, grassland develops as a direct expression of the climate and other sets of factors which are unfavorable for the growth of trees (Zerihun, 1985) including altitude, soil and farming system (Alemayehu, 2004). In the Highlands of Ethiopia, seasonal fluctuation in the availability and quality of natural pasture is a common phenomenon which results in serious feed shortage thereby affecting livestock production and productivity (Zinash *et al*., 1995; Alemayehu, 1998; Solomon, 2004). Grazing of pasture and rangelands is an integral component of livestock production systems in many countries (Johanston *et al*., 1996). Livestock grazing stimulates nutrient mobilization and uptake through consumption of vegetation; in that mobilization of nutrients to the growing points is enhanced by frequent defoliation (Mohamed, 1998).

The degradation of the BNB grazing land relates to a combination of human exploitation exceeding the natural carrying capacity of the land resources systems, and inherent ecological fragility of the systems (Mohamed and Abyie, 1998). Grazing lands biomass yield is very low (e.g., 1.6 ton ha^{-1} in Fogera) (Descheemaeker *et al.*, 2010b). This has a negative implication for LWP value. But the magnitude of biomass varies by intensity of grazing. For example, biomass yield on non-grazed area varied from 2.84–4.13 ton ha^{-1} whereas on grazed area varied from 0.84–2.25 ton ha^{-1}(Grima and Peden, 2003). According to Alemayehu (1987), in the Highlands of Ethiopia, the annual DM yield of the natural pasture on seasonally waterlogged fertile areas was estimated to be 4-6 ton ha^{-1}. But the concern here is that only water loving species may grow and thus the overall nutritional value of pastureland will be affected. Biomass yield decreased as the altitude increases. Farming systems and altitude are important variables affecting vegetation distribution (Ayana, 1999; Amsalu, 2000). Botanical composition of plant species and productivity of the pasture land are highly influenced by animal species, intensity of grazing and edaphic factors. Biomass production over time varies and therefore, causes seasonal variation in forage availability (Holechek *et al*., 1998).

In addition to biomass yield, pasture management practices appear to affect floristic composition. For example, continuous over stocking decreases the proportion of desirable species and favors infestation by less nutritious and unpalatable species (Ahmed, 2006).

2.1.2. Crop residues and other agro-industrial by-products

Crop residues represent a large part of feed resources, most of which are underutilized (Alemu *et al*., 1991). Cereal crop residues are the most important feed resources for ruminants in developing countries (Reed, 1985). Crop Residues described as roughages that become available for livestock feed after crops have been harvested (World Bank, 1989; Nordblom and Shomo, 1995). Crop residues are distinct from agricultural by-products: such as bran, oil seed cakes, which are generated when crops are processed in different industries for food main products. Crop residues can usually be grouped by crop type including cereals, grain legumes, roots and tubers. The role of crop residues as feed sources depends mainly on degree of intensification of crop-livestock systems and shortage of feed from natural pasture. In major parts of the BNB crop residues are important ingredient and the type of residues depends on the major cropping systems, (i.e., maize, teff, wheat, barley, rice based). As the ME values and digestibility of these crop varies associated LWP values can be influenced. In many parts of the BNB, farmers collect and store residues after harvest. Most farmers selectively feed milk cows and work animals during critical feed shortage time. Depending on cropping systems some farmers may mix cereals residues with legumes to enhance the nutritive value and consequently the LWP.

In most parts of the BNB, stubble is also important feed resources. For example, Bekele (1991) reported an average DM yield of 2 ton ha^{-1} $year^{-1}$ with 0.3 feed use factors (30% utilization rate of crop stubbles). According to FAO (1987), utilizable average Dry Matter Yield (DMY) of stubble grazing is estimated to be 0.5 ton ha^{-1} $year^{-1}$. This shows strong variability across systems. Zinash and Seyoum (1991) reported that in the central Highland zone (Shewa administrative region which include some parts of BNB) the available feed resources (grazing and agricultural by-products) could only meet the maintenance requirements of animals and half of the total cow herd the existing production requirements at level of 5 liter day^{-1}. Getachew *et al.* (1993) also indicated that on average, the available feed per farm meets only maintenance requirements of animals and very little is left over for growth and production. Small holder farmers' use of feed concentrates such as bran and oils seed cake occurs mostly in peri-urban areas due to less availability and affording capacity.

Many livestock production systems rely on crop residues as the main feed resource. Thus, enhancing water productivity on the plant side would also enhance productivity of the livestock. In general the interdependency between the crop production and livestock shows the role of livestock in improving resources uses efficiencies and obviously LWP will increase from efforts to improve crop water productivity (Sonder *et al.,* 2004).

2.2. Feeding Calendar and Farmers Coping Strategies

Study on feeding calendar of livestock in BNB is scarce. Mohamed and Abate (1995) identified three feeding periods and associated feeding strategies in the Central Highlands of Ethiopia, which also covers a significant part of the BNB. The first one is the main rainy season (June-September) when feed is adequate and livestock are under controlled grazing and crop residues supplement the green fodder from grazing and weeds. The second is the dry season (October-February) when feed from stubble grazing and crop residues gradually become available and depending on system farmers may practices open grazing on crop lands, communal grazing lands and in community forest areas and fallow lands. The last is the period starting from March to May, when feed supplies decline, although new re-growth may occur depending on the timeliness and amount of the short rains. In the last calendar period farmers may selectively feed productive animals (e.g., milk cows and calf) on hay and conserved crop residues and normally open grazing on: communal grazing areas, crop and fallow lands are major sources of feed (Getnet, 1999; Yoseph, 1999; Getachew, 2002; Solomon, 2004).

2.3. Livestock Water Productivity: The Concept and its Linkage to Feed Sourcing and Feeding Strategies

Livestock water productivity (LWP) is defined as the amount of water depleted to produce livestock products and services including energy (Peden *et al*., 2007; Sonder *et al*., 2004). In this respect, depleted water for feed production is mainly given due attention as drinking water for livestock is reported to be about 2%. Although, water accounting models have helped understand crop water productivity, no systematic consideration has been given to understand livestock's uses of water and impact on water resources (Sonder *et al.*, 2004). Thus, the concept of LWP framework was introduced by Peden *et al.* (2007) to investigate these interactions and find ways to increase livestock production without depleting more water or causing further environmental degradation. In broader terms, water productivity measures the ability of agricultural systems to convert water into food and feed and is defined as the ratio of agricultural outputs to the volume of water depleted for production (Molden *et al.*, 2010). Globally, current animal production depletes more than 1 x 10^{12} m^3 of water per year only for feed and this is about one seventh of the global water depletion for agriculture (Peden *et al*., 2007). However, by 2020, livestock will likely produce more than half of the total global agricultural output in monetary value. This will place a significant extra demand on agricultural water resources, especially for livestock feed production. The question is how this concept relates to feeding and feed sourcing strategies.

The LWP of animals is influenced by the type of feed they consume. In cases where livestock are fed crop residues and graze rangelands, which are unsuitable for crop production anyway, livestock make a very effective use of the invested water (Peden *et al*., 2007). Adequate feed supply largely determines livestock productivity while the way feed is produced affects the sustainability of water use (Blümmel *et al.*, 2009). The feed sources and the efficiencies with which feed is utilized within the animal determine the amount of water required to produce livestock products and services. Solomon *et al*. (2009) showed that about 11.5 m^3 of water was depleted to produce 1 kg of meat. According to Singh *et al.* (2004) and Amare *et al.* (2011a), the quantity of water used to produce feed can vary based on the livestock feed sourcing strategies, such as feed from food-feed crops (e.g., residues, and concentrates; i.e. multiple uses of water) or from fully irrigated fodders and pasture from grazing lands. Availability of surface or ground water, distance to and quantity and quality of feed resources and the way in which these are fed to the animals determine the level of output and water input and ultimately this impacts the value of LWP.

2.4. Drinking Water Supply and Grazing Land: Synchronizing their Spatial and Temporal Distribution

Spatial variability in water resources may have a significant effect on the landscape and efficient uses of grazing land resources (Ryel *et al.*, 2004). It is not always ecologically desirable or economically viable to bring all potential grazing land within reach of permanent watering points. Water supply has importance in determining grazing distribution on homogenous landscapes but forage palatability, terrain and tree density are also important in heterogeneous landscapes. The integrated response to these factors determines resources use efficiencies and livestock productivity in general. In most parts of the BNB livestock watering points are not synchronized with feed availability. Particularly in the dry seasons livestock must trek long distance in search of drinking water. In parts where there are watering points over grazing is not uncommon. In areas where drinking water is not accessible feed may not be efficiently used. This means also by distributing drinking water availability, in time and space, efficient uses of the existing feed can be enhanced and at the same time energy spent on walking in search of water can be reduced (Peden *et al*,. 2007).

2.5. The Livestock Water Productivity Framework

Increased LWP contributes to improving livelihoods and reducing poverty in smallholder farming systems, while reversing land degradation and safeguarding environmental resilience (Descheemaeker *et al*., 2009). Some findings carried so far concentrated on land degradation and livestock water requirement for drinking but inadequate attention has been given to livestock-water interactions (Peden *et al*., 2007). Generally, it was pointed out by Descheemaeker *et al*. (2009) that lack of knowledge and the insufficient understanding of livestock-water interactions impede sound decision-making and the implementation of targeted interventions to improve the often alarming situation, which lead to missed opportunities to reverse environmental degradation, low livestock productivity and smallholder poverty. The production system of livestock is more complex so that the developed framework LWP (Figure 1) was more useful to understand and integrate factors and options to efficiently utilize water for livestock and ecosystems sustainability.

The water flowing into the system is used for biomass production, drinking, and processing and servicing and allows the system to produce livestock outputs by using the different feed types and relying on other natural resources and inputs. Livestock outputs then contribute to livelihoods and environmental services. However, these contributions become positive or negative depending on the management of the resource input. The water lost through transpiration, evaporation, contaminated water and degraded runoff water is greater than the water left in the system such as discharge and percolation and in urine or faeces of livestock (Descheemaeker *et al*., 2009).

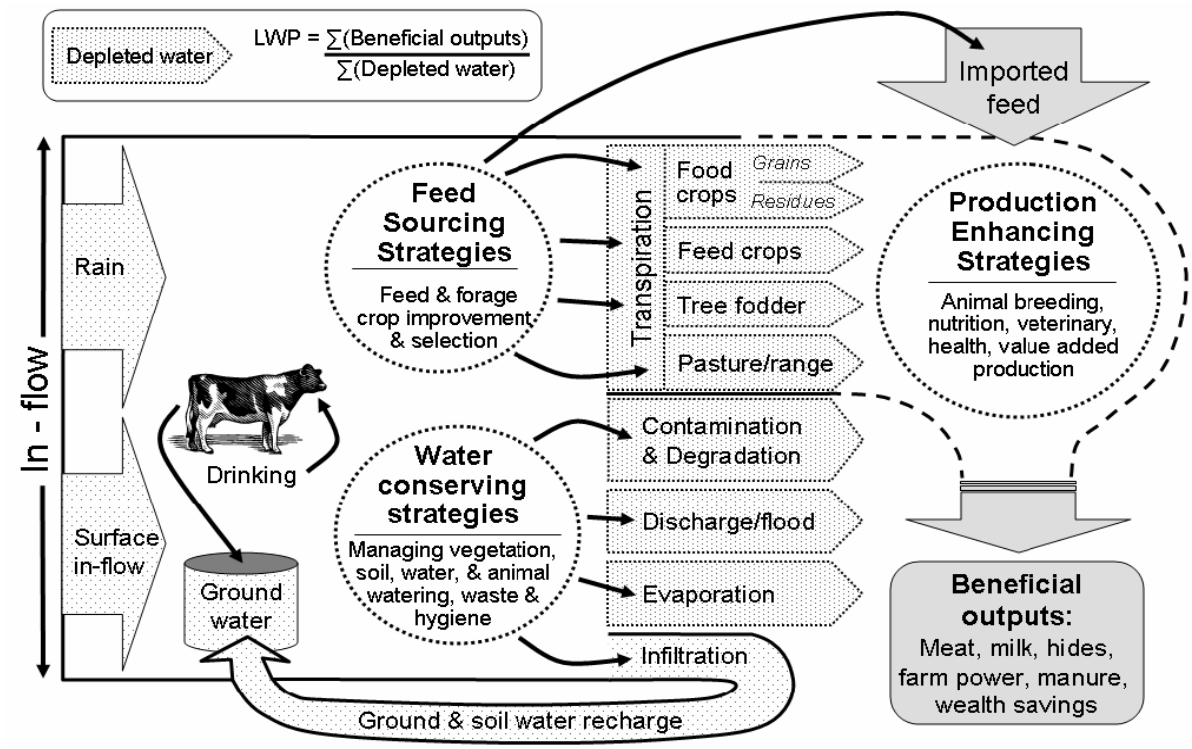


Figure 1. Simplified framework for assessing livestock water productivity (Peden *et al.,* 2007)

The LWP framework highlights feed sourcing as a major factor influencing water productivity (Figure 1). Transpiration is the primary and only water depletion pathway that drives plant photosynthesis and thus feed production. Improving feed quality, selecting water productive feeds, increasing water productivity of feeds, and pasture management practices provide opportunities to increase LWP by channeling primary production into animal production. Enhancing animal productivity and conserving agricultural water resources can also help increase LWP. Livestock water productivity is a scale-dependent concept and thus there is a need to understand the bio-physical and management processes at various levels ranging from individual animals, to herds, to communities, to landscapes, and to river basins.

3. MATERIALS AND METHODS

3.1. Description of the Study Sites

This research was undertaken in Diga, Jeldu and Fogera Woredas, as part of the Nile Basin Development Challenge (NBDC) project: a project which is financed by the Challenge Program on Water and Food (CPWF) and implemented by the International Livestock Research Institute (ILRI) and International Water Management Institute (IWMI). These three sites were already selected by the project team for their good access and representativeness of the mixed crop livestock systems of the BNB. Three study watersheds one from each Woreda were selected. The watersheds identified were; Dapo from Diga, Meja from Jeldu and Mizewa watershed from Fogera (Figure 2).

Diga Woreda

Diga Woreda is located in Oromia Regional Sate (Ethiopia) and in the Southwest of the BNB. The Woreda is bordered in the Northeast by Guto Gida Woreda and in the West by the Didessa River (Figure 2). The altitude of the Woreda varies from 1,200 to 2,342 meters above sea level (masl). The area is one of the highest rainfall regions of the Ethiopian Highlands. It has a range of mean annual rainfall of 1,376 –2,037 mm and mean minimum and maximum temperature 15 ^{0}C and 27 ^{0}C, respectively (Birhanu *et al*., 2011). According to information from the Woreda's Agriculture and Rural Development Office, the livestock population includes about 60,592 cattle, 11,893 sheep, 6,426 goats, 147 horses, 48 mules, 3066 donkey and 32648 poultry (DARDO, 2011). Human population in 2011 was about 80,105 of which 39,249 and 40, 856 were males and females, respectively.

The land use pattern in lower landscape position area is dominant by maize, sorghum, millet and sesame and perennial crops coffee and mango. In the medium landscape position, teff, millet and maize are important in that order of magnitude. Information from the Woreda Agriculture and Rural Development Office estimates area under the different land use land cover at 15,966 ha cereals, 1,118 ha pulse, 4,485 ha oil crops, 4,305 ha root and tuber, 156 ha vegetables and 2,872 ha fallow lands. The area of grazing estimated was 361 ha private grazing land and 5,700 ha forest and shrub land (DARDO, 2011).

Discussion with Woreda officials suggests that vegetation cover in Woreda has been decreasing from time to time through expansion of cultivation. Large areas of forest have been cleared in the last 10 years. Dominant tree species in the area are*; Ficus vasta, Vernonia amygdalina, Ficus gnaphalocarpa, Vepris dainelli, Piliostigma thonningii, Tephrosia spp., Stereosprmum kunthianum, Kalanchoe deficiens, Apodytes dimidiate, Stereosprmum kunthianum, Celtis africana and Acacia nilotica.* Some of the common herbaceous plants found in study site are*; Eleusine coracana, Cynodon dactylon, Andropogon gayanus, Digitaria abyssinica, Aeschynomene elaphroxylon, Phalaris paradox, Cenchrus pennistiformis, Enteropogon samalensis, Ageratum conyzoides, Bothriochloa radicans, Cyperus rigidifolius, Hyperania spp, Echinochloa crus-galli and Trifolium spp.*

Jeldu Woreda

Jeldu Woreda is located in Oromia Regional State and at about 130 km West of Addis Ababa and in South of the BNB. It lies at altitude of 1800-3200 masl and has a rainfall ranging between 900-1350 mm. The mean minimum and maximum temperature is 9 ^{0}C and 27 ^{0}C respectively. According to Jeldu Woreda Agriculture and Rural Development Office, livestock population in 2011 was about 195,681 cattle, 76,272 sheep, 36,897 goat, 17,771 horse, 755 mule, 7,377 donkey and 66,300 poultry. For the same physical year the total human population of the Woreda is estimated at about 202,655 of which 99,886 were males' population, while the differences were females (JARDO, 2011).

In Jeldu Woreda there are three farming system as defined by biophysical settings and farming practices. Barley, potato and wheat dominate the Highlands at altitude ranging between 2700 and 3200 masl. Teff, wheat and sorghum dominate mid altitude ranging between 2300-2700 masl. Teff, sorghum and maize dominate lower altitude ranging between 1800-2300 masl. In the Woreda, generally, cereals, pulses, oil crops and vegetables cover 45317 ha, 2152 ha and 787 ha, respectively. There are 1807 ha of grazing land and 3500 ha of forest (JARDO, 2011).

Like in Diga, here also vegetation cover has been decreasing due to heavy deforestation in the last 10-20 years. All farming systems exhibit decreasing species composition. Currently eucalyptuses occupy most of the watershed especially in the Highland and mid altitude areas and mainly planted to generate cash income. Some of the common tree species in the study farming systems area are: *Ficus vasta, Grewia ferruginea, Dracaena stedneri, Cordia Africana, Erythrina brucei, Vernonia amygdalina, Hagenia abyssinica, Maytenus ovatus, Apodytes dimidiate and Dracaena stedneri.* The common herbaceous plant species in study sites are *Andropogon gayanus, Cyperus rigidifolius, Andropogon dumereri, Erogrostis spp., Pennisetum schimperi, Snowdenia polystachya, Sporobolus indicus, Phalaris paradox and Trifolium rueppellianum.*

Fogera Woreda

Fogera Woreda is located in the Amhara Regional State and in the Northeast of the BNB specifically to the East of Lake Tana. Fogera Woreda comprises of a large flat floodplain in the vicinity of the lake and contributing hilly catchments to the East. The altitude varies from 1774-2410 masl (IPMS, 2005). Rainfall varies from approximately 1,000 mm on the plains to about 1,500 mm at higher altitudes and has a mean annual rainfall of 1200 mm and mean minimum and maximum temperature 11^{0}C and 27 ^{0}C, respectively. According to the Woreda Agriculture and Rural Development Office, for year 2011 the livestock population was estimated at 194,135 cattle, 19,027 sheep, 26,920 goats, 36 horses, 1,119 mules, 14,433 donkey and 133, 278 poultry (FARDO, 2011). For same physical year the total human population of the Woreda was about 216,211: of which 112,665 and 103,546 were males and females, respectively.

The land use pattern of Fogera Woreda includes: 46.4 % cultivated land, 8.2 % grazing land, 20.1 % water bodies (Belete, 2006). When the cultivated land is disaggregated annual crops such as cereals 33126 ha, pulse 1230.5 ha, oil crops 2988.5 ha, roots 470 ha and vegetables 251 ha constitute the major share. The area allocated to grazing and forest land was 13,490.6 ha and 2101.54 ha, respectively (FARDO, 2011). Accordingly, teff-millet/maize and rice-pulse are the two farming systems in Fogera Woreda. Vegetation cover in the area is low because of a long agricultural practice and enormous erosion hazard in hilly areas. Discussion with local communities suggests that both farming systems exhibit decreasing species composition and areas of woody vegetation. In rice-pulse farming system the dominance of eucalyptus trees are thoroughly noticed. Some of the common tree species in teff-millet/maize based system are *Cordial Africana, Phytolacca dodecandra, Dodonacea viscose, Syzygium guineense and Vernonia natalensis.* The common herbaceous plant species in study sites: *Andropogon gayanus, Echinochloa crus-galli, Cyndon dactylon, Andropogon dumereri, Erogrostis spp., Commelina benghalensis, Cyperus rotundus, Trifolium rueppellianum and Trifolium spp.*

3.2. Stratification and Household Survey

A multi stage stratified random sampling technique was employed to select farm households for this study. First, three Woredas were selected from the BNB and then watershed was selected from each Woreda. In each watershed, farming systems were stratified based on dominant cropping pattern and farming practices. From each farming system, two representative peasant associations (PA) were selected. Households in each PA were grouped into better off, medium and poor smallholders based on key livelihood assets [e.g., Livestock and landholding (Appendix Table 1)]. From each peasant associations 4-6 of households were randomly selected for each group of wealth status. A total of 220 households were randomly selected and interviewed (Table 1). A questionnaire was designed for collecting data on farm household characteristics, access to agricultural assets, farming, feed sourcing and feeding practices. The questionnaire was pretested before the actual survey in Diga and Fogera Woredas and refined for the formal survey. After designing the questionnaire, two enumerators drawn from each Woreda experts, in livestock production, were given orientation and training on household survey. A senior ILRI staff was supervising the formal survey. To triangulate information collected through household survey, transect walk was made and group discussions were held with elder farmers, Development Agents, Woreda experts.

