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Livestock-Water Interactions: The Case of Gumara Watershed in the Upper Blue Nile Basin, Ethiopia
Livestock-Water Interactions: The Case of Gumara Watershed in the Upper Blue Nile Basin, Ethiopia

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Dedicated to

My late parents; father Alemayehu Asfaw and mother Mulunesh W/Giorgis
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<tr>
<td>ACIAR</td>
<td>Australian Center for International Agricultural Research</td>
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<td>ARTool</td>
<td>Aligned Rank Transformation Tool</td>
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<td>asl</td>
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<td>BPF</td>
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<td>CGIAR</td>
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<td>CPWF</td>
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<td>CWP</td>
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<td>FAO</td>
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<td>GLM</td>
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<td>Deutsche Gesellschaf für Technische Zusammenarbeit</td>
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<td>HBY</td>
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<td>lw&lt;sub&gt;t&lt;/sub&gt;</td>
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<td>SR</td>
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SSA - Sub-Saharan Africa
TLU - Tropical Livestock Unit
TMF - Tef/finger Millet based mixed crop-livestock Farming
WWF - World Wide Fund for nature
UNEP - United Nations Environment Programme
Chapter 1

General Introduction
1.1 Role of agriculture in the Ethiopian economy

Ethiopia is an agrarian country where about 85% of the people depend on farming for their livelihoods in the rural areas (Degefu, 2003). The contribution of agriculture to the country’s economy is still large, accounting for about 50% of the gross domestic product, generating over 90% of the export revenue, and supplying around 73% of the raw material required by agro-based domestic industries (MEDaC, 1999). From this, it is vivid to judge that economy of the country is highly dependent on agriculture, of subsistence level, reflecting its backwardness in the overall development. Five major cereals namely tef, wheat, maize, sorghum and barley are the core of Ethiopia’s agriculture and food economy accounting for three-quarters of the total area cultivated and 64 percent of calories consumed (Taffesse et al., 2011). But, the yields are rather very low by international standards and overall production is highly susceptible to weather shocks, particularly droughts. The inter-annual distribution of rainfall determines crop yield levels (Bewket, 2009). The average cereal yield oscillates around 1.2 t ha\(^{-1}\) (Degefe and Nega, 2000), where the production is unable to pace with the population growth. The main reason for low crop productivity is because peasant farm production is characterized by poor technology, inappropriate land management, low levels of modern inputs and little irrigation (Deresa and Hassan, 2009).

Similarly, the performance of the livestock sector, mainly composed of indigenous breeds is extremely low in Ethiopia when compared to other African countries (Degefe and Nega, 2000). The present figure of per caput consumption of milk is 16 liter and of meat is 13.9 kg per year (FAO, 2009). Unlike other developing countries, sub-Saharan Africa (SSA) in general and Ethiopia in particular has made little progress in the last three or more decades towards improving its food security situation. The average aggregate of per caput availability of food is rather worse off than in the past (Sekitoleko, 2001). As a result, Ethiopia remains to be trapped in vicious circle of poverty and food insecurity problems.

1.2. Mixed crop-livestock farming in the highlands of Ethiopia

The highland zone of Ethiopia extends from 1500m above sea level to 3000m, above which frost becomes a limiting factor (Mwendera, 1996). It accounts for nearly 40% of the Ethiopian land mass but is home to 80% of the country’s human and livestock populations.
This zone is favourable to diverse crops and livestock production because it is characterised by moderate temperature, adequate rainfall and absence of many tropical diseases like malaria and trypanosomiasis. This has resulted in a concentration of large human and livestock populations. However, natural resource depletion perpetuating land degradation is a critical problem of the highland areas. The present land degradation in the Ethiopian highlands has a particular origin, which includes poverty and lack of agricultural intensification (Nyssen et al., 2004).