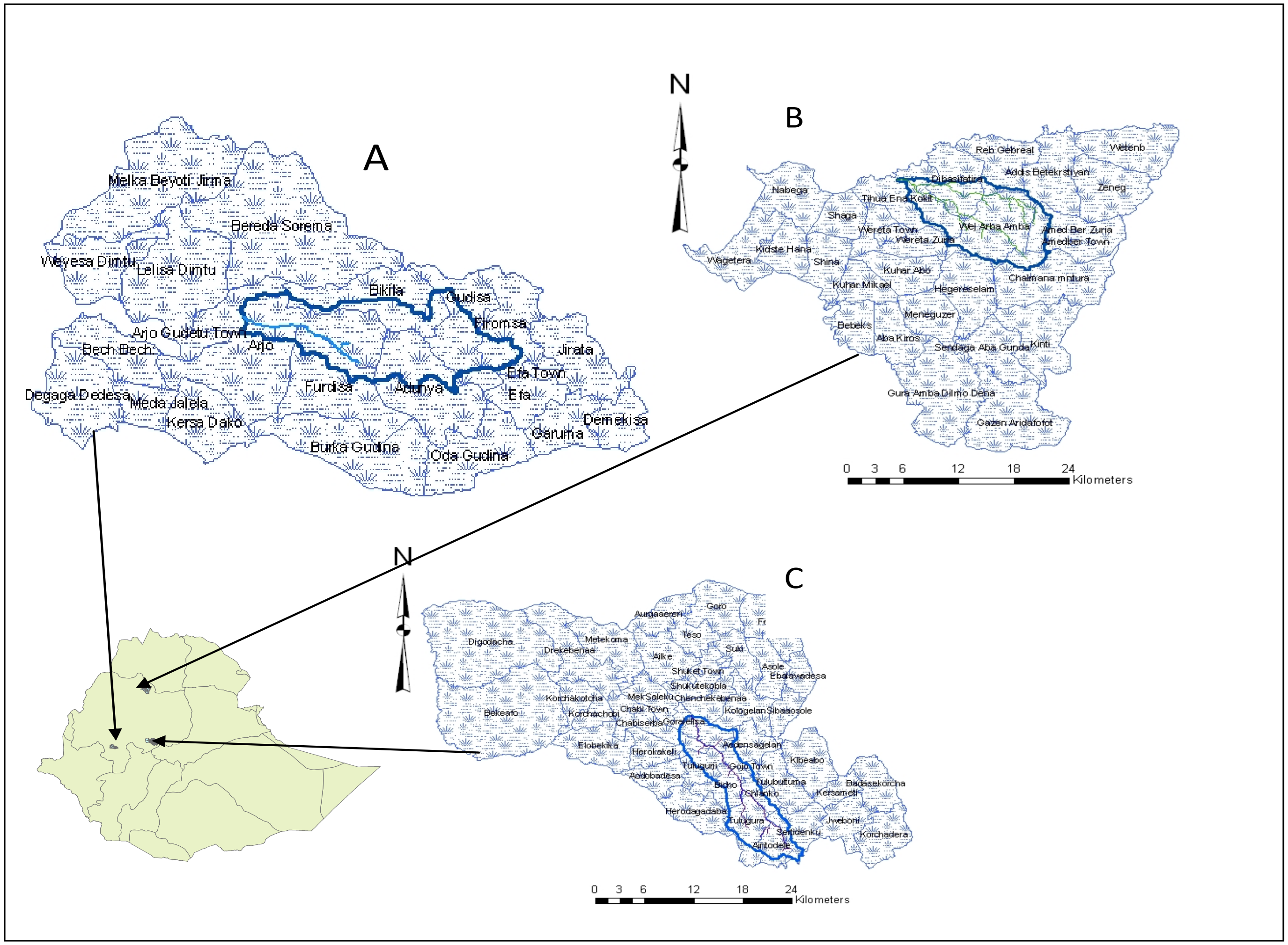


Figure 2. Map of study sites; (Amare *et al*, 2010, unpublished)

A= Diga Woreda (dapo watershed); B= Fogera Woreda (Mizuwa watershed); C= Jeldu Woreda (Meja watershed) with their selected watershed

Table 1. Distribution of sample households across farming systems in selected watersheds and wealth classes

Sample cluster	Farming systems in Dapo watershed		Farming systems in Meja Watershed			Farming systems in Mizuwa watershed	
	TMS	MSS	BPS	TWS	TSS	TMMS	RPS
Better off (rich)	12	11	10	11	10	11	10
Medium	11	10	9	10	10	10	10
Poor	12	11	12	9	10	11	10
Sub total	35	32	31	30	30	32	30

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system

3.3. Feed Resource Assessment

Different data sources and types were used to investigate feed sourcing, feeding strategies and LWP in smallholder farmers. A number of field sampling, mathematical approaches and assumptions were involved in generating data that can help in achieving the study objectives illustrated at the beginning of this thesis. In the following sections details of approaches and procedures employed for key analysis will be presented.

3.3.1. Estimation of dry matter productivity and production of grazing lands

Dry matter yield and associated water depletion in the production process are two of the important indicators for performances of livestock in terms of water resources economy. To estimate the dry matter productivity this study randomly laid four sample plots (25m x 10m) on private grazing land in each farming system used. The exception was the teff-sorghum system of Jeldu where only two sample plots were taken because of lack of non-grazed private land. Furthermore, in each plot, four or five quadrats (0.5 m x 0.5 m), depending on uniformity of plot, were randomly laid and herbaceous vegetation was harvested. Sample was collected during the last week of September, 2011 to first week of October, 2011 when approximately 50% of the herbaceous vegetation was in flowering. Immediately after harvest, sample was separated into grasses and legumes species and weighted by scale grid of 20gm and placed in plastic bags. Dominant herbaceous species in each quadrat were identified on the field and those species that were difficult for identification were recorded in local language and translated into scientific name with Glossary of Ethiopian Plant Names (Wolde, 1987). Dry matter of grasses and legumes were determined after oven drying at 105 °C for 24 hours at ILRI laboratory in Addis Ababa. Based on the DM weights obtained, percentages of grasses and legumes from each sample sites were calculated and summarized to get the value for each farming systems.

3.3.2. Assessment of feed dry matter production and productivity on arable and communal property resources

Dry matter production from arable land became increasingly an important sources of livestock feed in mixed crop livestock systems. To estimate the dry matter production and productivity from crop land a harvest index approaches were used. Data on land holding, cropping pattern and productivity were collected through household survey. These data sets were cross-checked with Woreda annual report of crop productivity and production. The quantity of crop residues produced from each crop type was estimated by harvest index as suggested in FAO (1987). Accordingly, a multiplier of 1.5 for small cereals such as wheat, barley, oat and teff straw; a multiplier of 1.2 for pluses such as faba bean, field pea, chick pea and haricot bean straw, a multiplier of 2.0 for maize and 2.5 for sorghum was used (Appendix Table 2). The annual stubble grazing was estimated with a conversion factor of 0.5 ton ha^{-1} (FAO, 1987). Harvested crop residue does not necessary implies that it is used for feed. There are competitive uses and also limitation by accessibility and nature of the residues itself. Given strong feed deficits and priority given to livestock in the highland mixed crop livestock systems we assumed that about 90% of crop residues are used as a feed to determine the potential supply (Adugna and Said, 1994). Access to feed resources on common property resources is important in the mixed crop livestock systems. The fact that this land unit is openly grazed and communally owned makes its dry matter productivity estimation and understanding the share of individual household often very difficult. In this thesis dry matter productivity (2 ton ha^{-1} yr^{-1}) was estimated as suggested by FAO (1987). Then this was factored into total communal grazing areas in a farming system, total households and associated TLU eligible to graze on this the land unit. Trees used for browsing were rarely encountered in all study systems. This is mainly associated with dominance of eucalyptus trees which are not normally preferred by livestock. The exception is for Diga where fodder tree species were available and farmers were claiming feeding of livestock on tree leaves if drought prolonged. Accordingly, estimation of dry matter from browsing trees and shrubs of leaf biomass was estimated at 1.2 ton ha^{-1} (FAO, 1987). In quantifying tree feed resources from common property resources (e.g., open forest areas) at individual household level similar approaches, as communal grazing area mentioned earlier, was used. Empirical evidence, from WBISPP (2002), suggests that only about 75% of all available DM is accessible by livestock for use and therefore this study used the same accessibility factor to quantify total DM utilized by livestock from grazing and browsing areas.

3.4. Estimation of Water Depleted in Producing Livestock Feed

Livestock provide benefits and services using metabolisable energy embodied in the different feed resources. In the process of converting solar energy to Metabolisable energy huge amount of water is depleted through evapotranspiration [ET (Amare *et al.,* 2011a)]. LWP is an indicator of how water productive on these livestock productive and services are and therefore it is a factor of information on: livestock beneficial outputs, services and evapotranspired water to produce livestock feed.

To generate the evapotranspiration (ET) information, climatic parameters such as radiation, temperature, humidity, precipitation and wind speed needed. This study used a tool called New LocClim (FAO, 2005) which can generate these metrological data for sites with known geographical positions. Then, to calculate ET of a known crop the reference evapotranspiration (ETo) in mm day^{-1} and crop coefficient (Kc) approaches (FAO, 1998) were used. ET for each crop types for growing length was computed from weather data using CROPWAT 8.0 software (FAO, 2003). FAO (1992) recommended Penman-Monteith method as a standard method for the definition and computation of the reference evapotranspiration (ETo). Reference evapotranspiration calculated for Diga Woreda was from Nekemte and Didesa metrology stations where as for Jeldu Woreda Ambo and Guder metrology stations were used. For Fogera

Woreda Bahir Dar, Debra-Tabor, Addis Zemen and Gorogora metrology stations were used (Appendix Table 3). The Length Growing Period (LGP) used for each crop was collected from group discussion held in each study farming system. Kc values from some pulse crop are not established. In calculating ET of these pulse crops, average Kc of a family was used (for example, chickpea, and grass pea and haricot bean). Proportion of grass to legume was considered during the calculation of ET for natural pasture in each farming system. On crop field, this depleted water serves both for the grain and residues. Therefore separation between grain and residues was important (Amare *et al*., 2011a). In this thesis harvest index approaches as suggested by Amare *et al*., (2011a) employed and linked to area under each crop types and utilization factors indicated in previous section and Table 13 and 14. The following equations shows mathematical relation of the different data sets used in calculation of water depleted for livestock feed.

ETci= ETo*Kci*LGPij……………………………………………………………………Eq. (1)

Where;

ETci = The total water depleted for i^{th} crop types biomass (grain and crop residues) or grazing land in mm per during growing season in i^{th} farming system

ETo_i = The average reference evapotranspiration in mm per day of the i^{th} farming system

Kc_i = Crop coefficient of the i^{th} crop type/grazing land

LGP_{ij} = Length of growing period in days of the i^{th} farming system for j^{th} crop types/grazing land

1. Water depleted for crop residues

WDCRi =(ETci*(1-HIi)*GA*CRu_i)/1000 ....Eq. (2)

Where;

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

ETci = Total water depleted in mm per growing period of the i^{th} crop type in i^{th} farming system

HIi = Harvest index used to portioned grain to crop residues of i^{th} crop type (grain yield of i^{th} crop types to total biomass above ground of i^{th} crop types)

GA = Growing area of i^{th} crop types in meter square per household

CRu_i = Utilization factor (%) of the crop residue of the i^{th} crop type per household.

2. Water depleted for grazing lands (private, communal and fallow lands)

$$WDGLxi = (ETc_{xi} * GLA_{xi} * GLu_l)/1000 \quad \text{……..Eq. (3)}$$

Where;

$WDGLx_i$ = Total water depleted for production of feed dry matter on grazing land in m^3 for household x in the i^{th} farming system

ETci = Total water depleted in mm per growing period for grazing land in i^{th} farming system

GLAxi = Grazing land area of farm x (in m^2) per household of the i^{th} farming system

GLu_i = Feed use factor of grazing land of the i^{th} farming system

3. Depleted water for livestock feed

$$DWLFx_i = \sum_{i=1}^{n} WDCRx_i + \sum_{l=1}^{n} WDGLxi \quad \text{……..Eq. (4)}$$

Where;

$DWLF_i$ = Total depleted water in m^3 per x household per year for livestock feed in the i^{th} farming system

$WDCRx_i$ = Water depleted for crop residues in m^3 per x household farm of the i^{th} crop type and utilized by livestock

$WDGL_{xi}$ = Total water depleted for dry matter from grazing land in m^3 per x household farm of the i^{th} farming system

3.5. Estimation of Livestock Beneficial Outputs and Service

Livestock beneficial outputs and services involve milk, meat, traction, threshing, transportation, manure estimated in monetary value of particular sites. The estimation of livestock products and services requires information on the livestock herd structure (Amare *et al.*, 2009). Livestock products and services data established based on information on livestock herd structure and age composition, activities and productivity levels collected through the household survey. The output and services of livestock value was estimated in US$ per household as fallows;

1. Milk yield value

MYVji = (AMYji*NLCji*ALGji*MVi)……………………………………………………Eq. (6)

Where,

MYVji = Milk yield value (US$) of j^{th} household in the i^{th} farming system
AMYji = Average milk yield (liter) per day per cow of the j^{th} household in i^{th} farming system
NLCji = Number of lactating cow in j^{th} household in the i^{th} farming system
ALGji = Average lactation length (days) cows in j^{th} household in the i^{th} farming system
MVi = market price of milk (US$ per liter) in i^{th} farming system in reference to 2010-11

2. Off-take value (sold, slaughtered and gifted)

In this study off-take rate at household level was use as indicator of beneficial outputs obtained from livestock. It was estimated by considering current market price (in ETB converted to US$) of livestock according to age of the different livestock species that a farm has sold, slaughtered and gifted out.

$\text{OTVji} = \sum_{i=1}^{n} \text{NLOTi} * \text{MVi}\, j$……………………………………………………Eq. (7)

Where,

OTVji = Total value of off take from all types of livestock per j^{th} household per year in the i^{th} farming system

NLOTi = Number of livestock off take (slaughtered, sold and gifted) of the i^{th} livestock types per household

MVij = Market value (US$) of respective slaughtered, sold and gifted of the i^{th} livestock types per j^{th} household in the farming system

3. Services from livestock

The services from livestock considered in this study were ploughing, threshing and transportation. These were estimated using equation 8 as follows;

$$VOSji = \sum_{i=1}^{n}(\text{NLji} * \text{TDji} * \text{MVJI}) \quad \text{...Eq. (8)}$$

Where,

VOSji = The total value of services from all livestock types delivered per year per j^{th} households in the i^{th} farming system

NLji = Number of the j^{th} type of livestock performed i^{th} type of service per household

TDji = Average total days of the j^{th} type of livestock performed i^{th} type of service per year

MVji = Market value (US$) of the j^{th} types of livestock performed i^{th} type of services per day in reference to 2010-11

4. Estimation of produced manure value

Most often estimation of livestock manure production is mentioned as difficult as it varies by livestock age, feed type and activities (Amare *et al*., 2006). The method adopted for this study similar to Amare *et al*. (2006) in which each species of livestock converted to TLU with specific conversion factor (Appendix Table 4). Dry matter level manure production was estimated for cattle as 3.3 kg day^{-1} TLU^{-1} and for equines, and sheep and goats were 2.4 kg $day^{-1}TLU^{-1}$. Nutrient composition of the manure was estimated as 18.3gN kg^{-1}, 21.3gK kg^{-1} and 4.5gP kg^{-1} of manure. The value (US$) of nutrients (K, N and P) was estimated from Urea and DAP prices in reference to 2010-11. Accordingly the cost of N, P and K were 0.29, 0.41 and 0.41US$ kg^{-1}, respectively.

$$TMVji = \sum_{i=1}^{n}(MTLUi * 0.018N * MPin + MTLUi * 0.0213k * MPik + MTLUi * 0.0045P * MPip) \ldots\ldots Eq. (9)$$

Where;

TMVji = Total manure value (US$) from all TLU of livestock species per j^{th} household per year in i^{th} types of farming system

MTLUi = Total manure produced from i^{th} livestock species on dry weight basis (kg) per household per year

0.0183N = Nitrogen content (kg) from 1kg of manure on dry weight of i^{th} livestock species

0.0213K = Potassium content (kg) from 1kg of manure on dry weight of i^{th} livestock species

0.0045P = Phosphorus content (kg) from 1kg of manure on dry weight of i^{th} livestock species

MPin = market value (US$) of N per kg in i^{th} of Woreda in reference to the year 2010-11 price.

MPik = market value (US$) of K per kg in i^{th} of Woreda in reference to the year 2010-11 price.

MPip = market value (US$) of P per kg in i^{th} of Woreda in reference to the year 2010-11 price.

3.6. Livestock Water Productivity Estimation

To estimate LWP; spreadsheet model developed for LWP by Amare *et al*. (2009); and livestock feed demand-supply and linkage to land and water requirement (King, 1983) are required. LWP as defined earlier, is based on the ratio of livestock beneficial outputs to depleted water (Amare *et al*, 2009). For this study LWP was estimated as:

LWPji = (MYVji+OTVji+TVOSji+TMVji)/DWLFji……………………………………Eq. (10)

Where;

LWPji = livestock water productivity per j^{th} household in i^{th} farming system

MYVji = Milk yield value (US$) per household j^{th} per year in i^{th} farming system

OTVji = Total value of off-take from all types of livestock per j^{th} household per year in i^{th} farming system

TVOSji = Total service value from all livestock types delivered per j^{th} household per year in i^{th} farming system

TMVji = Total manure value (US$) from all TLU of livestock species per j^{th} household per year in i^{th} farming system

DWLFji = Total depleted water (in m^3 per j^{th} household per year) for livestock feed in the i^{th} farming system

3.7. Feed Demand-Supply Balance Estimation

The feed demand supply balance estimation uses two major data sets: i) the supply side which was estimated from household survey, biomass harvesting and literature values as presented earlier. These feeds biomass (dry matter basis) was converted to ME in MJ kg^{-1} using literature value on energy content (Appendix Table 5) of different feed resources to estimate feed Metabolisable Energy at household level (Abdinasir, 2000; Tsigeyohannes, 2000). ii) On the other hand the total energy requirements of livestock types was calculated as the sum of the maintenance energy requirements and additional energy to account for the effect of standing and walking, milk production, body weight gain and traction service. In the demand side estimation a standard method developed by King (1983) for tropical regions was used. Maintenance energy requirement was calculated according to equation 11:

$$MEx = \frac{0.343 \times LW^{0.73}}{\mathrm{Km}} \quad \text{……Eq. (11)}$$

Where by MEx is ME (MJ day^{-1} animal^{-1}) for maintenance; LW is the live bodyweight. Km (MJ kg^{-1}) is the efficiency with which ME is used for maintenance and related to the average forage metabolisability. The average dry matter (DM) digestibility and gross energy value were considered based on the dominant diet composition (crop residues types and grazing land) for each of the particular study system (Appendix Table 5).

One of the productive uses of feed energy is lactation. The ME required for lactation was calculated as given in equation 12:

$$ME1 = \frac{DMy \times NE}{K1} \quad \text{Eq. (12)}$$

Where MEl is ME for lactation (MJ day^{-1} cow^{-1}), DMy is daily milk yield, NE is net energy for milk calculated as function of butter fat content (g kg^{-1}) and solids-non-fat content (g kg^{-1}). A constant value (60.8 g kg^{-1} butter fat and 82.2 g kg^{-1} non-solid fat) was assumed for Jeldu and Diga Woredas (Alganesh, 2008) and for Fogera Woreda 49.9 g kg^{-1} butter fat and 102.2 g kg^{-1} non-solid fat was applied (Teshome, 2009). Kl is the efficiency with which ME is converted to milk.

In estimating ME for weight gain, equation 13 was used as indicated below in which MEg is ME for weight gain (in MJ), LWG is live weight gain (kg day^{-1} animal^{-1}) and W is the actual live weight of an animal (kg). Daily live weight gain for each species were assumed constant for all study sites where 0.29 kg for cattle (Habtamu *et. al*., 2011); 0.034 kg for sheep and goats (Assefu, 2012) and 0.8 kg for equines (Pagan and Hintz, 1986).

$$MEg = \frac{LWG\,(6.28+0.0188W)}{(1-0.3LWG)} \quad \text{Eq.(13)}$$

Calculating the energy requirements of draught animals is data intensive and varies considerably by the duration of work and age of the animal. Given diverse draught power demands subjected to differences in land owned by farmers and cropping pattern, accurate calculation is difficult. Assumption employed was, however, 10% of the MEx as suggested by IPCC (1996). Like for traction energy for walking is data intensive. It involves walking for grazing and water drinking.

In the present study this energy value was estimated using equation 14 below. Data needed for input to the equation were aggregated at system level. MEw is ME for walking to grazing and water sources, WD is walking distance (km), W is the actual live weight of an animal (kg) and S is the slope (%) of walking distance (averaged per system) estimated.

MEw= (WD*W*0.0018) + (0.0018*S*W*0.028)…………………………………………….. (14)

3.8. Statistical Analysis

Descriptive and inferential statistical tests were performed separately for each of the study Woreda among their respective farming systems. Data from survey, measured samples and relevant secondary data were organized, summarized and analyzed using SAS (Version 9.0) statistical package (SAS, 2002). Descriptive statistics was employed to present the qualitative variables obtained from the household survey. To separate means of significantly different variables among the different stratum General Liner Model (GLM) procedure of SAS was employed and least significant difference (LSD) at 5% level test was used. Pearson's coefficient of correlation was used to determine the relationship of variables. A simplified model for statistical model can be presented as follow:

1. $Y_{ik} = \mu + S_i + e_{ik}$,

Where;

Y_{ik} = Household variables (e.g., dry matter productivity of private grazing, dry matter productivity of arable land, water depleted for feed production, beneficial output, livestock water productivity and feed water productivity)

μ=overall mean

S_i = The effect of i^{th} stratified farming system within Woreda (i=1, 2, 3)

e_{ik} = Random error

4. RESULTS AND DISCUSSION

4.1. Characteristics of the Sample Farms

4.1.1. General characteristics

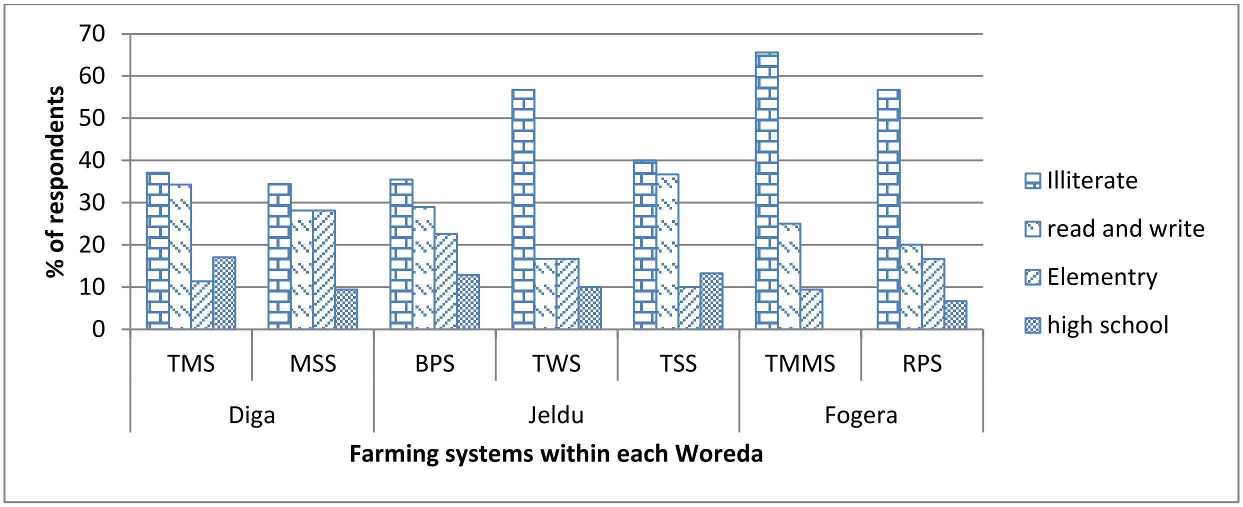
Table 2 depicts mean values of household size, productive and unproductive household size in the study systems. The average ages of the respondents were 40.3, 45.1 and 42.9 years for Diga, Jeldu and Fogera Woreda, respectively (Table 2) and the values were comparable across the Woredas and among farming systems. The average family size of households in Diga and Fogera, and also between their respective farming systems was similar. But the family size in Jeldu appeared to be higher than the other two Woredas implying stronger competition for land resources. For Jeldu among systems family size differences was statically significant. For example the family size of respondents between barley-potato and teff-wheat systems differed ($P<0.05$). The family size in Fogera Woreda is comparable to the value reported by Teshome (2009). The proportion of males and females were almost equal in the study systems except in the Jeldu Woreda where the average number of females was relatively greater than males. The number of productive people (15-60 years of age) per household among the farming systems of the Diga and Fogera Woreda was similar. However, there was a difference in the number of productive people between barley-potato and teff-wheat systems of the Jeldu Woreda. Arguably such high proportion of unproductive household member can be accounted for by migration of youngsters to the nearby town which is generally triggered by land shortage and degradation. The trend may impact the size of labor available for agricultural activities and therefore the productivity of the agriculture in general.

Table 2. Household characteristics of the respondents in the study areas (Mean±SE)

Woreda	Farming System	N	Age of respondents	Family size	Number of males	Number of females	Productive age (15-60 years)	Non- productive age (< 15 and > 60 years)
Diga	TMS	35	42.7±2.8	6.2±0.4	3.3±0.3	2.9±0.3	2.7±0.3	3.5±0.3
	MSS	32	37.8±2.1	6.6±0.5	3.2±0.3	3.3±0.3	3.3±0.3	3.3±0.3
	Mean	67	40.3±1.8	6.4±0.3	3.3±0.2	3.1±0.2	3.0±0.2	3.4±0.2
Jeldu	BPS	31	42.1±3.1	6.8±0.5[b]	3.2±0.3	3.6±0.3	2.6±0.3[b]	4.0±0.4
	TWS	30	48.3±2.5	8.4±0.7[a]	4.1±0.4	4.5±0.5	3.6±0.3[a]	5.0±0.5
	TSS	30	45.0±2.7	7.1±0.4[ab]	3.2±0.3	3.9±0.3	2.8±0.3[ab]	4.1±0.4
	Mean	91	45.1±1.6	7.5±0.3	3.5±0.2	4.0±0.2	3.0±0.2	4.5±0.3
Fogera	TMMS	32	43.6±2.3	6.3±0.4	3.1±0.3	3.2±0.2	2.7±0.2	3.6±0.3
	RPS	30	42.1±2.6	5.6±0.4	2.9±0.3	2.7±0.3	2.4±0.3	3.0±0.3
	Mean	62	42.9±1.7	5.9±0.3	3.0±0.2	2.9±0.2	2.6±0.2	3.4±0.2

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondents; [a-b] means with different superscripts letters along column within same Woreda differ significantly ($p<0.05$)

The average numbers the respondents that attended elementary school and have capacity to read and write were comparable across the study areas (Figure 3). In all study systems, on average above 50% of the respondents were literate and those systems in Diga tends to have more proportion. The question is as to how such trends in the level of education influences farmers perception of scarce water resources and the need to improve water productivity.



TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet/maize system; RPS = Rice-pulse system

Figure 3. Frequency distribution of the level of education in the study systems

4.1.2. Landholding and land use pattern

In the BNB Highlands, the dominant land use pattern is highly influenced by farming systems and landscape positions. Mean value of sample farms land holding and cropping patterns are depicted on Table 3 and Appendix Table 6. In the teff-millet system of Diga, 26.5% and 19.2% of total landholding was covered by teff and finger millet respectively, whereas in the maize-sorghum system, maize (34.1%) and sorghum (27.2%) covered out of total landholding. In the barley-potato system of Jeldu, barley, potato and wheat covered 45.9%, 29.9% and 17.7% of the total landholding, respectively. In the teff-wheat system of the same Woreda, teff and wheat covered 29.3% and 25.6% of total landholding, respectively whereas in teff-sorghum system; teff and sorghum covered 29.6% and 24.2% of total landholding, respectively (Appendix Table 6). Similarly in Fogera in teff-millet/maize system, the dominant crops teff, finger millet and maize covered on average 39.3%, 30.0% and 22.7% of total landholding in that order whereas in the rice-pluses system, rice and pulse covered 63.6% and 23.6% of total landholding per household, respectively.

Table 3. Mean value of landholding (ha) across the study systems (Mean±SE)

Woreda	Farming system	Landscape position	N	Crop land (ha)	Private grazing land (ha)	Fallow land (ha)	Total land (ha)
Diga	TMS	Medium	35	1.8±0.2	0.2±0.06	0.5±0.07[a]	2.6±0.2
	MSS	Low	32	2.2±0.2	0.4±0.08	0.3±0.06[b]	2.9±0.3
	Mean		67	2.0±0.1	0.3±0.05	0.4±0.05	2.7±0.2
Jeldu	BPS	Upper	31	1.4±0.1[b]	0.3±0.06[a]	0.6±0.10[a]	2.2±0.2[b]
	TWS	Medium	30	1.9±0.1[a]	0.7±0.08[b]	0.09±0.06[b]	2.7±0.2[a]
	TSS	Low	30	1.7±0.1[ab]	0.3±0.06[a]	0.2±0.07[a]	2.3±0.1[ab]
	Mean		91	1.7±0.07	0.4±0.04	0.3±0.06	2.4±0.1
Fogera	TMMS	Medium	32	1.4±0.1	0.2±0.03	0.07±0.02	1.5±0.1
	RPS	Low	30	1.3±0.1	0.1±0.02	0.03±0.02	1.4±0.1
	Mean		62	1.3±0.1	0.1±0.02	0.05±0.01	1.5±0.1

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondents; [a-b] means with different letters superscripts along column within same Woreda differ significantly ($p<0.05$)

The overall average total landholding varies across the study Woreda. The total land holding size was also comparable among farming systems within Woreda except among those farming systems of Jeldu (Table 3) where sample farms in the teff-wheat systems had a significantly higher land holding size ($P<0.05$).

4.1.3. Livestock herd size and structure

As elsewhere in the mixed crop livestock system, in all study areas livestock are important system components. Table 4 depicts mean livestock holding in TLU by species and by system for the study areas. Although the mean TLU of all species were comparable across systems and between study Woreda, apparent variation exists in terms of species composition. Jeldu study systems were exceptional in that a statically significant difference exists between the wheat-teff and the other two systems under investigation in terms of the mean TLU of all species and also herd composition. This can be accounted for by a contrasting differences between the different farming system investigated in Jeldu [e.g., compare altitude ranges) (Table 4)]. The many of the values of mean TLU reported here are in good agreement with the values reported by Amare *et al.* (2009) and Belete (2006) (e.g., for Fogera study systems). Mean value of sheep TLU showed greater divergences across systems. For example there was contrasting differences of mean sheep TLU across farming systems in Diga and Jeldu. Many previous works account this for by to sheep adaptability to agro ecological zone (Amare *et al*., 2009). Even though the importance of cattle was similar across the study sites, in barley-potato system of Jeldu the mean value of cattle TLU were by one unit lower than the other systems and this can be accounted for by farmers alternative uses of horses both for transport and threshing purpose so replacing the role of oxen. The question is as to how these differences in species composition and herd size within and among systems influences LWP value.

Table 4. Mean livestock holdings (in TLU) by species of sample farms in the study system (Mean±SE)

Woredas	Farming systems	Mean values of livestock species by TLU						Total
		Cattle	Sheep	Goats	Donkey	Horse	Poultry	
Diga	TMS (N=35)	5.43±0.58	0.22±0.05[a]	0.04±0.02	0.22±0.04	-	0.02±.003[b]	5.90±0.61
	MSS (N=32)	5.67±0.71	0.11±0.03[b]	0.01+0.01	0.28±007	-	0.05±0.01[a]	6.07±0.77
	Mean (N=67)	5.54±0.45	0.16±0.03	0.03±0.01	0.25±0.04	-	0.03±0.005	5.98±0.48
Jeldu	BPS (N=31)	4.47±0.57[b]	0.75±0.12[a]	0.03±0.01	0.13±0.05[b]	1.79±0.19[a]	0.02±0.01	6.99±0.91[b]
	TWS (N=30)	6.67±0.66[a]	0.48±0.09[b]	0.02±0.02	0.26±0.08[a]	1.64±0.27[a]	0.02±0.00	9.25±0.83[a]
	TSS (N=30)	4.95±0.46[b]	0.22±0.06[c]	0.05±0.03	0.28±0.09[a]	0.53±0.15[b]	0.01±0.00	6.04±0.59[b]
	Mean (N=91)	5.35±0.34	0.49±0.06	0.03±0.01	0.22±0.04	1.32±0.14	0.02±0.00	7.42±0.47
Fogera	TMMS (N=32)	5.96±0.62	0.03±0.02	0.17±0.04[a]	0.35±0.07	-	0.07±0.02	6.52±0.61
	RPS (N=30)	5.13±0.59	0.18±0.07	0.03±0.01[b]	0.24±0.06	0.04±0.04	0.04±0.01	5.61±0.67
	Mean (N=62)	5.56±0.43	0.10±0.04	0.10±0.02	0.30±0.04	0.02±0.02	0.05±0.01	6.08±0.47

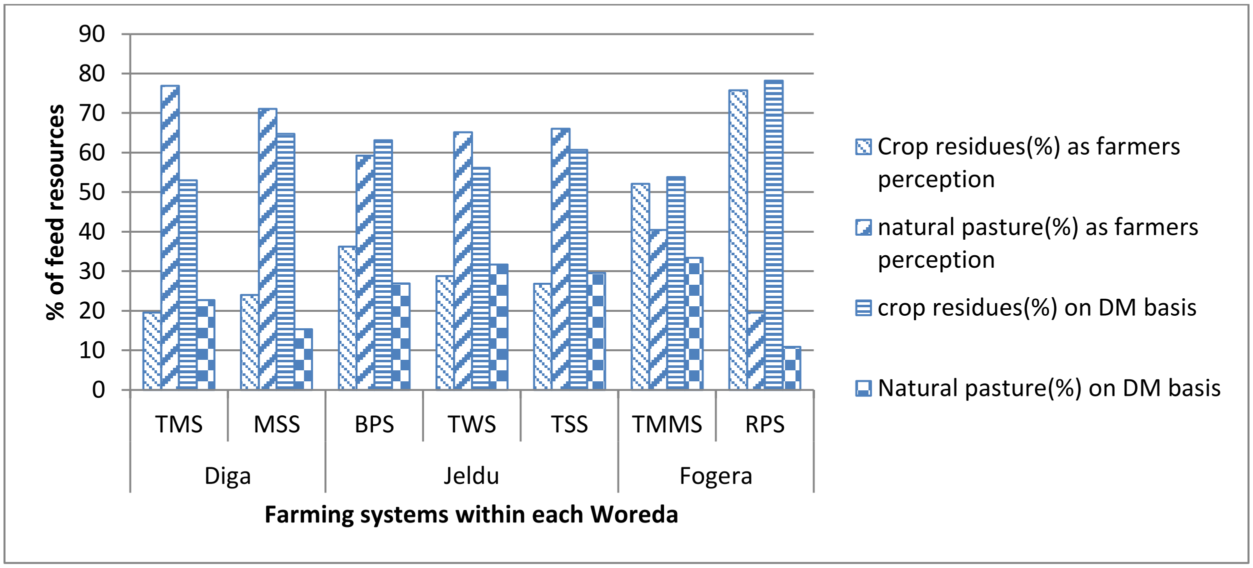
TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondents; [a-b-c] means with different letters superscripts along column within same Woreda is significantly different ($p<0.05$)

4.2. Variability of Feed Resources Availability and Ingredients Across the Study Systems

Sufficient and quality feed resources availability are some of the major determinants of livestock productivity. Figure 4 illustrates quantitative and farmers perception of feed availability and ingredient. Accordingly in all study systems majority of sample farmers responded that crop residues and green grass from natural pasture are major feed resources. Green forages from weeds and thinning of maize and sorghum also contribute to feed resources during wet season (August and September).

Quite interestingly the contribution of each of the feed ingredients to the diet of livestock varies between farmers perception (qualitatively) and estimated dry matter of each ingredient (Figure 4). For example for systems in Diga and Jeldu, according to the sample farm households' perception natural pasture has highest share of feed resources, 74.0% and 63.4%, respectively. But when computed on a dry matter basis the contribution of feed resources by natural pasture was by far lower: only 18.8% and 24.2%, respectively (Figure 4). This divergence between empirical values and farmers perception may have three major implications: i) the inconsistencies of information across different approaches and therefore evidences provided for policy actions; ii) Perhaps the fact that farmers under estimation of the role of crop residues as feed ingredient indicates the loose decisions farmers are making regarding crop residues use for animal feed; iii) farmers are perceiving the role of each feed ingredients from the time livestock are spending and therefore awareness in terms of total biomass yield and associated carrying capacity is lacking. Arguably these farmers under estimation of crop residues role in feed might have been due to limited volume of crop residues they are using for animal feed while the bulk of residues produced goes to waste. The point is as to whether the latter argument is a valid scenario in time of increasingly feed deficit situation in mixed crop livestock systems of Ethiopia. In this respect Peden *et al*. (2009) indicated that crop residues used for livestock feed is without additional cost of water. Generally for all farming systems, the crop residues contribution to feed on a dry matter basis ranged from 58.5% to 78.2%. This value is in good agreement with Kahsay (2004), in the central Highlands of Ethiopia and Bekele (1991) in Ada Woreda who suggested that the contribution of crop residues to feed resources is 76.6% and 71%, respectively. Moreover, the study of Adugna (2007) showed that the contributions of crop residues reach up to

80% during the dry season of the year. The importance of green forages (weeds, thinning of maize and sorghum) depends mainly on the type of crops and intensity of weed management. For example in barley-potato system and rice-pulses system of Fogera the role of these feed resources is reported to be negligible compared to these farming systems in Diga.



TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet/maize system; RPS = Rice-pulse system

Figure 4. Variability of feed resources availability and ingredients across the study systems based on sample farms perception and researchers' estimate of dry matter production

4.2.1. Dry matter productivity and grass-legume composition on private grazing lands

Decline of areas and dwindling of biomass productivity of grazing lands in the study areas are some of the major concerns. Table 5 compares the productivity of grass and legume species composition on private grazing lands. Both productivity and species composition (e.g., grass-legume) impacts the feed quantity and quality and therefore water productivity of livestock. For example Amare *et al*., (2011a) suggested that a unit increase in feed quality (energy density) can improve the water productivity of livestock by significant amount.

Table 5. Dry matter productivity of grasses and legumes from private grazing land (ton ha^{-1}) in study systems (Mean±SE)

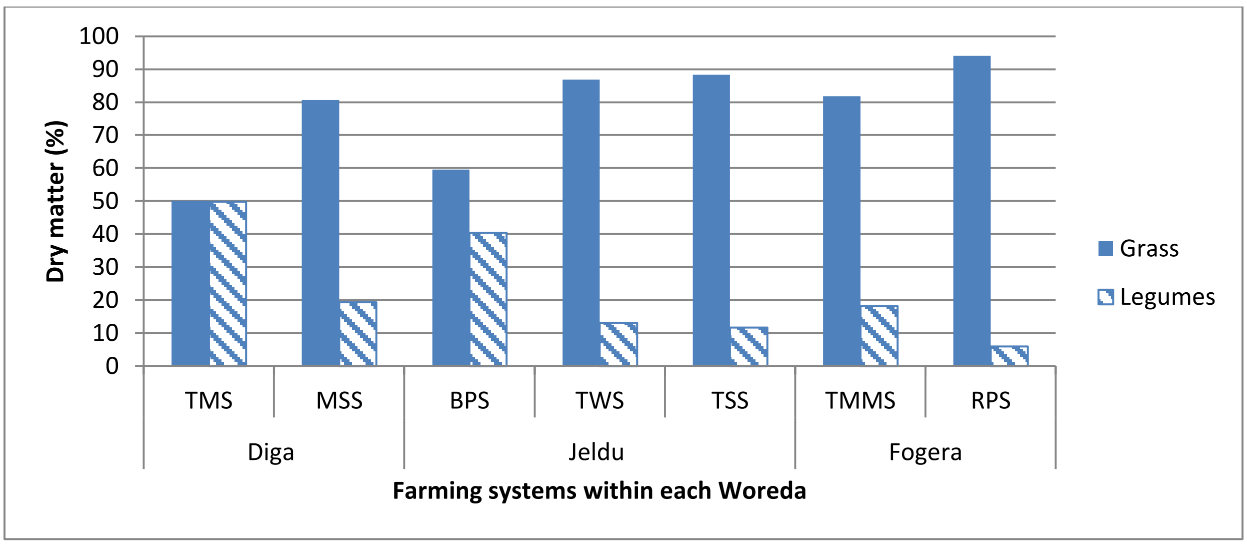
Woreda	Farming system	Landscape position	N	Above ground dry matter (ton ha^{-1})		
				Grass	Legumes	Total
Diga	TMS	Medium	16	1.54±0.10[a]	1.54±0.04[a]	3.08±0.13[b]
	MSS	Low	20	3.15±0.12[b]	1.08±0.08[b]	3.91±0.11[a]
	Mean		36	2.44±0.16	1.3±0.06	3.54±0.11
Jeldu	BPS	Upper	20	1.63±0.27[b]	1.14 ±0.17[a]	2.74± 0.24[c]
	TWS	Medium	16	3.06±0.26[a]	0.59±0.13[b]	3.52± 0.23[b]
	TSS	Low	8	3.98±0.37[a]	0.44±0.21[b]	4.51 ±0.34[a]
	Mean		44	2.67±0.22	0.81±0.11	3.40±0.18
Fogera	TMMS	Medium	20	4.37± 0.41	1.03 ± 0.24	5.54 ±0.40
	RPS	Low	16	5.48 ±0.57	0.61 ±0.12	5.82±0.57
	Mean		36	4.86±0.35	0.79±0.12	5.67±0.33

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system; [a-b] means with different letters superscripts along column within same Woreda is significantly different ($p<0.05$); SE = standard error; N= number of quadrats

In response to discrepancies in agro climate, level of overgrazing and farmers' management practices overall dry matter productivity of grass and legume composition showed variation across systems except systems of Fogera. The highest yield was estimated for systems in Fogera while the lowest was for systems in Jeldu. There were also apparent differences in grass-legume composition across systems and landscape position. This was in line with the Seyoum and Feyissa, (2007) who suggested that biomass production and grass-legume proportion of grazing land is highly related to landscape position, grazing management, climate factors (temperature, rainfall) and also soil types. What is encouraging in terms of future improvement of dry matter productivity and associated LWP is the huge yield gaps between these traditional practices and research managed intervention. For example in Fogera as much as 11.8 ton dry matter yield per hectare was reported (Ashagre, 2008) from improved natural pasture. By closing yield gaps as high as 100% improvement in LWP is reported for mixed crop livestock systems of India

(Amare *et al*., 2011a). Despite lower total dry matter productivity, the proportion of legume in Diga was higher than all other study systems (Figure 5). The point here is to see how these trends influence LWP value. The results in Diga and Jeldu Woreda in general were comparable with result of previous studies (Grima and Peden, 2003; Seyoum and Feyissa, 2007). The private grazing lands are generally protected from grazing for about three months depending on the feed availability.

The lower legume proportion in the grazing lands and in areas of abundant crop residues as feed resources which are low in quality (Nour, 2003; Teshome, 2009) may lead to low productivity of livestock and hence low LWP value.



TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-maize/millet system; RPS = Rice-pulses system

Figure 5. Proportion of grass-legumes composition on dry matter bases in study sites

In maize-sorghum system of Diga, *Eleusine coracana* and *Cyndon dactylon* and in the teff-millet system *Setaria acuta* were the most frequent grass species. *Andropogon gayanus*, *Andropogon dumereri* and *Cyndon dactylon* were the dominant grass species in barley-potato, teff-wheat and teff-sorghum systems of Jeldu, respectively. In study systems of Fogera, *Andropogon gayanus* were the dominant grass species. In all study farming systems *Trifolium rueppellianum* was the most frequent species of legumes (Appendix Table 7).

4.2.2. Variability of mean dry matter availability per sample farms in the study systems

Feed dry matter access considered here includes from private grazing land, fallow land and communal grazing land and crop residues. Table 6 depicts mean value of feed dry matter availability by farm households in study systems. Fallow lands in all farming systems were very rarely found except barley-potato system of Jeldu and teff-millet system of Diga Woreda (Table 3). Similarly, communal grazing land was also rarely found in all farming system of the study sites except in teff-millet/maize system of Fogera Woreda where on average 0.7 ha per household was found. The area of private grazing land per household ranged from 7.0-13.5% of total landholding in all farming systems.

In Diga and Fogera Woredas, mean dry matter production per household from grazing lands was similar (Table 6). However, the dry matter from grazing lands per household between the farming systems of Fogera was significantly different ($P<0.05$) but not between the farming systems of Diga. Similarly, in Jeldu, dry matter yield of grazing land per household of teff-wheat system was greater ($P<0.05$) than the barley-potato system. The DM yield from grazing land in the teff-millet/maize system of Fogera and teff-wheat system of Jeldu appeared to be higher than other systems. This may be due to the location of private grazing lands, which are located in seasonally water logged areas that produce high dry matter than in drained areas. The DM production from crop residues in the study sites varies depending on the cropped land size, crop types and productivity. The farming systems within Woreda vary ($P<0.05$) in the amount of DM produced from crop residues per household. Values were greater for maize-sorghum in Diga, for teff-wheat system in Jeldu and for rice-pulse system in Fogera. The dry matter of crop residues per household in farming systems was comparable with the study of Tesfaye, *et al.* (2006) for eastern Shewa region. The lower crop residues production in barley-potato system of Jeldu might be due to the damage of wheat by rust in 2010-11 year production. Currently potato production shares more land but not accounted for residues because no respondents used them for feed. Similarly, in Diga the lower dry matter crop residues in the teff-millet system might be due to the termite effects on the total biomass production. The study of Alemayehu (2009) indicated that straw yield of major cereals (teff, finger millet, maize, sorghum) were reduced by more than 60% within ten years interval due to termite infestation in West Wollega. It also indicated that almost all forage species attacked to termites. The total dry matter of crop residues production appeared to be comparable for all the three Woreda considered in this study.

Table 6. Dry matter production (ton) from feed sources in study sites per sampled household (Mean±SE)

Woredas	Farming systems	Landscape positions	N	CR	N	GL	Total
			Parameters				
Diga	TMS	Medium	35	4.0±0.3[b]	35	1.7±0.1	5.7±0.3[b]
	MSS	Low	32	7.3±0.4[a]	29	2.2±0.3	11.4±1.1[a]
	Mean		67	5.6±0.3	64	2.0±0.1	8.4±0.6
Jeldu	BPS	Upper	31	4.0±0.3[b]	27	1.7±0.2[b]	5.4±0.4[b]
	TWS	Medium	30	5.1±0.3[a]	30	2.9±0.3[a]	8.0±0.5[a]
	TSS	Low	30	4.5±0.3[ab]	28	2.2±0.3[ab]	6.5±0.5[b]
	Mean		91	4.5±0.2	85	2.3±0.2	6.6±0.3
Fogera	TMMS	Medium	32	4.2±0.3[b]	31	2.6±0.2[a]	6.6±0.5
	RPS	Low	30	6.5±0.5[a]	26	0.9±0.1[b]	7.3±0.6
	Mean		62	5.3±0.3	57	1.8±0.2	7.0±0.4

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-maize/millet system; RPS = Rice-pulses system; [a-b] means with different letters superscripts along column within same Woreda is significantly different ($p<0.05$); SE = standard error; DM = Dry matter; CR = Crop residues; GL= Grazing land, N = number of respondents

4.2.3. Improved forages production practice and major constraints

Table 7 depicts percentage of farmers involved in improved forage production. In view of increasing feed shortage improved forage production is important in many of the mixed farming systems in the BNB (WBISPP, 2002). In terms of quality also many scholars underline that the present crude protein content is not even sufficient for maintenance. Therefore, improved forage production practices both for enhanced productivity and higher feed quality are paramount importance in mixed crop livestock systems of the BNB.

Contrastingly the results of this study demonstrated that improved forages production was rarely practiced in all study sites. More than 85% of respondents in all study systems mentioned that they do not practice improved forages production (Table 7). The study of Zewdie (2010) in central Highlands of Ethiopia also indicated that the proportion of farmers practicing improved forage production is only 13%. Farmers reason for not practicing improved forage production varies across the study Woredas while among farming systems within the Woredas they tends to be similar. For example for farming systems in Diga the main reasons for not practicing improved forage production were lack of awareness followed by lack of seeds (Table7). For systems in Jeldu, the main reason for not practicing improved forage production was lack of seed. Although lack of awareness is a common denominator for many of the study systems, but in Fogera shortage of land emerges as an important constraint. Problem identified in this study agrees with report of Zewdie (2010). According to Alemayehu (2005), for last two decades forage adaptability and production trials were made across the different agro ecosystems in the country and some promising forages were selected.

In addition to the feed quality traits these forage species could be multi-cut and the growing period is longer and this creates opportunities for better water uptake and thus converts the evaporative green water losses to productive transpiration. Among the selected grass species, Rhodes grass (*Chloris gayana*), Guinea grass *(Panicum maximum*) and Napier grass (*Pennisetum purpureum*) are highly productive, their annual DM yields ranging between 10 and 15 tons ha^{-1}. Moreover, in suitable areas, yields of oat-vetch mixtures are commonly more than 8 ton ha^{-1} and that of fodder beet ranged from 15-20 ton ha^{-1} (Lulseged, 1987). Although we do not have actual figure on DM yields of oat, in the teff system of Jeldu, we observed a poor crop performance. Focusing on those high yielding variety can reduce competition for space with the food crops. One of the limitations of soil and water conservation structures built (e.g., millet systems of Fogera) is unproductive uses of spaces under physical structures. Species like Napier grasses can be planted with legumes as a mixed stand on farm boundary or as soil conservation measures. This is vital for high soil erosion prone areas like Jeldu (barley and teff systems) and also in millet systems of Fogera. Among the selected forage legumes, spurred butterfly pea *(Centrosema virginianum)* and cowpeas (*Vigna unguiculata*) have been identified as potential species for cut and carry system of feeding. These are good to plant on farm boundary and also on physical conservation structure. Species recommended for under sowing in perennial cash crops like coffee or cereals like maize and sorghum are Desmondium (*Desmodium intortum*, and *Desmodium uncinatum)* and Rhodes grass (Lazier, 1987). This will be a good intervention for the maize system in Diga. Some species are suggested for intercropping with cereal food crops such as barley and wheat. These include annual clovers, (T*ylosanthes guianensis, Macrotyloma axillare,* and *Lablab purpureum* (Lazier, 1987)). This will be important for barely based system of Jeldu and also wheat plots in teff system in Jeldu. Such intervention can increase the DM and crud protein (CP) in the wheat straw and thus positively impacts LWP through productive and high quality (e.g., improved digestibility) feed. In addition to the grasses and legumes, useful browse species pigeon pea (*Cajanus cajan*), glricidia (*Glricidia sepium*) and sesbania (*Sesbainia susba*) leucena (*Leucena leucocephala***)** have also been selected for the purpose of hedge planting (Lazier, 1987; Lulseged, 1987). In one of this study areas Descheemaker *et al*. (2011) illustrated an improvement in LWP as a result of on farm integration of shrubs like pigeon pea.

But to date adoptions of technologies are generally limited to pre-urban and urban area. Relevant question here is probably as to why policy measures that enhances improved forage production could not be implemented and as to whether policy recommendations, if it exists, are system specific or generalized.

Table 7. Percentages of respondents' practicing and reasons for not practicing improved forages production in study sites

Woredas	Farming systems	Landscape position	N	Practicing improved forage production		N	Reasons for not practicing improved forage production			
				Yes	No		Lack of seed	Seeds are expensive	Shortage of land	Lack of awareness
Diga	TMS	Medium	35	14.3	85.7	30	33.4	3.4	16.7	46.7
	MSS	Low	32	6.3	93.8	30	46.7	-	3.3	50.0
	Mean		67	10.4	89.6	60	40.0	1.7	10.1	48.4
Jeldu	BPS	Upper	31	19.4	80.6	25	72.0	8.1	12.0	8.1
	TWS	Medium	30	13.3	86.7	26	88.5	-	3.8	7.7
	TSS	Low	30	-	100	30	70.0	3.3	3.3	23.3
	Mean		91	11.0	89.0	81	76.5	3.7	6.2	13.5
Fogera	TMMS	Medium	32	6.3	93.8	30	3.3	3.1	63.4	30
	RPS	Low	30	13.3	86.7	26	23.1	-	34.6	42.3
	Mean		62	9.7	90.3	56	12.5	1.7	50.0	35.8

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondent

4.2.4. Sources of supplemental feeds

In view of the poor feed quality across the study systems, it is important that farmers supplement livestock with high energy density and higher protein content feed, if their livestock production objective is to exploit opportunity offered by the increasing demand for livestock products both locally and globally. Supplementary feed such as legume based, in addition to providing crude protein for increased animal productivity, it reduces the rumen carbon to nitrogen ratio and thus improve the digestibility of the poor quality feeds such as cereal residues. This improves LWP values significantly (Amare *et al.*, 2011b). Table 8 depicts percentage of sample farm households practicing supplementary feeding, sources of supplementary feed and type of animal they favor. The result demonstrated that in study systems, farmers practice feed supplementation very rarely particularly with sources outside their farm (e.g., bran, oil cake). This can be accounted for by to both lack of access and awareness. The consequence of not supplementing animal is far reaching: e.g., low productivity and high mortality. The most commonly used supplementary feed is residues of local brewery. Although the nutritional value this feed is rated as good (e.g., Zewdie, 2010), the availability is very limited and therefore does not satisfy the demand. Very exceptionally sample farms in Jeldu and Diga, responded that they provide roasted and boiled grains to oxen and weak animals.

Although farmers selective feeding of productive animal is a good indication of their understanding of the role of supplementation in enhanced productivity, the question as to whether farmers supplement their livestock sufficiently or not is a question for further investigation.

Table 8. Percentage of respondents on types of feed supplemented, season of feed supplemented and for which livestock type feed is supplemented in the study sites

Woredas	Farming systems	Landscape position	N	Seasons of supplementary feeding			Type and sources of supplemented feed				For which livestock type Supplemented				
				D	W	AA	Salt	BMH	BRG	LBR	TAL	WA	C	O	CO
Diga	TMS	Medium	35	5.7	42.9	51.4	37.1	2.9	28.6	31.4	14.3	-	5.7	20.0	60.0
	MSS	Low	32	18.8	43.8	37.5	37.5	9.4	34.4	18.8	15.6	3.1	9.4	21.9	50.0
	Mean		67	11.9	43.3	44.8	37.3	6.0	31.3	25.4	14.9	1.5	7.5	20.9	55.2
Jeldu	BPS	Upper	31	3.2	6.5	90.3	22.6	16.1	22.6	38.7	19.4	3.2	3.2	61.3	12.9
	TWS	Medium	30	3.3	10.0	86.7	10.0	10.0	13.3	66.6	20.0	-	-	80.0	-
	TSS	Low	30	16.7	16.7	66.7	26.7	10.0	10.0	53.3	6.7	10	3.3	66.6	13.3
	Mean		91	7.7	11.0	81.3	19.8	12.1	15.4	52.7	15.4	4.4	2.2	69.2	8.8
Fogera	TMMS	Medium	32	3.1	18.8	78.1	25.0	-	6.3	65.6	3.1	3.1	6.3	84.4	3.1
	RPS	Low	30	-	6.7	83.3	20	-	-	80	10	-	10	70	10
	Mean		62	1.6	12.9	80.6	17.7	-	3.1	75.8	6.2	1.6	6.5	80.7	4.8

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet-maize system; RPS = Rice-pulse system; N = number of respondents; D = Dry; W = Wet; AA = As available; BMH = by-product of mill house; BRG = Boiled/roasted grains; LBR = Local brewery residue; O = Ox; WA = weak animal; C = Cow; TAL= To all livestock; CO = Cow and ox

4.3. Feed Resources Management and Feeding Strategies

4.3.1. Feed resources management

In the study systems about 95.5%, of sample farmers in Diga, 92.3% in Jeldu and 88.7% in Fogera responded that the grazing lands are deteriorating. Given the low biomass yield and poor feed quality the current stocking density across the study areas seems high (1.7 TLU ha^{-1} in Diga, 2.2 TLU ha^{-1} in Jeldu and 2.9 TLU ha^{-1} in Fogera). Generally, the management of feed resources has impact on feed supply and quality and thus on LWP (Amare *et al.*, 2011a and Descheemaeker *et al.*, 2010a). Unless properly managed over stocking decreases the proportion of desirable species and favors infestation by less nutritious and unpalatable species (Ahmed 2006). Farmers across the study systems manage grazing land differently. But commonly private natural pasture is protected from grazing during June to September (Table 9). It is grazed late August to December privately then open to livestock of other farmers during dry season. Some studies suggested that protection from grazing is an important management practices to reduce compaction and to increase the biomass of the grazing land. For example Tefera *et al.* (2005) indicated a 50% above ground woody species composition increase as a result of enclosure. Moreover the study of Descheemaeker *et al.* (2010c) indicated that by protecting 40% of the grazing lands, the water productivity of the feed increased by about 20% and hence enclosure establishment could lead to similar improvements in livestock water productivity (LWP).

The second most important but most often neglected grazing land management is clearing of invasive species. In all study system invasive species are mentioned as major problem. For example in Diga, weed known as *Sida schimperiana* (*karaba*) is highly invasive species in lower landscape position. The species is widely spread on grazing land, fallow land and road sides. *Sida schimperiana* may compete with grass and legume species for nutrients and suppress the productivity of natural pasture. Such weeds contribute to non-productive of evapotranspiration (ET) which is one of the major areas on intervention to improve LWP. Moreover, in medium landscape position (teff-millet system) of Diga, respondents' complain about termite damage to their livestock's grazing lands. This affect LWP is several ways: it competes for the biomass and thus biomass will not be converted to beneficial output that can support the livelihood of the community. Secondly termite feed also on seed of pasture thus reduce generally biomass productivity of the areas. Similarly, in Fogera, weed known as *Asracantha longifolia* (Amekela) invades most of the communal grazing lands. This is an annual weed of the swampy or poorly drained areas, often found in black soils. Belete (2006) documented that the weed grows erect to a height of 15-50 cm and has hairy leaves with spines that protect the cattle from free grazing. The impact of this weed is not only on feeds of livestock but also on water use. It was observed that, this weed is not a problem to some extent in privately owned pastures because the farmers that have private pastures remove it by hand weeding before the flowering stage.

Table 9. Grazing lands management practices in study site as per respondents interviewed

Woredas	Farming systems	N	Percentages of respondents on management practices				Percent of manure used for fertilizer
			Resting* of private grazing	Clearing invasive species	Bylaws for grazing land management		
					Yes	No	
Diga	TMS	35	59.4	11.4	11.4	88.6	95.57
	MSS	32	62.9	28.1	6.3	93.8	96.44
	Mean	67	65.0	19.4	9.0	91.0	96.05
Jeldu	BPS	31	64.5	22.6	0	100	54.76
	TWS	30	93.3	3.3	3.3	96.7	57.83
	TSS	30	66.7	6.7	0	100	55.83
	Mean	91	74.4	11.0	1.1	98.9	56.16
Fogera	TMMS	32	63.3	12.5	59.4	40.6	57.52
	RPS	30	46.9	3.3	56.7	43.3	30.29
	Mean	62	54.8	8.1	58.1	41.9	44.83

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet/maize system; RPS = Rice-pulse system; N = number respondents;*private grazing land protected from grazing from June to August

The problem of weed infestation is mainly on communal property resources (Belete, 2006) and one of the major contributing factors, for example in farming systems of Diga lack of bylaws to manage common property resources (Table 9). The situation in Fogera seems better as about 58% of respondents mentioned that they have a rule mainly related to protecting the grazing areas from livestock that comes from other areas. But absence of removal of invasive species and seeding of nutritious and high yielding forage species one of the major problem farmers are facing on communal property resources. In respect to this; the study of Tilaye *et al*, (2011) also suggested that improving livestock water productivity depends on how local communal grazing resources are governed and that institutional deficiencies need attention in the mixed farming systems to improve water productivity.

Generally grazing removes nutrient with the biomass and incurs also erosion. Unless this is replaced systematically for example through manure application it depletes nutrient stock and thus plant will not be vigorous to take up water for transpiration and thus higher biomass yield. This is very much associated with LWP as suggested by Amare *et al.*, (2011a). In the study systems use of manure for fertilizer purpose largely depends on locally available alternative households' energy sources (Table 9). In Diga 96.05% the respondent used manure for fertilizer on private grazing land, crop lands and fallow lands. Conversely, in Jeldu and Fogera significant proportions of respondents were use manure for household energy. They even collect droppings from grazed land (communal and private grazing land) especially during the dry season. The study of Grima *et al*. (2003) indicated that removing cow dung from grazed plots decreased biomass production and species richness. Moreover, in barley-potato system, about 61.3% of the respondents fallow their land for an average of 1.6 years. About 25.8% and 12.9% of respondents' motive for fallowing land was for livestock grazing and fertility of the soil, respectively whereas about 22.6% of respondents for both livestock grazing and soil fertility. However, Amare *et al.* (2006) reported that one year grass fallow does not affect soil quality indicators (e.g., pH) significantly. Generally, Mohamed (1995) indicated that interventions for increasing the grazing pasture yield and quality include fertilizer inputs and forage legume over sowing accompanied by soil ripping.

Like for grazing lands management intensity of crop residues for feed depends mainly on level of feed deficit. This study found out that crop residues management varies across study sites mainly in terms of storage, utilization and feeding calendar. For example for systems in Diga, there was no much storage of large cereals straw, and only some small cereals straw was stored (Table 10). Although very much generalized, McIntire *et al.* (1989) reported that grazing *in situ* is the dominant form of use throughout the sub-Sahara countries. According Reed and Geo, (1989) the nutritive quality of crop residues declines the longer they remain in the field. In contrast, in both farming systems of Fogera, most of the respondents practiced storage of the available crop residues around home. But there were no treatments or improvements made during feeding to increase the quality of straws (Table 11). Said and Wanyoike (1987) indicated that even when stover is stored and fed as whole stalk and leaves without chopping, wastage is high and intake is low. This resulted in low productivity of livestock and hence the reduced LWP. In barley-potato system of Jeldu (80.6%), teff-wheat system (60%) and teff-sorghum system (50%) sample farmers responded that practiced storage of the small cereal residues under shed around home. This shows the management of crop residues in barley-potato system was better than the other farming systems of Jeldu. Probably such conservation of feed can be ascribed to the degree of feed deficit. Owen and Aboud (1998) account farmers failure to conserve and properly store feed to distance of cropped land from home, which involves additional labor and lack of transportation means. This constraint was also pointed out through group discussion in the study systems. The fact that different systems grow different crop combinations and some crop residues like large cereals are not convenient for storage unless chopped can be also one of the major reasons for variation. Generally the storage practices of small cereals straw in Fogera and Jeldu are comparable with the work of Tesfaye *et al*. (2009) that reported about 53% to 90% respondents practice storage of small cereals straw. But most often storage practices are without shade and thus expose the crop residues to weather. For example stored crop residues in rice-pulses systems of Fogera was under open condition, but Devendra (1982) observed a decrease in nutritive value of rice straw due to exposure to weather.

Table 10. Percentages of respondents conserving/storing feed in the study systems

Woredas	Farming systems	N	Large cereals				Small cereals			
			PHWS	PHWOS	PFWOS	LF	PHWS	PHWOS	PFWOS	LF
Diga	TMS	35	-	-	-	100	2.9	22.9	42.9	31.4
	MSS	32	9.4	-	3.1	87.5	9.4	25.0	18.8	31.3
	Mean	67	4.5	-	1.5	94.0	6.0	23.9	31.3	31.3
Jeldu	BPS	31	3.2	3.2	-	-	80.6	12.9	-	-
	TWS	30	3.3	13.3	10.0	33.3	60.0	30.0	3.3	6.7
	TSS	30	6.7	23.3	13.3	50.0	50.0	40.0	6.7	-
	Mean	91	4.4	13.2	7.7	27.5	63.7	27.5	3.3	2.2
Fogera	TMMS	32	6.3	-	78.1	-	15.6	75.0	-	-
	RPS	30	-	3.3	36.7	-	6.7	90.0	-	-
	Mean	62	3.2	1.6	58.1	-	11.3	82.3	-	-

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet/maize system; RPS = Rice-pulse system; N = number respondents; PHWS = pile at home with shed; PHWOS = pile at home without shed; PFWOS = pile at farm without shed; LF = left over the field

As indicated on Table 10, in all study systems, crop residues are most often stored without shed except in systems of Jeldu. Works of Mulugeta, (2005) in Yarer area reported that about 91% of the farmers stored crop residues outdoor. The question here is to understand the potential gain in LWP using proper storage as an entry point.

Another potentially important area of feed management to improve quality is crop residues management. Regardless of whether farmers are practicing proper storage or not overall the practices of crop residues treatment were insignificant (Table 11). This ultimately results in less efficient use of crop residues (Scarr, 1987) and hence low productivity of livestock. Only few sample farmers responded that they soak small cereals residues crop residues with salt water (Table 11) to feed oxen during ploughing. Number of practices are suggested and to some extent experimented in Ethiopia to treat crop residues to improve its palatability and digestibility. Amare *et al*., (2011b) and Descheemaeker *et al*., (2011) already demonstrated that crop residues management like chopping and urea treatment improves the feed quality and therefore LWP values. Smith (1993) also listed chopping, grinding, and treatment with urea as the most appropriate methods of improving the feed value of crop residues at the smallholder level. Hence, untreated crop residues may reduce the quality of available feed for livestock and lower the value of LWP. Physical treatment (chopping) of large cereals (maize and sorghum) was practiced to some extent in teff-wheat system and teff-sorghum system of Jeldu. In this regard, physical treatment of such residues, either to reduce their size (e.g., chopping) or to soften them (e.g., by soaking or wetting) is important to improve palatability leading to efficient utilization of the residues (Tesfaye, 1999).

Table 11. Percentages sample farmers who practice physical and/or chemical treatments of crop residues

Woredas	Farming systems	N	Large cereals residues				Small cereals residues			
			WSWS	CH	NT	NCR	WSWS	UT	NT	NCR
Diga	TMS	35	2.9	-	97.1	-	20.0	2.9	74.3	2.8
	MSS	32	3.1	-	96.9	-	6.2		78.1	15.7
	Mean	67	3.0	-	97.0	-	11.9	1.5	76.1	10.5
Jeldu	BPS	31	-	-	-	100	16.1	3.2	74.2	6.5
	TWS	30	-	36.7	30.0	33.3	10.0	-	86.7	3.3
	TSS	30	3.3	20.0	70.0	6.7	3.3	-	96.7	-
	Mean	91	1.1	18.7	35.2	45	9.9	1.1	85.7	4.3
Fogera	TMMS	32	-	-	93.8	6.2	-	-	96.7	3.3
	RPS	30	-	3.3	36.7	60	-	-	96.7	3.3
	Mean	62	-	1.6	66.1	32.2	-	-	96.8	3.2

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondents; WSWS = water soaking with salt; CH = chopping; NT = no treatments; NCR = no crop residues: UT = urea treatment

4.3.2. Feeding strategies and calendar

In previous section of this thesis it is illustrated that crop residues and green pasture from grazing made up important diets of the livestock in the study systems. Depending on availability of feed (sources, quality and quantity) and physiological stage of the animal and production objectives farmers feed animals differently. Sometimes prevalence tsetse fly also forces farmers to practice certain feeding strategies. The type of feeding is also influenced by the season of the year. In teff-millet system of Diga about 34.3% of the respondents practice tethering of livestock on grazing land (Table 12). However, in Jeldu and Fogera, most of the private grazing lands were grazed by herding and some of it used for hay making. For farming systems in Jeldu and Fogera the feeding systems of crop residues were similar, where most of respondents offer crop residues to their livestock in small amounts daily around stored place. About 95.6% and 96.7%, of respondents practice giving small amount of crop residues to livestock near homestead in farming systems of Jeldu and Fogera, respectively. The practices in maize-sorghum farming systems of Diga seems different in that about 50% of respondents practiced in situ grazing of crop residues. This is comparable with the findings of Kabatange and Kitalyi (1989) and Tesfaye (1999) where 61.5% and 60% of the respondents, respectively practiced in situ grazing of crop residues especially for large cereals straw. In all study systems, mixed straw feeding was not practiced except for the systems in Fogera where about 35.5% of respondents mix legumes straws with small cereals straws and provide to animals. Mixing legumes and cereals straws and feeding livestock increases palatability of the straws more than feeding alone. In all farming systems, feeding priority was given to oxen (Figure 6). Moreover, the most preferred straw across study sites was teff straw followed by millet straw or maize stover depending on availability. Sampled farmers in rice-pulses system of Fogera prefer legume straw rather than rice straw (Appendix Table 9). Descheemaeker *et al*. (2010b) clearly illustrated that feeding strategies that involve, for example, long walking and thus spending significant amount of Metabolisable Energy reduces influence LWP values.

Table 12. Percentages of respondents for feeding strategies of different feed sources in the study sites

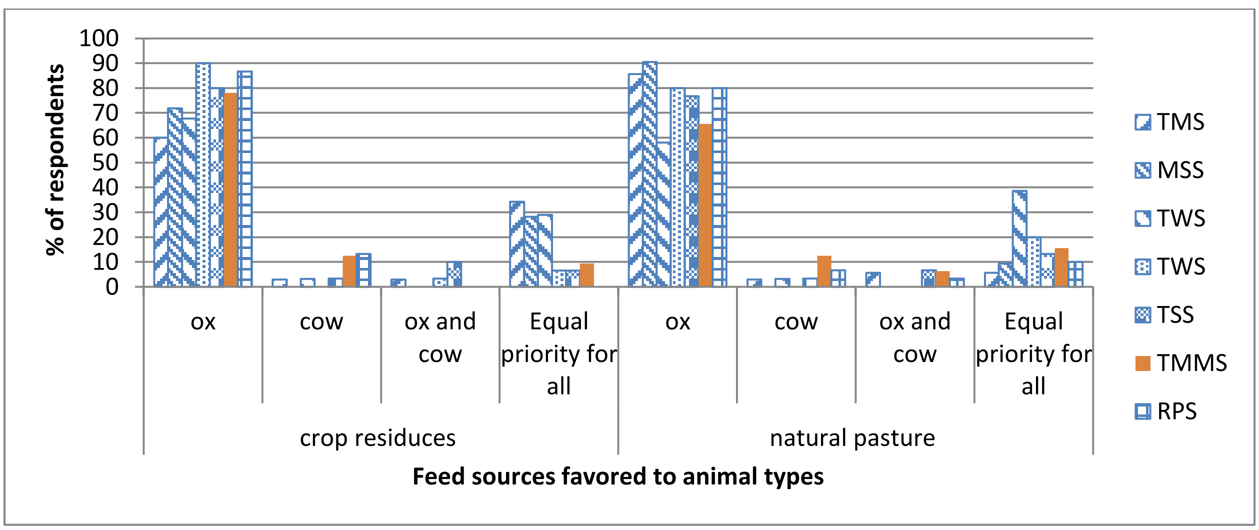
Woreda	Farming systems	N	Natural Pasture			Crop residues		Green forages	
			Grazing	Cut and carry	Tethering	In situ grazing	*Off situ feeding	Grazing	Cut and carry
Diga	TMS	35	60	5.7	34.3	62.9	37.2	14.3	5.7
	MSS	32	96.9	3.1	-	50	50	15.6	31.3
	Mean	67	77.6	3	19.4	56.7	43.3	14.9	17.9
Jeldu	BPS	31	100	-	-	6.5	93.5	-	41.9
	TWS	30	96.7	3.3	-	3.3	96.6	3.3	76.7
	TSS	30	86.7	10.0	3.3	3.3	96.6	6.7	86.7
	Mean	91	94.5	4.4	1.1	4.4	95.6	3.3	68.1
Fogera	TMMS	32	81.3	-	3.1	-	96.8	9.4	68.8
	RPS	30	53.3	23.3	-	-	96.7	-	60
	Mean	62	67.7	12.9	-	-	96.7	4.8	64.5

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondent; * crop residues offered for livestock in small amounts around stored place

Feeding calendar is important for management and utilization of available feed resources. Feeding calendar is unique to each site, especially for crop residues. Livestock feeding calendar varies depending on availability of the feed resources in the different months of the year (Alemayehu and Sisay, 2003). About 100%, 92.4% and 72.6% of the respondents in the Diga, Jeldu and Fogera responded that feeding of natural pasture was from June to December, and was almost similar in all farming systems of study sites. But in rice-pulses system of Fogera the grazing land is covered by water from June to August, and was grazed during September to December (Appendix Table 8). 86.8% of respondents in farming systems of Jeldu and 100% in Diga reported that they practice grazing of stubble from November to January and October to

January, respectively. In Fogera, about 58.1% of the respondents practice grazing of stubble from October to December but pluses stubble was also grazed in February (Appendix Table 8). In Diga farming systems sample farmers reported that the feeding calendar of crop residues were shorter while in Jeldu (61.3%) and Fogera (53.8%) of sample farmer reported that the feeding calendar of crop residues is from December to June. Generally this indicates that in farming systems of Fogera and Jeldu, crop residues are used for extended period without wastage and hence the associated water can more productive. The green forages (weeds, thinning of maize and sorghum) feeding calendar was similar (August to September) wherever available in the systems. Browsing of leaves and pods was from February to May depending on the availability of the browse trees and shrubs in all the systems of study sites.

Figure 6 below shows how farmers are selectively feeding their livestock. It was apparent that oxen have priority in access to feed resources in all study systems. Probably the trends reveal the findings of Descheemaeker *et al*. (2010a) who suggested that oxen are the key economic focuses of farmers and thus farmers are giving priority to feed oxen. The question is as to how this influences herd level LWP values.



TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet-maize system; RPS = Rice-pulse system

Figure 6. Farmers selective feeding of livestock across system

4.3.3. Efficiencies of utilization of crop residues and implication on LWP

Despite the important share of crop residues in feed ingredients of the study systems as illustrated earlier this study revealed that crop residues is under competitive uses. It is generally used for livestock feed, fuel and constructions (Table 13 and 14). Crop residues utilization varies across the study systems in different Woredas, although tends to be similar within Woredas. The intensity of use is much related to the grazing land pressure illustrated at the beginning of this thesis. For example about 53.6% of small cereals residues in Diga, 79.2% in Jeldu and 90.2% in Fogera were used as livestock feed (Table 13). Quite interesting is the magnitude of crop residues that is waste and marketed. In view of increasing feed shortage and also opportunity costs of crop residues (conservation agriculture) can be placed from wasted. The magnitude generally relates with the degree of intensification of systems.

Table 13. Percentages of small cereal residues usage for various purposes as per interviewed in the study sites (Mean±SE)

Woredas	Farming systems	N	Feed	Construction	Sold	*Wastage
Diga	TMS	35	51.3±3.6	3.3±0.8	5.3±2.6	38.8±4.9
	MSS	27	56.5±5.1	2.0±0.7	2.3±1.9	38.6±3.8
	Mean	62	53.6±3.0	2.7±0.6	4.0±1.7	38.7±2.9
Jeldu	BPS	31	79.1±2.2	8.5±1.3	-	11.8±1.8
	TWS	30	77.8±1.8	9.3±1.3	0.5±0.4	11.9±1.8
	TSS	30	80.7±3.2	5.5±1.0	0.8±0.4	12.7±2.8
	Mean	91	79.2±1.4	7.8±0.7	0.4±0.2	12.2±1.3
Fogera	TMMS	31	91.4±1.3	5.3±1.0	0.8±0.5	2.5±0.7
	RPS	30	89.0±3.9	3.7±0.7	6.8±4.0	0.7±0.3
	Mean	61	90.2±2.0	4.5±0.6	3.8±2.0	1.5±0.4

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet-maize system; RPS = Rice-pulse system; N = number of household; *= crop residues not fed, and wasted during storage and/or feeding on the field; Small cereal = teff, wheat, barley, rice and finger millet

For example the average percentages of wastage from small cereals straw were high in Diga (38.8%) than Jeldu (12.2%) and Fogera (1.5%). Utilization of feed resources has significant impact in improving LWP.

A similar trend was observed between type and efficiencies of uses of large cereals stover such as maize and sorghum. Unlike the small cereals straws, larger cereals residues are uses for fuel in higher proportion. The average percentages of large cereals residues (maize and sorghum) used as livestock feed varies across the Woredas, but comparable among the farming systems within each Woreda (Table 14). Hence, the average proportion of large cereals residues used for livestock feed in Diga (38.9%) was less than Jeldu (52.5%) and Fogera (80.5%). Conversely, the average proportions of wastage of large cereals residues were higher in Diga (36.0%) than in Jeldu (22.5%) and Fogera (6.3%).

Table 14. Percentages of large cereals residues usage for various purposes as per interviewed in the study sites (Mean±SE)

Woreda	Farming systems	N	Feed	Fuel	Construction	Wastage*
Diga	TMS	35	35.7±2.4	17.6±2.2[b]	3.9±2.1	42.2±3.5[a]
	MSS	32	42.3±4.1	28.1±3.4[a]	0.5±0.3	28.9±3.6[b]
	Mean	67	38.9±2.4	22.6±2.1	2.2±1.1	36.0±2.6
Jeldu	BPS		-	-	-	-
	TWS	22	65.5±3.9[a]	10.9±2.1[b]	0.7±0.5	25.2±4.0
	TSS	28	42.3±4.2[b]	32.9±4.1[a]	4.2±1.8	20.3±4.1
	Mean	50	52.5±3.3	23.2±2.9	2.6±1.0	22.5±2.3
Fogera	TMMS	30	76.8±2.6[b]	14.4±1.9	0.17±.16	8.7±1.8[b]
	RPS	12	89.8±3.1[a]	9.8±2.9	-	0.4±0.4[a]
	Mean	42	80.5±2.2	13.1±1.6	0.12±.11	6.3±1.4

TMS =Teff-millet system; MSS = Maize-Sorghum system; BPS = Barley-potato system; TWS =Teff –wheat system; TSS = Teff-sorghum system; TMMS =Teff-millet-maize system; RPS = Rice-pulse system; N = number of household; [a-b] means with different letters superscripts along column within same Woreda is significantly different ($p<0.05$); *crop residues stored but not fed, and wasted during storage and/or feeding on the field. Large cereals include = maize and sorghum

The average proportions of legumes straw usage for livestock feed were 6.7%, 79.2% and 94.8% in Diga, Jeldu and Fogera, respectively. Small straws from barely, wheat, rice and teff were sold to some extent to meet some household expenditure. Teff straw, and in rare cases barley and wheat straw are mixed with mud as binding material for plastering walls of local houses.

4.4. Variation in Temporal Feed and Water Resources Availability

Optimum distribution and synchronizing livestock feed and water availability across seasons of the year is important measure to reduce land degradation and increase livestock productivity. As indicated on Table 15 temporal feed availability and access of livestock to drinking water varies among farming systems. Feed availability depends on sources of feed, feeding strategies, managements and feed use factors as illustrated in preceding section of this thesis. Framers reported that there is time where feed is adequate, surplus and deficit. For example in farming systems for Diga and Jeldu, the shortages of feeds was experienced in winter and spring, adequate feed was available in summer and autumn (Table 15). For farming systems in Fogera, the feed availability between the systems was highly different, and autumn was the relatively better time for feed availability for teff-millet/maize system and winter was for the rice-pulse system. This may be because of the water logged on grazing land during summer and high biomass of rice straw available in the system during winter season.

Quite interesting observation was the pattern of seasonal distribution of feed in the two adjacent farming in Fogera. As indicated on Table 15 the feed distribution in these farming systems tends has an inverse relation: i.e. when feed is sufficiently available in one system it is scarce in the other. Framers are explaining this trend as an indicator of interdependency of those two adjacent systems. This means also that improvement in water productivity of livestock needs across system linkage (e.g., system in upstream and system in downstream). For example improved soil and water conservation in the system in the upper landscape position (teff-millet/maize) can mitigate flooding on the foot slope position (rice-pulses system) which already farmers in lower landscape position complained as the major limiting factor for livestock feed production.

Table 15. Percentages of respondents on feed availability across season of the year in the study sites

Woreda	Farming systems	Landscape position	N	Seasons											
				Summer			Autumn			Winter			Spring		
				IA	A	S	IA	A	S	IA	A	S	IA	A	S
Diga	TMS	Medium	35	9.4	68.8	21.9	15.6	71.9	12.5	90.6	3.1	6.3	96.9	3.1	-
	MSS	Low	32	2.9	65.7	31.4	22.9	65.7	11.4	88.6	11.4	-	100	-	-
	Mean		67	6.0	67.2	26.9	19.4	68.7	11.9	89.6	7.5	3.0	98.5	1.5	-
Jeldu	BPS	Upper	31	35.5	64.5	-	29.0	38.7	32.3	93.5	6.5	-	96.8	3.2	-
	TWS	Medium	30	50.0	50.0	-	6.7	53.3	40.0	66.7	26.7	6.7	96.7	3.3	-
	TSS	Low	30	43.3	56.7	-	3.3	60.0	36.7	76.7	13.3	10	93.3	6.7	-
	Mean		91	42.9	57.1	-	13.2	50.5	36.3	79.1	15.4	5.5	95.6	4.4	-
Fogera	TMMS	Medium	32	53.1	18.8	28.1	31.3	34.4	34.4	75.0	18.8	6.3	87.5	9.4	3.1
	RPS	Low	30	80.0	13.3	6.7	70.0	23.3	6.7	20.0	30.0	50	53.3	33	13
	Mean		62	66.1	16.1	17.7	50.0	29.0	21.0	48.4	24.2	27	71.0	21	8.1

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondents Summer = June, July and August; Autumn = September, October and November; Winter = December, January and February; Spring = March, April and May; IA = Inadequate; A = adequate; S = surplus

Rivers are the most important sources of water for livestock drinking in all study sites during dry and wet seasons. For farming systems in Diga and Jeldu the source of water for livestock is mainly river and in wet season to some extent from still water. But, for farming systems in Fogera, well and ponds were source of water during dry season to some extent (Table 16). This type of source of water may be good in decreasing energy lost in searching of water from rivers.

Table 16. Percentages of respondent on source of water for livestock drinking in the study sites

Woreda	Farming systems	N	Source of water in dry season				Source of water in wet season			
			Well	River	Pond	Still water	Well	River	Pond	Still water
Diga	TMS	35	-	97.1	-	2.9	-	82.9	-	17.1
	MSS	32	-	100	-	-	-	93.8	-	6.3
	Mean	67	-	98.5	-	1.5	-	88.1	-	11.9
Jeldu	BPS	31	-	100	-	-	-	58.1	-	41.9
	TWS	30	-	93.3	-	6.7	3.3	63.3	3.3	30.0
	TSS	30	-	96.7	-	3.3	3.3	60.0	3.3	33.3
	Mean	91	-	96.7	-	3.3	2.2	60.4	2.2	35.2
Fogera	TMMS	32	9.4	28.1	37.5	25	3.1	84.4	3.1	9.4
	RPS	30	13.3	56.7	16.7	13.3	-	50	-	50
	Mean	62	11.3	41.9	27.4	19.4	1.6	67.7	1.6	29

TMS =Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet-maize system; RPS = Rice-pulse system; N = number of respondents; still water = natural stagnant water stay for short or long time

The distance to source of water for livestock mostly ranges from 0.5 km to 2 km in all the systems (Table 17). A significant proportion of respondents mentioned that the distance to water sources for livestock drinking in teff-millet system of Diga, barley-potato system of Jeldu and teff-millet/maize system of Fogera is greater than 2 km. Moreover, the dry matter production from grazing lands was lower on the upper landscape positions (Table 5). This indicates that the shortage of feed coupled with more energy wastages in search of water will reduce the productivity of livestock. The study of Peden (2009) pointed out that minimizing stress on the animal associated with factors such as excessive trekking to watering sites is important to reduce the water cost of animal production. In dry season, the distance to water sources would be longer and the frequency of water drinking is mainly two times per day in all farming systems (Table 17). This aggravates the energy loss mostly in upper or medium position compared to the lower landscape position of farming systems. Staal *et al*. (2001) showed that providing on-site drinking water to livestock reduces stress and energy costs associated with drinking enabling substantive increases in animal production, which can improve LWP.

Table 17. Percentages of respondents on frequency of drinking of livestock and estimated distance to sources of water in the study sites

Woreda	Farming systems	N	Wet season						Dry season					
			Frequency of drinking			Distance to water (km)			Frequency of drinking			Distance to water (km)		
			Twice a day	Once a day	Once in two days	<0.5	0.5-2	2-5	Twice a day	Once a day	Once in two days	<0.5	0.5-2	2-5
Diga	TMS	35	11.4	85.7	2.9	14.3	57.1	26.6	100	-	-	14.3	50.8	34.5
	MSS	32	9.4	90.6	-	12.5	56.1	31.2	100	-	-	6.3	61.5	31.3
	Mean	67	10.4	88.1	1.5	13.4	56.7	29.8	100	-	-	10.4	56.7	32.8
Jeldu	BPS	31	9.7	90.3	-	9.7	67.7	22.7	100	-	-	-	67.7	32.3
	TWS	30	3.3	96.7	-	33.3	63.3	3.3	90	10	-	20	76.6	3.3
	TSS	30	-	93.3	6.7	20	73.3	6.7	73.3	23.3	3.3	16.7	66.7	16.7
	Mean	91	4.4	93.4	2.2	20.9	68.2	11	87.9	11.0	1.1	12.1	70.4	17.6
Fogera	TMMS	32	6.3	81.3	12.5	6.3	75.1	18	75.0	12.5	12.5		78.1	21.9
	RPS	30	10.0	86.7	3.3	60	36.6	3.3	96.7		3.3	46.7	43.3	10
	Mean	62	8.1	83.9	8.1	32.3	54.6	11.3	85.5	6.5	8.1	22.6	61.4	16.1

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; WTS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-millet/maize system; RPS = Rice-pulse system; N = number of respondents

4.5. Major Constraints on Feed Sourcing and Feeding

Table 18 below depicts major problem related with feed sourcing and feeding in the study systems of the Blue Nile Basin. Shortage of grazing land ranked first in all study sites. The findings of this study agrees with the work of Zewdie (2010) which illustrated shortage of grazing land as the major contributes to critical feed shortages in the Highland areas. This part of this study also commensurate well with farmers opinion regarding determinates of weak adoption of improved forage production reported in the preceding section of this work. Land degradation and low biomass yield were ranked as second in Diga and third in Jeldu. Issues of land degradation in the study systems are also reported by Birhanu *et al*. (2011). In Fogera, livestock population pressure ranked as second constraint of feed sourcing and feeding strategies. Probably what is peculiar in those relatively high rain fall areas is the fact that poor rain fall distribution stood the second important problem for systems in Jeldu. Water logging on grazing land was a constraint in farming systems of Fogera mainly in rice-pulses system.

In their study of scenario based comparison of the impacts of livestock and feed based intervention on LWP values, Amare *et al*., (2011a) illustrated that feed based intervention has a significant magnitude of impacts on LWP compared to the livestock based. The fact that some of the livestock based intervention takes longer year to generate impacts also limits the short term targeting of this intervention.

Table 18. Major constraints of feed sourcing and feeding strategies in study sites

Woredas	Constraints	Rank given by respondents (%)					Indices	Rank by indices
		1	2	3	4	5		
Diga (N=67)	Rainfall distributions problem	13.4	16.4	9.0	7.5	53.8	0.17	3
	Shortage of grazing land	43.3	16.4	14.9	9.0	16.5	0.30	1
	Livestock population pressure	6.0	11.9	16.4	16.4	59.7	0.16	4
	Land degradation and low biomass yield	23.9	22.4	17.9	10.4	25.4	0.20	2
	Poor storage facilities of feed sources	9.0	10.4	13.4	22.4	44.8	0.16	4
Jeldu (N=91)	Rainfall distributions problem	36.3	15.4	9.9	8.8	29.7	0.23	2
	Shortage of grazing land	49.5	36.3	4.4	4.4	5.5	0.33	1
	Land degradation and low biomass yield	5.5	22.0	30.8	14.3	27.5	0.19	3
	Low quality and variability of feed in year	3.3	7.7	14.3	24.2	50.6	0.14	4
	Lack of improved feeding systems	1.1	3.3	6.6	11.0	78	0.10	5
Fogera (N=62)	Rainfall distributions problem	21.0	8.1	11.3	4.8	54.9	0.17	4
	Shortage of grazing land	40.3	35.5	17.7	3.2	3.2	0.30	1
	Land degradation and low biomass yield	8.1	11.3	12.9	14.5	53.2	0.15	5
	Livestock population pressure	8.1	21.0	25.8	17.7	27.4	0.20	2
	Water logging on grazing land	16.1	14.5	14.5	4.8	50	0.18	3

Index for all Woreda for constraints= sum of single constraint parameter ranked in each Woreda i.e. (5*1st ranked constraint parameter) + (4*2nd ranked constraint parameter) + (3*3rd ranked constraint parameter) + (2*4th ranked constraint parameter) + (1*5th ranked constraint parameters)/sum of all weighted constraints parameters described by the respondents in each Woreda; N = number of respondents
.

4.6. Feed Demand-Supply Balance Estimation and Implication for LWP

The dry matter (DM) and associated Metabolisable Energy (ME) of feed resources were in all farming systems depicted in Table 19. Major feed resources used for the estimation of DM supply side were natural pasture, crop residues and stubble grazing. Accordingly, the major dry matter and ME supply comes from values noted in Table 6. Generally the dry matter and metabolisable energy were below annual livestock requirements in all framing systems except for maize-sorghum system of Diga. This was pointed out by the study of Mohamed (1995) that the feed supply in most of the Ethiopian Highland is far below the livestock annual requirement. WBISPP (2002) also suggested similar trends for most parts of Ethiopia including our study sites. In Diga the annual ME estimated per household meet about 68.1% and 122.3% of the annual requirement of livestock in teff-millet and maize-sorghum systems, respectively: i.e. the metabolisable energy was deficit in teff-millet and surplus in maize-sorghum systems of Diga. This can be accounted for by the difference of crop residues production and grazing land productivity. In barley-potato, teff-wheat and teff-sorghum systems of Jeldu the annual ME estimated of supply side meets only 56.4%, 60% and 73% of ME requirements of livestock, respectively. The ME deficit was stronger for systems in Jeldu than other. This may be due to the difference in crop production types in relation to feed sources (e.g., livestock feed from Potato production in Jeldu is normally very less). Similarly, the annual available ME meets only 68.7% and 74.5% the energy requirements of livestock in teff-millet/maize and rice-pulses systems in Fogera in that order. This indicates that the shortages of feed became more in teff-millet system than in rice-pulse system. This disagrees with the study of Belete (2006) that noted feed shortage in the rice system to be higher than in the millet system and probably the differences can be accounted by changes in production of rice since Beletes work. Energy is usually the most important feed component needed to nutrient requirement of livestock. The value of feed is clearly related to the amount of energy it can supply, since energy is usually the chief limiting nutrient (Wilson and Brigstocke, 1983). According to Blümmel *et.al* (2009), feed metabolisable energy (ME) content should be used as an important determinant of livestock productivity; and water requirement for feed and fodder production should be related to a unit of feed ME rather than feed bulk. Study of Amare *et al*. (2011a) also indicated that improving feed quality by 1.5MJ kg^{-1} saves water about 120 m^3 per cow per year.

Scholars are increasingly concerned as to how livestock can survive and produce in states of negative feed ME balances (Amare *et al*., 2011a). This thesis argues that demands might be overestimated and supplies underestimated due to inconsistencies in analytical methods. Systems are also not self-contained. Farmers in mixed crop livestock systems are diverse (e.g. in terms of farmers' access to resources).

Table 19. Average estimated annual DM (kg) and ME (MJ) supply, demand and balance per household farm in the study sites

Woredas	Farming systems	N	Annual feed supply		Annual feed demand		Balance of supply and demand	
			TDM	TME	TDM	TME	TDM	TME
Diga	TMS (5.9 TLU)	35	7509.3	59834.4	10382.8	87886.7	-2873.5(72.3%)	-28052.3(68.1%)
	MSS (6.1 TLU)	32	13300.3	110101.2	10201.7	90006.7	+3098.6(130.4%)	+20094.5(122.3%)
	Mean (6.0 TLU)	67	10275.2	83842.4	10296.3	88882.4	-21.1(99.8%)	-5040(94.3%)
Jeldu	BPS (7.0 TLU)	31	6214.8	54081.6	11140.5	95732.4	-4925.7(55.8%)	-41650.8(56.4%)
	TWS (9.3 TLU)	30	9045.5	79719.2	15207.9	132780.5	-6162.4(59.5%)	-53061.3(60%)
	TSS (6.0 TLU)	30	7414.1	63303.9	10710.6	86665.6	-3296.5(69.2%)	-23361.7(73%)
	Mean (7.4 TLU)	91	7543.4	65573.9	12339.7	104957.0	-4396.3(61.1%)	-39383.1(62.5%)
Fogera	TMMS (5.6 TLU)	32	7704.3	68391.2	11455.3	99596.7	-3751(67.3%)	-31205.5(68.7%)
	RPS (4.8 TLU)	30	8360.7	66010.9	10004.1	88622.9	-1643.4(83.6%)	-22612(74.5%)
	Mean (6.1 TLU)	62	8021.9	67239.4	10753.1	94286.8	-2731.2(74.6%)	-27047.4(71.3%)

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS =Teff-sorghum system; TMMS = Teff-maize/millet system; RPS = Rice-pulses system; TDM = Total dry matter; TME = Total metabolisable energy; N = number of respondents

The overall feed deficit coping mechanisms are depicted in Table 20. In Diga crop residues usage and movement of livestock across the systems were the coping mechanisms during feed shortages. The coping mechanism of feed shortages in Jeldu and Fogera includes preservation of crop residues, hay making and purchasing of grazing land. However, it was observed during survey time that the harvesting time of natural pastures were during seed shedding. This may deteriorate the quality of the hay and thus LWP values. In Jeldu, movement of livestock in search of feed sources called '*Daraba*', to a less livestock populated areas is practiced. About 33% of respondents move their all cattle except oxen and lactating cows from June end to September. According to the respondents, it needs approximately 12 hours for livestock trekking to cover around 42 km to the source of feed.

Table 20. Percentages of respondents on coping mechanisms during feed shortages

Woredas	Farming systems	N	Move livestock to search feed		Hay making	Purchase of grazing land	Usage of crop residues	No measure taken
			Yes	No				
Diga	TMS	35	20	80	-	5.7	71.5	22.9
	MSS	32	12.5	87.5	-	9.4	62.5	28.1
	Mean	67	16.4	83.6	-	7.5	67.2	25.4
Jeldu	BPS	31	9.7	90.3	35.5	3.2	74.2	22.6
	TWS	30	40	60	43.3	13.3	83.3	3.3
	TSS	30	50	50	10	30	50	20
	Mean	91	33	67	*29.7*	15.4	69.2	15.4
Fogera	TMMS	32	30	70	40.6	9.4	53.1	9.4
	RPS	30	3.1	96.8	13.3	16.7	50	10
	Mean	62	16.1	83.9	*27.4*	12.9	51.6	9.7

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-maize/millet system; RPS = Rice-pulses system; N = number of respondents

4.7. Water Depleted for Livestock Feed Production and Values of Livestock Beneficial Outputs and Services

In this study, evapotranspired (ET) water was considered as depleted water for feed production. The water depleted (m^3 ha^{-1}) for feed production in the study areas is presented in Table 21. For farming systems in Diga and Fogera, water depleted for feed production significantly differed between farming systems ($P<0.05$), while for systems in Jeldu ET value was statistically insignificant ($P>0.05$). The value of ET depends on climatic factors such as temperature, rainfall, sunshine and wind, crop types and patterns.

The overall average of the water depleted for feed production per hectare was comparable between system in Diga and Jeldu, but it was relatively higher for systems in Fogera. Crop types (e.g., rice), which has high ET in Fogera rice system could be accountable for the difference. In Diga and Fogera the water depleted per hectare increases as altitude decreases. The water depleted for feed production may be greater than the estimated in this thesis obtained for all farming systems, had some feed sources (e.g., local brewer residues, weeds and thinning of sorghum and maize), which are difficult to quantify, were included in the calculation.

Variability of livestock beneficial output among study systems was not apparent. Only values of livestock beneficial outputs (US$ TUL^{-1}) were significantly different between ($P<0.05$) the farming systems of Diga. This result was mainly from difference in output of milk yield. For example the milk productivity per cow in teff-millet of Diga was 1.05 liters day^{-1} whereas in maize-sorghum it was 1.56 liters day^{-1}. Generally the differences in beneficial outputs and services may be differed depending on the livestock structure and size, livestock breed types, services and market prices for the beneficial outputs in the farming systems. Unlike the productivity of livestock per TLU, the productivity of livestock per hectare (US$ ha^{-1}) was not significantly different ($P>0.05$) among farming systems of all. But it shows an increasing trend along increasing livestock density. The question then as to whether higher LWP triggered by such higher livestock population density could be considered as a sustainable water saving strategy. The livestock productivity per hectare of this study is comparable with the study of Amare *et al.* (2009) in rice based system of Gumera watershed.

Table 21. Water depleted for livestock feed and productivity of livestock in study sites (Mean±SE)

Woreda	Farming systems	Landscape positions	N	Parameters		
				Water depleted (m^3 ha^{-1})	Beneficial output (US$ TLU^{-1})	Beneficial output (US$ ha^{-1})
Diga	TMS	Medium	35	1888.2±76.9[b]	128.6± 10.5[b]	230.0± 21.7
	MSS	Low	32	2143.6± 49.1[a]	176.8± 21.6[a]	227.9± 25.5
		Mean	67	2010.2±48.8	151.6± 11.9	229.0± 16.5
Jeldu	BPS	Upper	31	2075.0±84.8	138.8± 11.7	304.6± 38.3
	TWS	Medium	30	2135.6±71.2	138.6± 9.4	349.3± 33.6
	TSS	Low	30	2005.6±94.0	158.8± 11.3	308.0± 28.1
		Mean	91	2072.1±48.2	145.3± 6.3	320.5± 19.3
Fogera	TMMS	Medium	32	2989.8± 128.7[b]	167.2± 10.3	481.3± 30.6
	RPS	Low	30	4379.2± 175.2[a]	149.1± 12.1	448.1± 50.2
		Mean	62	3662.1± 138.9	158.5± 7.9	465.2± 30.6

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS =Teff-sorghum system; TMMS = Teff-maize/millet system; RPS = Rice-pulses system; [a-b] means with different superscript letters along the column for the same parameter in the same Woreda do significantly differ ($P<0.05$); 1US$ = 17 ETB; N = number of respondents

4.8. Feed Water Productivity

Water productivity for feed resources in the study systems is shown in Table 22. The total feed water productivity was computed from major feed resources (crop residues, grazing lands and stubble grazing). For systems in Diga, maize-sorghum system showed a significantly higher feed water productivity values at ($P<0.05$). In Jeldu, the grazing land water productivity increased with decreased in altitude and was significantly different at $P<0.05$. For farming systems in Fogera, total feed and crop residues water productivity showed statistically significant difference at $P<0.05$. The magnitudes of water productivity for feed sources (e.g., crop residues and grazing land) were generally higher in lower landscape position and the degree of water depletion showed similar trend. The point here is how these trends, elaborated so far, feed productivity, depleted water, feed water productivity and livestock beneficial out puts, influences the LWP values and what these imply in terms of entry points to improve LWP. Number of empirical evidence suggests that feed water productivity is one of the key determinants of LWP (Amare *et al*., 2011a and Descheemaeker *et al*., 2010b). The value for crop residues water productivity ranges from 1.2 kg m^{-3} to 1.9 kg m^{-3} in the study farming systems. This is comparable with study of Mekete (2008) that noted 1.19 and 1.38 kg m^{-3} in rainfed Golina and Awehula watersheds, respectively. However, the water productivity for grazing land reported here was higher than study of Mekete (2008) which was conducted in Golina (0.26 kg m^{-3}) and Awehula (0.32 kg m^{-3}). The differences can be accounted for by the differences in the level moisture in the two study areas.

Table 22. Water productivity for feed sources (kg m^{-3}) in the study sites (Mean±SE)

Woreda	Farming systems	Landscape positions	N	Parameters		
				CRWP	GLWP	TFWP
Diga	TMS	Medium	35	1.2±0.06[b]	0.56±0.03[b]	1.3±0.05[b]
	MSS	Low	32	1.9±0.07[a]	0.74±0.03[a]	1.9±0.15[a]
	Mean		67	1.5±0.06	0.64±0.02	1.6±0.09
Jeldu	BPS	Upper	31	1.26±0.06	0.46±0.03[c]	1.30±0.08[b]
	TWS	Medium	30	1.27±0.04	0.75±0.02[b]	1.41±0.04[ab]
	TSS	Low	30	1.34±0.05	0.89±0.06[a]	1.59±0.06[a]
	Mean		91	1.30±0.03	0.70±0.03	1.43±0.03
Fogera	TMMS	Medium	32	1.3±0.04[b]	0.73±0.04	1.4±0.04[b]
	RPS	Low	30	1.5±0.05[a]	0.82±0.04	1.8±0.05[a]
	Mean		62	1.4±0.03	0.77±0.03	1.6±0.04

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS = Teff-wheat system; TSS = Teff-sorghum system; TMMS = Teff-maize/millet system; RPS = Rice-pulses system; [a-b-c] means with different superscript letters along column for the same parameter in the same Woreda do significantly differ ($P<0.05$); SE = standard error; CRWP = Crop residues water productivity; GLWP = Grazing land water productivity; TFWP= Total feed water productivity

The overall average total feed water productivity was comparable across the study Woredas. However, Peden *et al*. (2007) concluded from available literature that evapotranspired water used to produce 1 kg of dry animal feed is highly variable, ranging from about 0.5 kg m^{-3} of water to about 8 kg m^{-3} of water. This implies the potential for improvement. The low value of grazing land feed water productivity is likely partially related to the fact that grazing land often has shallow or degraded soil (Table 18) that is not or no longer suitable for crops. This guides for more attention on grazing land management to increase the productivity of water. The study of Gibon (2005) indicated that appropriate grazing management is primarily intended to maintain a sufficient vegetative ground cover, contribute to healthy and productive pastures that not only provide biomass for fodder but also to environmental services such as biodiversity conservation and protection of downstream water uses.

4.9. Livestock Water Productivity

Table 23 depicts the LWP values of the study systems. Although the magnitude of LWP varies across systems and study sites, differences were not statistically significant. LWP is derived from number of data sets and assumptions. Therefore the reason for similarity or divergence of LWP values among system can trace back to those data sets. A simple example of those is the livestock beneficial outputs and the water depleted for feed production indicated on Table 22 and 21. The beneficial output on TLU basis, for example, does not show many discrepancies among system. This implies that the farming practices from which the beneficial outputs mainly derived is very similar. Probably difference emerges when considered at farmers' wealth category level where difference in land holding is important and thus beneficial out puts from livestock services differed between farm households. One major trend worth mentioning here also that in areas of higher beneficial outputs (e.g. Fogera rice system) as the results of livestock density, the water depletion for feed was very high and this offset the LWP value. Generally LWP values for the study farming systems falls between 0.15US$ m^{-3} to 0.19US$ m^{-3}. The LWP estimates of this thesis, for rice system, was comparable with the study of Amare *et.al* [2009) (0.15US$ m^{-3})] of Gumera watershed. However, the LWP value of barley based (0.45US$$m^{-3}$) and millet based systems (0.69US$$m^{-3}$) conducted in Gumera watershed by Amare *et.al.* (2009) are higher than this study. This may be due to the difference in methods followed and scales of investigation. Cook *et al*. (2008) also suggests those kinds of variability to the temporal and spatial scales at which livestock production systems are analyzed and strong fluctuations in water availability related fluctuations in livestock productivity. Descheemaeker *et al*., (2010a) also suggested that the amount of water used by different feed types and the influence of management practices and agro-ecological conditions lead to the variation of LWP value. The value of LWP (0.25 US$ m^{-3} to 0.39 US$ m^{-3}) from a controlled experiment reported by the Solomon *et al.* (2009) shows greater values than this study. This may be due to the difference of feed composition, animal age and weight under considerations. The feed composition such as oat, vetch and wheat bran mixes shows an increase the LWP but in this study the major feed sources comes from crop residues, which were low in quality. This indicates that there are options to increase LWP by improving feed quality in the study areas. Study of Blümmel *et al.* (2009) indicted that there was variability of water productivity for fodder feed (e.g., Crop residues) and planted forges. According to

Peden *et al.* (2007), application of livestock water productivity concepts may lead to some of the greatest enhancements in productivity of future agricultural water use in developing countries.

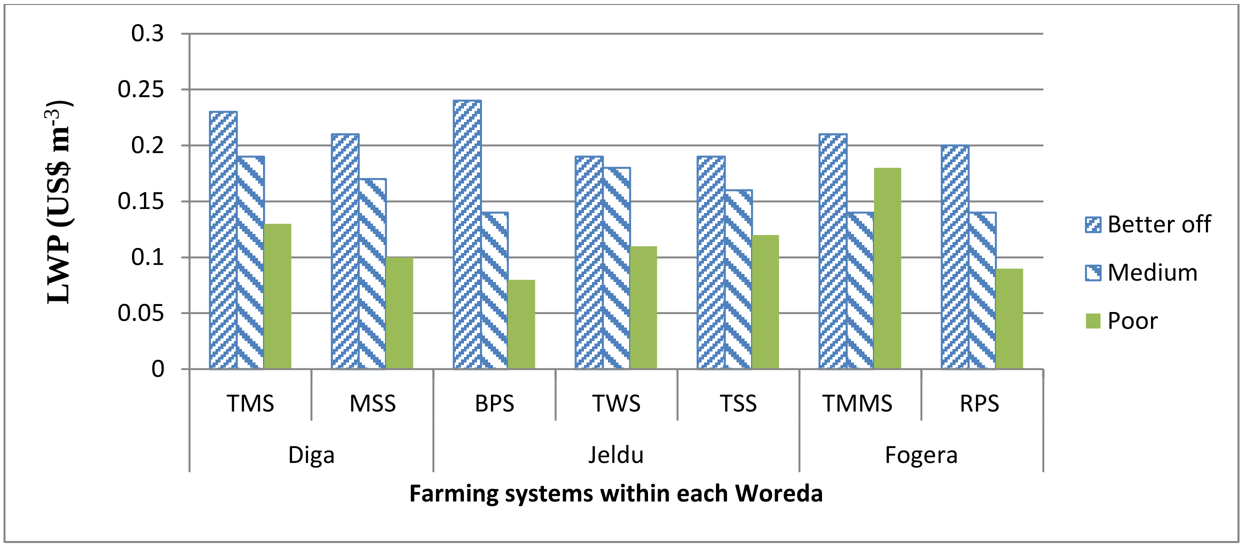
Table 23. Livestock water productivity (US$ m^{-3}) in the study sites (Mean±SE)

TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system;

Woreda	Farming systems	Landscape position	N	LWP
Diga	TMS	Medium	35	0.19±0.02
	MSS	Low	32	0.16±0.02
	Mean		67	0.17±0.01
Jeldu	BPS	Upper	31	0.15±0.02
	TWS	Medium	30	0.16±0.01
	TSS	Low	30	0.16±0.02
	Mean		91	0.16±0.01
Fogera	TMMS	Medium	32	0.18±0.01
	RPS	Low	30	0.15±0.02
	Mean		62	0.16±0.01

TSS =Teff-sorghum system; TMMS = Teff-maize/millet system; RPS = Rice-pulses system SE = standard error; LWP = Livestock water productivity, N = number of respondents

To understand more if there are any LWP differences related to household access to resources, LWP estimates in the study were disaggregated into household clusters. The result is indicated on Figure 8. The livestock water productivity, for example, among wealth group within each farming system varies (Figure 8). Generally, the livestock water productivity of poor smallholder lower than others wealth clusters. The average value of LWP among wealth status in this study lays between 0.08 US$ m^{-3} to 0.23 US$ m^{-3} per household for all farming systems. The value was within the ranges reported by Amare *et al* (2009). The fact that the range among wealth categories is wider than the system scale suggests also higher opportunities to improve LWP by targeting farmer's livelihoods. Amare *et al*., (2009) suggested enabling the poor to access to basic livelihood assets as a viable option to improve LWP.



TMMS = Teff-maize-millet system; RPS = Rice-pulses system; TMS = Teff-millet system; MSS = Maize-sorghum system; BPS = Barley-potato system; TWS =Teff-wheat system; TSS =Teff-sorghum system

Figure 7. Average livestock water productivity among wealth group of smallholders in the study sites

Correlation of LWP with some farm characteristics and land management seems strong and suggested important points of interventions. Livestock water productivity shows significant ($P<0.01$) and positive correlated with family size in Diga (r^2=0.63) and Fogera (r^2=0.58) and also significant in Jeldu (r^2=0.26) ($P<0.05$). The family size is highly related with labor force, more family size may contribute to more labor force for feeding and herding and also for crop production activities that increases crop yield and therewith the feed water productivity. Livestock water productivity shows significant ($P<0.05$) and positively correlation with total feed production (r^2=0.25) and dry matter from crop residues (r^2=0.24) for systems in Jeldu. Hence, the more feed produce is the water productivity of feed and thus this positively influences LWP. But for system in Fogera like rice system LWP was not significantly ($P>0.05$) related with total feed production and dry matter from crop residues. In rice system of Fogera lack of strong relation between feed productivity and LWP can be generally explained by the fact that the feed production there costs more water than for similar volume of dry matter elsewhere.

4.10. Opportunities to improve LWP

Improving grazing land management (private and communal) is an option to increase water productivity. This would be through institutions responsible for communal grazing management and private grazing land improvement. Clearing of invasive species (e.g., the case of Fogera *Asracantha longifolia and Diga, Sida schimperiana*) increases the yield of natural pasture and nutrition and decreases water depleted by non-productive invasive plants. Proper grazing management and leaving of the livestock's dung on the grazed lands improves species composition and diversity. This increases the productivity of natural pasture and water infiltration. For example in Fogera simple improved management of grazing land improves feed productivity by 100%.

Synchronizing feed and water sources were also an option to save water. In Diga and Jeldu, livestock move long distance in search of water for drinking during dry season other than the usual sources of water. This leads much energy lost and hence LWP value decreases. Most of the respondents not practicing improved forage production. This is also an option to increase the water productivity of feed and hence the LWP values.

Appropriate management of available feed sources also increases quality of feed and the productivity of livestock and hence the LWP. In all study areas, storage and utilization of crop residues were highly variable. Good storage of crop residues increases the quality. Utilization of available crop residues for feed was low in Diga, particularly in maize-sorghum system. So, compromising the use of crop residues for both feed and nutrient cycling would increases the water productivity and hence LWP. In all study areas, improving the quality of crop residues is not practiced. Hence, improving the quality of crop residues through different treatments (e.g., urea treatment) is an option to increase the productivity of livestock. Under sowing legumes fodder in cereals could also increase the feed quality and increase water productivity. Improved feeding of available sources in which almost the respondents have no experience also increases the water productivity (e.g., cut and carry system, supplementary of feed).

5. SUMMARY AND CONCLUSION

This study was conducted to assess livestock feed sourcing and feeding strategies and their implications on livestock water productivity (LWP) in mixed crop-livestock systems of Blue Nile Basin (BNB) highlands. Three Woredas (Diga, Jeldu and Fogera) that are assumed to represent the highlands of BNB were considered. From each Woreda, one watershed was selected. Each watershed was further stratified into different farming systems depending on crop dominations and landscape positions. Diga has teff-millet and maize-sorghum farming systems; Jeldu has barley-potato, teff-wheat and teff-sorghum farming systems; and Fogera has teff-millet/maize and rice-pulses farming systems. Multi-stage stratified random sampling was employed to select farm households.

The sources of feed identified in the study area were natural pasture, crop residues, stubble grazing and green forages such as weeds and thinning of maize and sorghum. Generally for all farming systems, the crop residues contribution to feed on a dry matter basis ranged from 58.5% to 78.2%. Overall dry matter productivity of grasses and legumes from private grazing land showed variation across systems except systems of Fogera. The highest yield was estimated for systems in Fogera (5.54 and 5.82 ton ha^{-1}) while the lowest was for systems in Jeldu (2.74 to 4.52 ton ha^{-1}). The dry matter production from grazing land per household was comparable across Woredas but varies among farming systems within each Woreda. The dry matter production of crop residues per household among the farming systems within each Woreda differed significantly. More than 85% of respondents in all study farming systems mentioned that they do not practice improved forages production. The result also demonstrated that farmers practice feed supplementation very rarely particularly with sources from outside their farm (e.g., bran, oil seed cake).

Management of feed resources also varies across the Woredas. In the study systems about 95.5% of sample farmers in Diga, 92.3% in Jeldu and 88.7% in Fogera responded that the grazing lands are deteriorating. Lacks of clearing of invasive species, bylaws to manage common property resources and manure usage for fertilizer purpose are the major problem of grazing land management.

This study found out that crop residues management varies across study sites mainly in terms of storage, utilization and feeding calendar. The storage of straws in study systems of Jeldu and Fogera was better than Diga. The feeding strategies of crop residues differed across the Woredas but were similar among farming systems within Woredas. Generally, there were no improvements made so far to increase the quality of crop residues. Crop residues are under competitive uses. They are generally used for livestock feed, fuel and constructions. Crop residues utilization varies across the study systems in different Woredas, although tends to be similar within Woredas.

Feed deficits were found in all the study Woredas. In Jeldu Woreda, ME meets about 62.5% of livestock feed requirement. In maize-sorghum system of Diga, about 22.3% ME was surplus than annual livestock feed requirements. But in teff-millet system of Diga Woreda ME meets about 68.1% of livestock feed requirements. In Fogera Woreda ME only satisfies 68.7% and 74.5% of livestock feed requirements in teff-millet/maize and rice-pluses systems, respectively.

The overall water depleted for feed production was comparable between Diga (2010.2 m^3 ha^{-1}) and Jeldu Woredas (2080.2 m^3 ha^{-1}) but it was higher for Fogera Woreda (3662.1 m^3 ha^{-1}). Variability of livestock beneficial output among study systems was not apparent. Only values of livestock beneficial outputs (US$ TUL^{-1}) were significantly different between ($P<0.05$) the farming systems of Diga. The total feed water productivity was similar across the Woredas, and about 87.5% to 93.5% of it was contributed by crop residues water productivity. The grazing land water productivity was comparable across the Woredas, but differed among farming systems of Diga and Jeldu Woredas. The livestock water productivity was not different among the farming systems in each Woreda. But, generally the average livestock water productivity among the grouped wealth status varies in each study systems. In view of the results, the followings key messages can be drawn:

- Currently, in all of the study farming systems, crop residues constitute the major ingredient of livestock diet. Supplementary feeding with high value feed is not commonly practiced. Livestock feed scarcity is considerable. These can be attributed, firstly, to the ongoing land use changes from grazing to arable lands and this resulted in shortage of land for grazing as widely reported by sample farmers. Secondly, failure of the crop production sector and also the grazing land to achieve the biological yield potential through integrated land and water management and thereby to offset the growing feed demand; and thirdly, in response to land use changes and as a result of dwindling feed supply, farmers' actions to improve feed sourcing (e.g., improved forages), feeding strategies are not being seen. Hence, strategic way of feed source diversification, improvement of quality, improved feeding strategies and efficient utilization of feeds are important entry for feed productivity improvement and hence LWP values.

- In view of this thesis generally improving water productivity of feed is major entry points to improve LWP. Very high yield gap between the result of this study and the results from on farm experiments (e.g., in Fogera) probably gives very good insights as to how much water we can save by improving the biomass yield from grazing areas.
- System scale LWP did not show apparent divergences between farming systems as the farm scale did. The farm scale showed a very wide range between the resources poor and better off farmers. Such big gap of LWP for farm households operating in the same farming system suggests a potential for improvements. Hence, to exploit this potential, policy measures that build farmers capacity to access key livelihood assets (e.g., land and livestock) is important.
- There are useful examples of good LWP enhancement strategies (e.g., virtual water transfer, '*Daraba*') in some of the systems. These can be out-scaled to other systems. But such an exercise must be contextualized and supported by research findings.

RECOMMENDATIONS AND FUTURE SCOPE OF STUDY

- Crop residues are most important in contributing to livestock feed but they tend to be of low quality. Hence, encouraging farmers to practice improved forage production with integration of crop production (e.g., food-feed crops, integration of legume forages in cereals crops).
- Construction of proper storage and treatment of crop residues, clearing invasive species from grazing land, improved feeding, more effective extension services and farmer training are required to increase feed productivity and hence human development.

- Farmers lack seeds and awareness of improved forages. Hence joint extension and training service and provision of seeds are required
- High feed energy deficits occurred in upper landscape positions of the farming systems. Enhancing feed supply needs attention in all farming systems.
- In this study, the LWP showed generally variation implying opportunities for improvement. Future development efforts and policy option must nurture these opportunities.
- The results presented in this thesis are based on a one-year survey. However, feed production, feed utilization, feed management, climatic factors, productivity of livestock (e.g., off take) and market prices related output and services of livestock in any given landscape vary over time. Thus, it is necessary to conduct multiyear and controlled experiments to reach to a conclusive LWP estimates.

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7. APPENDICES

Appendix Table 1. Landholding size and cattle number based wealth clusters

Woreda	Farming systems	Landscape positions	Better off smallholder		Medium smallholder		Poor smallholder	
			CN	LH (ha)	CN	LH (ha)	CN	LH(ha)
Diga	TMS	Medium	8-18	2.75-4.5	4-8	2-2.75	0-4	<2
	MSS	low	8-17	2.5-6	4-8	1.25-2.5	0-4	<1.5
Jeldu	BPS	upper	7-14	2.25-3.5	5-7	1.5-2.25	0-3	<1.5
	WTS	Medium	8-19	2.75-5	8-9	1.75-2.75	0-6	<1.75
	TSS	low	8-13	2.25-4	4-8	1.75-2.75	0-3	<1.75
Fogera	TMMS	Medium	8-17	1.75-3.25	4-7	0.75-1.75	1-4	<0.85
	RPS	low	7-15	1.75-3	4-7	0.75-1.75	0-4	<0.85

LH=landholding; CN=cattle number

Appendix Table 2. Grain to residues dry matter conversion factor

Sources of crop types	conversion factor	DM yield (t/ha/year)
Barley straw	1.5	
Wheat straw	1.5	
Finger millet straw	1.5	
Maize stover	2	
Sorghum stover	2.5	
Rice straw	1.4	
Oat straw	1.5	
Teff straw	1.5	
Faba bean straw	1.2	
Chickpea straw	1.2	
Field pea straw	1.2	
Communal grazing land		2
Fallow land		1.9
Aftermath grazing		0.5
Forest		0.7
Bush, wood and shrub land		1.2

(FAO, 1987) and (Teshome, 2009)

Appendix Table 3. Climatic factors (Temperature, humidity, Wind, Sun, Radiation and ET) in each farming system of Woreda

Barley-potato system (Jeldu) Altitude =2800; longitude =38.12°E latitude=9.19°N

Month	Min Temp	Max Temp	Humidity	Rain	Wind	Sun	Rad	ETo
	°C	°C	%	mm	km/day	hours	MJ/m²/day	mm/day
January	9.4	21.8	50	27.0	138	8.3	19.7	3.85
February	9.4	22.4	47	33.7	150	8.1	20.7	4.23
March	10.7	23.1	47	62.0	155	6.8	19.8	4.36
April	9.9	23.0	62	79.9	146	7.3	20.8	4.20
May	10.1	23.0	53	40.2	139	6.9	19.7	4.19
June	9.3	22.2	75	79.8	103	5.3	16.9	3.34
July	9.4	18.6	87	235.9	104	3.1	13.8	2.55
August	9.6	19.6	89	242.2	106	7.4	20.6	3.44
September	9.3	19.9	83	149.4	131	4.7	16.5	3.00
October	9.4	20.7	54	29.0	181	7.8	20.4	4.12
November	8.2	20.7	46	12.8	175	9.9	22.2	4.28
December	8.2	20.8	51	12.7	146	9.3	20.6	3.81
Average	9.4	21.3	62	1004.6*	140	7.1	19.3	3.78

Source: calculated by New LocClim 1.06, 2005 and CROPWAT 8.0 from Ambo and Guder metrology stations; *=total

Teff-wheat system (Jeldu) Altitude =2360; longitude =38.06°E latitude=9.32°N

Month	Min Temp	Max Temp	Rain	Humidity	Wind	Sun	Rad	ETo
	°C	°C	Mm	%	km/day	hours	MJ/m²/day	mm/day
January	10.6	24.4	17.7	58	123	8.6	20.1	3.87
February	11.5	25.7	28.6	52	141	8.4	21.1	4.42
March	12.6	25.8	50.9	54	145	7.5	20.8	4.54
April	12.1	25.7	70.3	65	137	7.7	21.4	4.42
May	12.0	25.2	54.9	63	122	7.3	20.3	4.21
June	11.0	23.5	103.7	82	90	5.6	17.4	3.35
July	11.1	20.6	206.0	95	99	3.7	14.7	2.62
August	11.2	21.6	210.0	96	95	8.4	22.1	3.68
September	10.6	21.9	122.3	88	110	5.3	17.4	3.12
October	10.5	23.1	27.7	60	155	8.2	21.0	4.15
November	9.8	23.4	13.9	52	150	9.9	22.2	4.27
December	10.0	23.6	10.4	58	135	9.5	20.9	3.90
Average	11.1	23.7	916.3*	69	125	7.5	20.0	3.88

Source: calculated by New LocClim 1.06, 2005 and CROPWAT 8.0 from Ambo and Guder metrology stations; *= total

Teff-sorghum system (Jeldu) Altitude =2060; longitude =38.01°E latitude=9.32°N

Month	Min Temp	Max Temp	Rain	Humidity	Wind	Sun	Rad	ETo
	°C	°C	mm	%	km/day	hours	MJ/m²/day	mm/day
January	11.5	26.4	12.4	59	128	8.7	20.3	4.04
February	12.6	27.8	26.9	54	147	8.4	21.1	4.60
March	13.5	27.7	44.2	55	148	7.7	21.1	4.74
April	13.3	27.7	67.1	65	140	7.8	21.5	4.62
May	12.9	26.8	64.1	68	130	7.1	20.0	4.24
June	12.1	24.9	122.7	84	96	5.6	17.4	3.40
July	12.2	22.1	183.0	96	105	3.8	14.8	2.67
August	12.0	23.1	188.8	98	98	8.7	22.6	3.79
September	11.3	23.5	105.2	91	109	5.4	17.5	3.17
October	11.2	25.1	26.8	65	154	8.3	21.2	4.22
November	10.7	25.3	14.3	55	153	9.8	22.0	4.38
December	10.9	25.6	9.2	60	145	9.5	20.9	4.07
Average	12.0	25.5	864.6*	71	129	7.6	20.0	3.99

Source: calculated by New LocClim 1.06, 2005 and CROPWAT 8.0 from Ambo and Guder metrology stations; *= total

Teff-millet system (Diga) Altitude =1720; longitude =36.41°E latitude=9.03°N

Month	Min Temp	Max Temp	Rain	Humidity	Wind	Sun	Rad	ETo
	°C	°C	Mm	%	km/day	hours	MJ/m²/day	mm/day
January	11.6	25.7	5.0	58	95	8.8	20.5	3.83
February	12.3	26.7	14.3	57	104	8.7	21.6	4.24
March	13.0	27.0	41.8	55	112	8.1	21.8	4.50
April	13.3	26.7	72.8	58	104	8.0	21.8	4.48
May	12.8	24.3	233.2	83	69	6.2	18.6	3.52
June	11.5	21.7	373.3	91	69	4.7	16.1	2.89
July	11.1	20.7	418.0	96	104	3.6	14.5	2.50
August	11.0	20.7	351.8	97	69	3.6	14.8	2.57
September	10.6	21.8	271.3	95	69	4.6	16.3	2.81
October	11.3	23.2	150.1	85	104	7.4	19.9	3.41
November	12.0	24.2	67.2	75	104	8.1	19.7	3.52
December	11.6	24.7	17.3	63	104	8.2	19.2	3.57
Average	11.8	23.9	2016.1*	76	92	6.7	18.7	3.49

Source: calculated by New LocClim 1.06, 2005 and CROPWAT 8.0 from Nekemte and Didesa metrology stations; *= total

Maize-sorghum systems (Diga) Altitude =1280; longitude =36.28°E latitude=9.05°N

Month	Min Temp	Max Temp	Rain	Humidity	Wind	Sun	Rad	ETo
	°C	°C	mm	%	km/day	hours	MJ/m²/day	mm/day
January	11.6	25.7	5.0	59	95	9.1	20.9	3.82
February	12.3	26.7	6.6	50	104	9.0	22.1	4.32
March	13.0	27.0	9.3	48	112	7.1	20.2	4.37
April	13.3	26.7	59.2	51	104	8.5	22.6	4.61
May	12.8	24.3	194.9	72	69	5.9	18.2	3.50
June	11.5	21.7	259.3	73	69	4.8	16.2	3.02
July	11.1	20.7	270.4	81	104	3.5	14.4	2.68
August	11.0	20.7	232.3	84	69	2.8	13.6	2.49
September	10.6	21.8	229.9	82	69	5.5	17.7	3.06
October	11.3	23.2	165.2	75	104	7.6	20.2	3.52
November	12.0	24.2	62.5	67	104	8.1	19.7	3.57
December	11.6	24.7	9.6	52	104	8.8	20.0	3.74
Average	11.8	23.9	1504.3*	66	92	6.7	18.8	3.56

Source: calculated by New LocClim 1.06, 2005 and CROPWAT 8.0 from Nekemte and Didesa metrology stations; *=total

Teff-millet/maize system (Fogera) Altitude =1940; longitude =37.89°E latitude=11.91°N

Month	Min Temp	Max Temp	Rain	Humidity	Wind	Sun	Rad	ETo
	°C	°C	mm	%	km/day	hours	MJ/m²/day	mm/day
January	8.0	29.1	6.0	79	112	9.1	20.2	3.81
February	8.3	27.7	11.0	71	112	10.1	23.1	4.33
March	9.0	28.2	42.0	65	147	9.6	23.8	4.84
April	9.8	27.2	46.0	62	147	9.0	23.4	4.83
May	10.1	26.8	93.0	74	138	7.6	21.0	4.26
June	9.0	24.8	180.0	89	130	6.0	18.3	3.45
July	8.8	21.1	501.0	97	104	2.4	13.0	2.35
August	8.6	21.0	476.0	96	95	2.5	13.2	2.36
September	8.1	23.0	193.0	95	95	6.7	19.4	3.28
October	7.3	23.0	66.0	85	104	9.7	22.8	3.73
November	7.0	23.7	21.0	84	104	9.9	21.5	3.49
December	6.6	24.5	16.0	83	104	9.5	20.2	3.27
Average	8.4	25.0	1651.0*	82	116	7.7	20.0	3.67

Source: calculated by New LocClim 1.06, 2005 and CROPWAT 8.0 from Debre tabor and Addis zemen metrology stations; *=total

Rice-pulses system (Fogera) Altitude =1780; longitude =37.67°E latitude=11.98°N

Month	Min Temp	Max Temp	Rain	Humidity	Wind	Sun	Rad	ETo
	°C	°C	Mm	%	km/day	hours	MJ/m²/day	mm/day
January	11.0	27.3	2.0	67	127	9.0	20.0	3.89
February	12.5	28.8	9.0	63	127	10.2	23.3	4.60
March	13.9	29.7	2.0	58	147	10.0	24.4	5.22
April	14.1	30.0	21.0	59	144	9.2	23.7	5.23
May	14.3	29.6	71.0	70	127	7.4	20.7	4.51
June	14.3	28.1	227.0	84	127	6.3	18.7	3.87
July	14.3	25.1	312.0	93	104	2.3	12.8	2.62
August	14.1	24.2	282.0	91	101	2.7	13.5	2.67
September	14.8	25.2	128.0	92	88	7.5	20.6	3.73
October	13.5	26.7	36.0	80	109	9.1	21.9	4.07
November	12.6	27.8	10.0	75	109	10.0	21.7	4.02
December	12.5	27.8	1.0	72	97	9.7	20.4	3.78
Average	13.5	27.5	1101.0*	75	117	7.8	20.1	4.02

Source: calculated using New LocClim 1.06, 2005 and CROPWAT 8.0 from Bahir Dar and Gorgora metrology stations; *=total

Appendix Table 4. Conversion factors of livestock number to Tropical Livestock Unit (TLU) and Daily Dry matter Requirements (DDMR) for livestock species

Livestock species	TLU	DDMR(kg)
Oxen/bull	1.1	4.8
Cow	0.8	4.4
Steer	0.6	3.6
Heifer	0.5	3.3
Calves	0.2	1.9
Sheep	0.1	0.65
Goat	0.1	0.64
Horse/mule	0.8	5.3
Donkey	0.5	2.5
Poultry	0.01	-

Source: Gryseels (1988); Bekele (1991); (ILCA, 1990) and Kearl (1982)

Appendix Table 5. Metabolisable Energy (MJ/kg DM), gross energy (GE) (MJ/kg DM) and IVDMD (%) of different feed sources

Source of feed	ME(MJ/kg DM)	GE (MJ/kg DM)	IVDMD (%)
Barley straw	8.38	18	53.5
Wheat straw	8.4	17.6	53.61
Finger millet straw	8.25	17	55.46
Maize stover	8.8	18.1	58.02
Sorghum stover	7.4	18.1	47.57
Rice straw	7.3	17.2	43.0
Oat straw	9.5	18.3	62.86
Teff straw	8.13	17.73	53.17
Faba bean straw	8.25	18.0	55.64
Chickpea straw	8.0	17.9	51.81
Field pea straw	7.75	17.9	49.42
Natural pasture grazing	9.8	18.9	64.0
Natural pasture hay	8.4	17.7	57.0

Sources: (ILRI (CGIAR system wide livestock programme), 2011) and McDonal *et.al*, (1988)

Appendix Table 6. Major crop domination of area (%) per household in the study sites

Woredas	Farming systems	Crop types	Converge area (%)
Diga	Teff-millet	Teff	26.5
		Millet	19.2
	Maize- sorghum	Maize	34.13
		Sorghum	27.2
Jeldu	Barley-potato	Barley	45.9
		Potato	17.7
	Wheat-teff	teff	29.3
		Wheat	25.6
	Teff- sorghum	Teff	29.6
		Sorghum	24.2
Fogera	Teff-milet/maize	Teff	39.3
		Millet	30
		Maize	22.7
	Rice pulses	Rice	63.6
		pluses	23.6

Source; Survey data of this study

Appendix Table 7. Dominant herbaceous names and frequency (%) in the study sites

Dominant species of native herbaceous found in natural grazing lands by farming system in Jeldu Woreda

Barley potato		Wheat-teff		Teff-sorghum	
Scientific name	% n=20	Scientific name	% n=16	Scientific name	(%) n=8
Andropogon gayanus	60	*Andropogon dumereri*	93.75	*Andropogon*	50
Cyperus rigidifolius	55	Cyperus rigidifolius	93.75	*gayanus*	
Andropogon dumereri	10	*Sporobolus indicus*	12.5	*Andropogon*	25
Erogrostis spp.	20	*Erogrostis spp.*	18.75	*dumereri*	
Pennisetum schimperi	5	*Andropogon gayanus*	25	*Cyndon dactylon*	75
Snowdenia polystachya	15	*Cyndon dactylon*	12.5	*Erogrostis spp.*	
Sporobolus indicus	25	*Trifolium rueppellianum*	62.5	*Ocimum*	37.5
Phalaris paradox	15	*Ocimum basilicum*	6.25	*basilicum*	12.5
Trifolium rueppellianum	70	*Commelina*	50	*Sporobolus*	
Commelina benghalensis	50	*benghalensis*		*indicus*	12.5
Ocimum basilicum	5			*Trifolium*	
				rueppellianum	37.5
				Commelina	
				benghalensis	25

Dominant species of native herbaceous found in natural grazing lands by farming system in Diga Woreda

Maize-sorghum system		Teff-millet system	
Scientific name	Frequency (%) N=16	Scientific name	Frequency (%) N=20
Eleusine coracana	60	Setaria acuta	68.75
Cyndon dactylon	60	*Phalaris paradox*	6.25
Andropogon gayanus	25	*Cyndon dactylon*	50
Digitaria abyssinica	35	*Commelina*	6.25
Aeschynomene elaphroxylon	15	*benghalensis*	37.5
Phalaris paradox	20	*Andropogon gayanus*	6.25
Cenchrus pennistiformis	5	*Digitaria abyssinica*	6.25
Enteropogon samalensis	5	*Sporobolus indicus*	18.75
Ageratum conyzoides	5	*Andropogon dumereri*	100
Bothriochloa radicans	5	*Trifolium spp.*	43.75
Cyperus rigidifolius	5		
Hyperania spp	5		
Echinochloa crus-galli	10		
Trifolium spp.	50		
Panicum monticola	15		

Dominant species of native herbaceous found in natural grazing lands by farming system in Fogera Woreda

Teff-millet-maize system		Rice-pulse system	
Scientific name	Frequency (%) N=20	Scientific name	Frequency (%) N=16
Andropogon gayanus	60	*Andropogon gayanus*	43.5
Echinochloa crus-galli	10	*Andropogon dumereri*	25
Cyndon dactylon	45	Echinochloa crus-galli	25
Andropogon dumereri	40	*Cyndon dactylon*	6.25
Erogrostis spp.	15	*Trifolium spp*	37.5
Commelina benghalensis	10	*Panicum monticola*	18.75
Cyperus rotundus	5		
Panicum monticola	50		
Trifolium rueppellianum	70		
Trifolium spp	10		

Appendix Table 8 . Feeding calendar for all Woreda

Feed availability and feeding calendar of Diga Woreda (same for two systems)

Feed sources	Feeding months											
	Jun	Jul	Aug	Sep	Oct	Nov	De	Jan	Feb	Ma	Ap	May
Natural pasture	x	X	x	xx	xx	xx	xx	x				
Crop stubble					x	xx	xx	x				
Crop residues							x	xx	xx	x	X	
Green forages(e.g., weeds)			xx	xx								
Leaves and pods										xx	X	x
Hay												
Salt			x	xx	xx	x						

x= less feeding month(s) of available feed source; xx= more feeding month(s) available of feed sources; Jun=June; Jul= July; Agu= August; Sep=September; Oct=October; Nov= November; De=December; Jan=January; Feb=February; Ma=March; Ap=April; May=May

Feed availability and feeding calendar in Jeldu Woreda (same for all systems)

Feed sources	Feeding months											
	Jun	Jul	Aug	Sep	Oct	Nov	De	Jan	Feb	Ma	Ap	May
Natural pasture	x	X	x	xx	xx	xx	xx	x				
Crop stubble						x	xx	x				
Crop residues	x						x	xx	xx	x	X	X
Green forages(e.g., weeds)	x	Xx	x	x								
Leaves and pods										x	X	X
Hay									x			
Salt			x	xx	xx	x						

x= less feeding month(s) of available feed source; xx= more feeding month(s) of available feed sources; Jun=June; Jul= July; Agu= August; Sep=September; Oct=October; Nov= November; De=December; Jan=January; Feb=February; Ma=March; Ap=April; May=May

Feed availability and feeding calendar in farming systems of Fogera Woreda

Feed sources	Feeding months											
	Jun	Jul	Aug	Sep	Oct	Nov	De	Jan	Feb	Ma	Ap	May
	Teff- millet-maize farming system											
Natural pasture	x	X	X	xx	xx	x	x					
Crop stubble					x	xx	xx	x				
Crop residues	x						x	x	xx	xx	xx	x
Green forage(e.g., weeds)		X	xx	xx								
Leaves and pods										x	X	x
Hay									x	x	X	x
Salt			X	xx	xx	x						
				Rice farming system								
Natural pasture	x			Xx	xx	x	x					
Crop stubble						x	x		x			
Crop residues	x						x	x	xx	xx	xx	x
Green forage(e.g., weeds)				X								
Leaves and pods										x	X	
Hay									x	x	X	x
Salt	x			Xx	x	x	x	x	x	x	X	x

x= feed source less feeding month(s) available; xx= feed sources more feeding month(s) available; Jun=June; Jul= July; Agu= August; Sep=September; Oct=October; Nov= November; De=December; Jan=January; Feb=February; Ma=March; Ap=April; May=May

Appendix Table 9. Rank given to preference for crop residues by livestock

Woreda	Farming systems	Crop residues	Rank (%)		Indices	Rank by indices
			1	2		
Diga	Teff-millet	Teff	48.6	20	0.39	1
		Millet	22.9	22.9	0.23	3
		Maize	20	42.9	0.28	2
		Sorghum	8.9	14.3	0.11	4
	Maize-sorghum	Teff	25.0	9.4	0.20	3
		Millet	28.1	28.1	0.28	2
		Maize	34.4	28.1	0.32	1
		Sorghum	12.5	34.4	0.2	3
Jeldu	Barley-potato	Barely	83.9	16.1	0.61	1
		Wheat	16.1	83.9	0.39	2
	Wheat–teff	Teff	63.3	16.7	0.48	1
		Maize	13.3	13.3	0.13	3
		Barley	23.3	43.3	0.3	2
		Wheat	0	20	0.07	4
		Sorghum	0	6.6	0.02	5
	Teff-Sorghum	Teff	83.3	16.7	0.61	1
		Maize	6.7	43.4	0.19	2
		Barley	3.3	16.7	0.08	3
		Wheat	6.7	6.7	0.07	4
		Sorghum	0	16.6	0.06	5
Fogera	Teff-millet/maize	Teff	78.1	21.9	0.59	1
		Millet	-	53.1	0.18	2
		Maize	-	12.5	0.04	4
		Barley	3.1	6.3	0.04	4
		Rough pea	12.5	6.3	0.1	3
		chickpea	6.2	-	0.04	4
	Rice-pulses	teff	16.7	10	0.15	3
		Millet	3.3	13.3	0.07	4
		Rice	20	36.7	0.26	2
		rough pea	60	26.7	0.49	1
		chickpea	-	13.3	0.04	5

Index for all farming systems for preferences of crop residues= sum of single preference crop residues ranked in each farming system i.e. (2*1st ranked preference of crop residues) + (1*2nd ranked preference of crop residues) /sum of all weighted preference of crop residues described by the respondents in each Woreda

Appendix Table 10. ANOVA output (Degree freedom and mean square of variables, coefficient of variation,) in study sites

Variables	Diga Woreda					Jeldu Woreda					Fogera Woreda				
	DF	Mean square	F value	Pr>F	CV (%)	DF	Mean square	F value	Pr>F	CV (%)	DF	Mean square	F value	Pr>F	CV (%)
Grasses dry matter from private grazing land	1	23.05	101.84	<.0001	19.5	2	16.71	14.71	<.0001	39.9	1	10.95	2.62	0.1149	42.1
Legumes dry matter from private grazing land	1	1.56	26.82	<.0001	18.2	2	1.53	4.39	0.020	75.2	1	1.45	3.04	0.0394	78.1
Total Biomass of Private grazing land	1	6.11	24.15	<.0001	14.2	2	8.52	9.57	0.0004	27.7	1	0.71	0.18	0.6780	35.5
Dry matter from crop residues per HHS	1	181207406.1	45.37	<.0001	36.0	2	10195744.8	3.88	0.0242	36.0	1	88779949.6	16.10	0.0002	44.3
Dry matter from grazing lands per HHS	1	4674155.45	3.56	0.0640	58.7	2	10222880.8	5.33	0.0066	61.1	1	39171570.4	42.50	<.0001	52.9
Water depleted for feed (m^3ha^{-1})	1	1090709.73	7.52	0.0079	18.9	2	144837.81	0.67	0.5156	22.4	1	29888562.8	41.57	<.0001	23.2
Beneficial output (US$ TLU^{-1})	1	38896.5240	4.25	0.0433	63.1	2	4059.6085	1.13	0.3267	41.2	1	5079.5	1.31	0.2562	39.2
Beneficial output (US$ ha^{-1})	1	73.977	0.004	0.9498	59.4	2	18753.431	0.54	0.5818	57.9	1	16982.6	0.29	0.5926	52.1
Total feed water productivity (kg m^{-3})	1	6.64251201	16.73	0.0001	39.1	2	0.6571	5.52	0.0055	24.2	1	2.70	44.55	<.0001	15.4
Crop residues water productivity (kg m^{-3})	1	8.50342155	59.63	<.0001	24.4	2	0.0884	1.06	0.3502	22.3	1	0.8477	13.98	0.0004	17.4
Grazing land water productivity (kg m^{-3})	1	0.530	19.91	<.0001	25.4	2	1.3162	26.16	<.0001	32.0	1	0.1112	2.24	0.1404	28.9
Livestock water productivity (US$ m^{-3})	1	0.01191890	1.08	0.3022	60.9	2	0.001879	0.22	0.8032	58.7	1	0.017228	2.69	0.1059	49.04

DF= degree of freedom; CV= coefficient of variation

Appendix Table 11. Questionnaires for the survey

Household Questionnaire to Study Smallholder Farms Livestock feed sourcing and feeding strategies and their Implications on Livestock Water Productivity in Mixed Crop-Livestock Systems of the Highlands of Blue Nile Basin:

Questionnaire Number__________________

SECTION 1: IDENTIFICATION *(enumerators to fill in the names, supervisor to provide the codes)*

Date of Interview: Dd/Mm/Year _______________/_____________/______________________

Region: ____________________________ Recode: ____

Woreda:____________________________ Wocode:____

Farming system____

Kebele: ____ Kebelecode: ________________________

Household Head full Name: ___________________________ Sex_____ Age______
Education__________

Farm experience_____________________________________ Marital status (*Single*, *Married*) _________

Gps Longitude ____

Gps Latitude ____

Altitude (m)____

Landscape position according to the farmer (Upper/Medium/Low)__________________________

Enumerator's Full Name: ____

Supervisor's full Name: ____

Date Entered: DD/MM/Year ___________________/_____________/________________

Entered By ____ Decode: ________________

SECTION 2: HOUSEHOLD CHARACTERISTICS

2.2. Household members: number and age of member including household head.

Total numbers of house hold members including HH head___________________________

Age Category (in years)	No. of members in the household *		
	Male	*Female*	Total
< 6 years old			
6-9 years old			
10-15 years old			
15-60 years old			
> 60 years old			

*Include all persons living permanently in the household and taking food from the same kitchen.

Chapter-1 Feed resource parts

SECTION 1: LAND HOLDING AND LAND USE

Types of Crops cultivated in 2003 E.C	Land ownership(in timad)					Landscape position types	Harvest of grain per year(in local unit)	Local unit =kg	Input used (kg), if used			Only show for which crop they use (mark)	
	owned	RI	RO	SI	SO		Grain		Improved seed	DAP	Urea	Compost	Manure

1.1.What area of land do you have? ---------------------------------- (in timad)

RI= rented in RO=rented out: SI= sharecropped in SO= sharecropped out; [2]**landscape position**; 1= upland 2= medium upland 2= lowland

1. There is sharing rules for grain and crop residues (proportion for the cultivator and land owner)? 1. Yes 2. No

2. If yes, when shared in (grain) %___________, residues %____________); when shared out (grain) % _________, residues% _______)

Grazing land types	Land ownership (Timad)			Landscape position types[1]
	Owned	Rent in	Rent out	
Fallow land				
Permanent private grazing land				
Communal grazing land*				
Forest and wood land				
Road side grazing land				
River side grazing				

[1]landscape position types: 1=upland; 2= medium land 3= low land

*** Number household used communal area, area coverage (estimated) and number of livestock (estimated)**

SECTION 2: FEED RESOURCE AND FEEDING STRATEGIES

2.1. How much do the various feeds contribute to the diet of the animal throughout a year? Proportion of nutrition derived from different sources. (on a scale of 0-10, where 10 = excess feed available, 5= adequate feed available and 0=no feed available)

Feed resources	Availability by months											
	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
Communal grazing land												
Permanent private grazing land												
Fallow land grazing												
Road /river side grazing												

Stubble grazing												
Cereal Crop residues(eg. teff straw, wheat straw rice straw)												
Legume crop residues (eg. field pea straw, faba bean straw etc)												
Green forage (eg. roadside weeds, cut fodder crops)												
Leaves and pods of trees**												
Supplement (eg. Salt , local brewery, oil cake, wheat bran)												
Hay												

**= Local name of tree leaves and pods that are used as livestock feed ----------------------

----

2.2. Contribution of each feed source group to total feed source over the year in (%)

Feed resource group	Contribution in (%) over the year
Crop residues	%
Cultivated forages	%
Purchased feed (eg. concentrated)	%
Grazing	%
Collected green fodder (weeds, leaves, pods, thinning maize etc)	%
Hay	
Total sum of feed source group should be	100%

2.3. Feeding strategies of the available feed resources (encircle from list corresponds to feed resources)

Feed sources	Ways of feeding	Feeding access	Feeding place
Grazing pastures (private, fallow, river/road)	fr-sf-br-te-ot	fa-re	ho-fa-ot

Crop residues(eg. teff straws , rice straw, wheat straw)	fr-sf-br-te-ot	fa-re	ho-fa-ot
Green forages (eg. roadside weeds, fodder crops)	fr-sf-br-te-ot	fa-re	ho-fa-ot
Supplement (salt, atela, bran, oil cake etc)	fr-sf-br-te-ot	fa-re	ho-fa-ot
Hay	fr-sf-br-te-ot	fa-re	ho-fa-ot
Leaves and pods of tree	fr-sf-br-te-ot	fa-re	ho-fa-ot

fr= free grazing; sf= stall feeding (cut and carry system); br = browsing; te=tethering ot= others (specify) fa= free access re= restricted ho= at homestead fa= at farm (produced place) ot=others (specify)

2.4. Feeding priority given to group of animals (encircle from the list in each season corresponds to feed resources)

Feed source	Seasons			
	Jun, Jul, August	Sept, Oct, Nov	Dec, Jan, Feb	Mar , Apr, May
Grazing pasture(fallow, private river/road)	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot
Crop residues (eg. teff straws , rice straw, wheat straw)	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot
Green forages(eg. roadside weeds, fodder crops)	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot
Supplement (salt, local	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot

berwry residues , bran, oil cake etc)				
Hay	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot
Leaves and pods of tree	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot	ox-mc-ca-sr-eq-wa-ot

ox=oxen; mc= milking cow; ca= calf; sr= small ruminant; eq= equines; wa= weak animals; **MB=multiple answer is possible**

SECTION 3: MANAGEMENT OF GRAZING LAND

1. Encircle with correspondence list accordingly

Types of grazing land	Do you have/access?	Cover types	Problems	Management if any
Communal grazing land	yes/no	o-trc-shc-stc-sw-wec	wp-wl-er-sc-cn-ot	clr-ovs-acs-mn-swc
Private grazing	yes/no	o-trc-shc-stc-sw-wi	wp-wl-er-sc-cn-ot	clr-ovs-acs-mn-swc

o= open; trc=tree covered; shc= shrub covered; stc= stony covered; sw=swampy; wi=weed invaded

wp=weed plant invasion; wl=water logging; er=erosion; sc=soil compaction; cn=confilict; ot=others

clr= clearing invasive weeds; ovs=oversowing; acs=area closure; mn = manuring; swc=soil and water conservation

2. Do you have any bylaw on communal grazing land management? 1. Yes 2. No, if yes mention it---
3. Do you rent out your grazing land? 1. Yes 2. No, If yes, for how much? -------------------birr/ha/year
4. Do you purchase feed for your livestock? 1. Yes 2. No; if yes how many?---------kg/year-----------birr/year; name of feeds--
5. Do you preserve pasture as hay? A. Yes B. No,

6. If you are not producing hay from pasture land, what are the reasons? 1. Land shortage 2. Labor shortage 3. Less productive 4. No livestock 5. Other (specify)-------------------------
7. If you make hay, how do you decide appropriate cutting time? 1. Pattern of rain fall 2. Plant growth 3. Depending on need of animal 4. Other specify)---------------
8. Dou you have fallow land? 1. Yes 2. No
9. If yes what is the main reason for fallowing the land? 1. For grazing 2. Restoration of soil fertility 3. Have no oxen 4. The land is surplus 5.Others (specify)-------------------
10. For how long you keep your land under fallow ?------------------------(in year)
11. Is your size of fallow land the same from year to year? 1. Yes 2. No
12. If no what are the major reason for the change? --
13. Do you apply any management practices on fallow land? 1. Yes 2. No
14. If yes, what type of managements? 1. Green manure 2. Weed control 3.Forage legumes planting 4. Night cattle penning 5. Others (specify)

SECTION 4: MANAGEMENT AND UTILIZATION OF CROP RESIDUES

4.1.How do you use the crop residues? (write the amount used in percent (%))

Uses for:	Sources of crop residues			
	Large cereals (maize ,sorghum)	Small cereals (eg. Wheat, barley, teff, rice, finger millet)	Legumes (field pea, faba bean, lentil, ground nut etc)	Oil crops (eg.nug)
Feed				
Fuel				
Construction				
Sold				
Left on the field (as mulch)				
For composting				
Wastage because of wrong storage, transportation, animal				

refusal				
Others				
Total (100%)				

4.2.**Crop residues management**

	Crop residues sources				
Types of management	Large cereals (maize ,sorghum)	Small cereals (eg. wheat, barley, teff, rice, finger millet)	legumes (field pea, faba bean, lentil, ground nut etc)	Oil crops (e.g., .nug)	Others
Parts of crop stored[1]					
Time of feeding[2]					
Technique & storage place[3]					
Improvement/treatment[4]					

Note: [1]**parts of crop stored;** 1= leaves, 2= stems 3= all) [2]**time of feeding;** 1= Soon after collection 2= One month after collection 3= Two month after collection 4= Over two month collection 5= others (specify). [3]**storage;** 1= stack/heap at homesteaded and shaded 2= stack/heap at farm and shaded 3= stack/heap at home and without shade 4= stack/heap at farm and without shade [4]**improvement**; 1= Water soaking 2= mix with green fodder 3= Urea treatment 4= chopping 5= no treatment

How many cropping season do you have per annum? 1, 2 or 3 encircle one of it

1. Do you produce crops by irrigating? 1. Yes 2. No, if yes how many ---------ha and ------ times per annum? name the crop types -------------------------------------and yield(kg/ha) ---
2. Do you consider high quality and quantity of feed in selecting the crops you grow in relation to animal feeds? A. Yes B. No
3. What indicators do you use for feed quality? 1. Palatability 2. Color 3. More leafy 4. Smell 5. Texture 6.Others (specify)---
4. Fill the table accordingly

	name of crop residues
Name of crop residues(rank them as preferred by	1. ------------------- 4. ------------------------- 2. -------------------

livestock	3. -------------------
Which crop residues combination used together for feed	1. 3. 2. 4.
Which crop rotated one after the other (up to three)	1-------------------------then----------------------then---------------- 2---------------------------then--------------------then---------------

5. **Supplemental feeds (encircle one in the following)**

Name of feed	Season	Frequency of supplement	For which livestock	Reason of not supplement
Salt	D-W	D-w-fn-m-y	Da-wa-my-pc-ca-ot	Na-ex-nr-ot
Byproduct (mill house waste, bran, fagullo etc)	D-W	D-w-fn-m-y	Da-wa-my-pc-ca-ot	Na-ex-nr-ot
Boiled/roasted grain	D-W	D-w-D-fn-m-y	Da-wa-my-pc-ca-ot	Na-ex-nr-ot
Local brewery residues (eg. *atella*)	D-W	D-w-fn-m-y	Da-wa-my-pc-ca-ot	Na-ex-nr-ot
Others				

D-dry, W- wet; D-daily, w-weekly, fn-fortnightly, m-monthly, y-yearly; Da-draft animal, wa-weak animal, my-milk yielding cow, pc-pregnant cow, ca-calves, ot-others; Na- not available, ex-expensive, nr-not required, ot-others

6. **Improved forages production**

6.1.Do you Practice improved forage production before? Yes/No if yes fill the table

Species	Names of forages	Area (Timad)	Strategies of development [1]
Grasses			
Legumes			
Fodder tree			

Strategies of development[1];1= over sowing/reseeding on private/communal grazing; 2=under sowing;3=planting tree legumes as fence 4= planting as pure stand

6.2.If no, what are the reasons not to produce forages? 1. Lack of seed 2. Seed expensive 3.Shortage of land 4. Others (specify) ---------------------------------

Section 7. Water Access: main sources (encircle or write)

Livestock & season	Source of water	Ownership	Frequency of access	Distance	Water quality
1.Cattle: 1.1 Wet	Wel, rvr, pnd, tw, sw, others	Own, com, gov't	Twice in d-once in d-once in 2d-w	…km	Cln, Mud, salt, others
1.2. Dry	Wel, rvr, pnd, tw, sw, others	Own, com, gov't	Twice in d-once in d-once in 2d-w	…km	Cln, Mud, salt, others
2. Small ruminant : 2.1 Wet	Wel, rvr, pnd, tw, sw, others	Own, com, gov't	Twice in d-once in d-once in 2d-w	…km	Cln, Mud, salt, others
2.2 Dry	Wel, rvr, pnd, tw, sw, others	Own, com, gov't	Twice in d-once in d-once in 2d-w	…km	Cln, Mud, salt, others
3.Equines 3.1 Wet	Wel, rvr, pnd, tw, sw, others	Own, com, gov't	Twice in d-once in d-once in 2d-w	…km	Cln, Mud, salt, others
3.2 Dry	Wel, rvr, pnd, tw, sw, others	Own, com, gov't	Twice in d-once in d-once in 2d-w	…km	Cln, Mud, salt, others

Type: wel=well, rvr-river, tw-tape water, pnd-pond,sw-still water: ownership: own, com-communal, gov't-government, Frequency: twice in d- twice in a day, d-day, once 2d-once in two days, w-weekly, Water quality: cln-clean, mud

1. If there is water scarcity, what are the measures taken to alleviate the problem? 1. Selective drinking of animals 2. Water harvesting 3. Reduce frequency of drinking 4. Digging holes 5. Others (specify)---
2. Have you ever practiced rain water harvesting for livestock production? 1. Yes 2. No
3. If yes, what is the container/structure type--------------------

8. <u>Feed availability, shortage coping mechanism and consequences</u>

8.1.How does the availability of feed vary over an average year? (on a scale of 0-10, where *10 = excess feed available*, 5= *adequate feed available and 0=no feed available*)

Months	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
Feed availability												

(score 0-10)												

8.2. What are the consequences of the feed shortage on your livestock if there? 1. Weight loss . 2. Milk yield reduction 3. Increased mortality 4. Abortion frequency 5. Weakness 6. Others, specify-----------------

8.3. Measures taken to alleviate the issues of feed shortages? 1. Feed preservation as hay 2. Use of improved forage production 3. Purchase concentrates. 4. Forage purchase (rent grazing land) 5.Destocking. 6. No measures taken 7. Others (specify)

8.4. Do you give milking cow to other person to overcome feed shortage? 1. Yes 2. No, if yes what is your agreement? ---

8.5. Do you give sheep/goat for other person to overcome feed shortage? 1. Yes 2.No; if yes what is your agreements? ---

8.6. Do you give oxen for other person to overcome feed shortage? 1. Yes 2.No; if yes what is your agreement---

SECTION 8: FEED CONSTRIANTS

8.1.Major feed source and feeding system constraints in your area (rank 1,2, 3,…5 where 1 is the most important constraint and 5 is the least important constraint)

Constraints	**Rank**	**Remark**
Shortage of rainfall		
Livestock population pressure		
Shortage of grazing land		
Land use conflict		
Land degradation and low biomass yields		
Low quality and variability of feed across seasons		
Water logging on grazing land		
Lack of extension services		
Lack of high quality forage seeds		

Lack of knowhow on improved feeding		
Poor access to feed market		
Poor storage facilities/techniques		

1. How many hours and kilometer walking to grazing area per/day from night penning?

Livestock group	Dry season		Wet season	
	In kilometers	In hours	In kilometers	In hours
Cattle				
Calf				
Sheep and goat				
Equines				

1. Is a grazing system differing during wet and dry season in your area? 1. Yes 2. No

2. Do you think important grass species decrease for last decades on your grazing land? 1. Yes 2. No; if yes name the grass species that has decreased? ---------------

Section 9: Show the livestock- feeding calendar (mark the months)

Feed resources	**Seasonal calendars**												
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Remark
Communal grazing													
Road side grazing													
Stubble grazing													
River side grazing													
Private grazing													
Crop residues													
Fodder trees													
Improved forges													
Roots and tubers													
Weeds													
Maize thinning													
Sorghum thinning													
Fallow land grazing													
Supplements/concentrates													
Hay													

Chapter-2: LIVESTOCK RESOURCES and OFF-TAKE

2a) Number of livestock owned at the beginning of the year for 2003 and changes in inventory during the year 2003 E.C.

Animal holdings: **(Cattle**_______ **Sheep**_______ **Goat** ____________ **Donkey**___________ **Horse**________ **Mule** _____**Chicken** M/F___________)

Animal Species	**Sub-group**	**Beginning** stock 2003E.C (n)	**Died/Lost** in 2003 E.C (n)	**Bought** in /gift in 2003 E.C (n)	Purpose Bought (n) & reason (*)		**Gift** out/**sold/slaughtered** in 2003 E.C (n) & reason (**)		If **sold** why (n) & reason (***)		**Born** in 2003 E.C. (n)	Market value/animal ****	
					n	*	n	**	n	***		Reason	Price
Cattle	calf (<12 months)												
	1st yr heifer (13-24 months)												
	1st yr steer (13-24 months)												
	2nd yr heifer												
	2nd yr steer												
	3rd yr heifer												
	3rd yr steer												
	mature cow: dry												
	mature cow: pregnant												
	mature cow: lactating												
	Ox												
Sheep	lamb (<12 mths)												
	1st year												
	Mature ewe: dry												
	Mature ewe: Lactating												
	Ram/wether												

Animal Species	Sub-group	**Beginning** stock 2003E.C (n)	**Died/Lost** in 2003 E.C (n)	**Bought** in /gift in 2003 E.C (n)	Purpose Bought (n) & reason (*)		**Gift** out/**sold/slaughtered** in 2003 E.C (n) & reason (**)		If **sold** why(n) & reason (***)		**Born** in 2003 E.C. (n)	Market value/animal for ****	
					n	*	n	**	n	***		Reason	Price
Goat	Kid												
	1st year												
	Mature doe: dry												
	Mature doe: Lactating												
	Mature buck												
Donkey	Foals												
	1st year												
	2nd year												
	3rd year												
	Jenny												
	Asses												
Horses and Mules	Foals												
	1st year												
	2nd year												
	3rd year												
	Mares												
	Stallion												
Chicken	M&F												

*** If bought:** **1**= Replace animal that died, **2**= Breeding & increase herd size, **3**= Breed improvement, **4**=Fattening, **5**= other (specify)
****Reason out:** **1**=Gifted out, **2**= Sold**,** **3**=Slaughtered, **4**=Died
*****If sold:** **1**=to meet household expenses + clothing, **2**=business; **3**= Culling (**a**=*unproductive*, **b**= *old*, **c**= *diseased*, **d**= *Bad temperament*), **4**= Fattened, **5**=others (specify)
******Market values for** **1**=Sold, **2**= slaughtered, **3**= gifted, **4**= die

Milk yield

Animal Species	Breed Type	lactation length in months	Average milk yield per day (mention local unit)	
			Wet	*Dry*
Cattle	Local			
	Cross			

What is the price of liquid milk per liter? --

Traction power, threshing and transport

Animal group and performed activities			Service types		
			Ploughing	Threshing	Transports
			Days/Year	Days/Year	Days /Year
Oxen	Traction (plow, thresh, transport?)				
Donkey	Transport crops to market *				
	Transport crops to home				
	Transport to fetch water *				
	Transport to the mill house *				
Horse	Transport	Human			
		Merchandise			
Mule	Transport	Human			

		Merchandise			

- * Round trip
- "*Jigi" :* Collaborative working arrangements
- Have you used "*Jigi*" last year? 1) Yes 2) No
  - If you used, how many *animals?* ________________for how many *days*_______________________________
- Number of animals performing the activities together at once: Threshing__ _____
- stimated hire value (birr/day) for group of animals: Threshing_________________
- Time of starting and ending of ploughing for different seasons (months):________

  ____

  ____

- Time of starting and ending of Threshing in a day for different crops: ________________

  ____

(Animals used for threshing *(underline the ones you used)*: oxen, cow, heifer, donkey, horses…)

- Average wage rate (man days) in the locality (Birr/day) __________________
- Average daily rate for animal traction rental in the locality (Birr/day) Oxen plow/thresh __________/_________, Donkey ________, Horse ________, Mules ______

1) Do you move your animals to other places at certain times of the year?

   a) Yes b) No

2) Reason of movement____

3) Season of movement *(month to go out*________________), *Month to go back*_________

4) Types of animals to be moved and their number__________________________

5) Way of movement and perceived benefit obtained______________________________

6) Cost per animal per month for hosting____