Rain fed mixed crop-livestock farming system, at subsistence level, is the most prevailing practice in the highlands of Ethiopia. The development of this system is strongly affected by the limited availability of key resources like land, water, plant nutrients, cash and labour (van Wijk et al., 2009). The situation worsens due to mismanagement of these resources in the fragile environment of the Ethiopian highlands. Crop-livestock integration is considered critical in the functioning of the mixed farming systems, and in sustaining the livelihood and social systems of the Ethiopian highlands. The livestock component of mixed farming is of highest significance due to its multifunctionality (Thornton and Herrero, 2001; Thomas et al., 2002). Integrating crop and livestock production enables complementary resource use generating mutual benefits that include the use of animal power for crop cultivation and the transfer of nutrients from grazing land to cropland through manure for soil fertility replenishment while crop residues in turn provide animal feed (Devendra, 2002). Livestock often help to minimize risk especially that of bad seasons and are a means of accumulating wealth for future family needs. They may also be the best means of investing family labour where no other form of employment is available.

The evolutionary trend of mixed farming systems has shown that as the pressure on land increases, herds are restricted to smaller grazing areas during the cropping season to avoid crop damage (Pender et al., 2001), which poses nutritional problems for the livestock and increases the risk of overgrazing. Nowadays, the sustainability and profitability of many crop–livestock systems is in flux due to changes in the relative demand and value of the products from the farming system (Gerber et al., 2005). However, these changes lead to high impact on environment, on public health and on rural development (De Haan et al., 2001; Steinfeld et al., 2006). Improving the profitability of crop–livestock systems requires improvement in each component of the system and exploring ways to improve the
complementary aspects of the crop and livestock components. In the Ethiopian highlands, owing to the scarcity of the natural resource and vulnerability of the environment, increasing livestock production should carefully be handled in order to mitigate its negative impact on the environment (water, land, greenhouse gas emission and others).

1.3 Livestock water interactions in the highlands of Ethiopia

Globally, livestock production accounts for some 20% of agricultural evapo-transpiration (de Fraiture et al., 2007), and this proportion is projected to grow substantially with the increasing consumption of animal products (Molden et al., 2010). Reducing the amount of water required for livestock production could thus contribute considerably to reducing future agricultural water needs. The challenge to sub-Saharan Africa is that food supply is still below the needed for national food security (FAO, 2011) whereas water scarcity is the major bottleneck threatening livelihood of the people and the environment (Amede et al., 2009). This shows that there will be intense competition for water resource in sub-Saharan Africa in the future steps for reducing poverty and ensuring food security.

Water is both an essential part of livelihood systems, and an important component of agricultural production (Cook et al., 2009). While sufficient water with its desirable quality is essential to sustaining livestock production, direct water intake is only of minor significance (50 l/day for a TLU) in terms of livestock water budgets in a farming system or watershed as compared to the amount of water required for feed production which can rise up to 5000 l/TLU per day or 100 times the amount directly consumed (Peden et al., 2003). Water development projects targeted at rural water supply and small-scale irrigation have largely ignored livestock demand for water (Peden et al., 2007). Consequently, livestock may cause water pollution due to direct contact and defecation, natural resource degradation around the water points, and siltation of water streams. The concern on water resource becomes more important than ever before in face of the present climate change (Zhang et al., 2007) aggravating water shortage, and the intensified competitive use of scarcely available water (Molden et al., 2010).

Water is a critical limiting factor to livestock production in the highlands of Ethiopia majorly by influencing the seasonal availability of feed resources. This is further aggravated by the
ever decreasing grazing land, which has led to overgrazing problem. To increase livestock production, it is necessary to maximize the utilization of feed resources. Crop residues and natural pastures are the most prominent feed resources available to livestock production in the mixed farming system. Feed production is dependent on soil, plant and water resources that are very susceptible to degradation unless properly managed. Grazing systems have the most direct interface between livestock and land, water and bio-diversity (Andrew and Lodge, 2003; Steinfeld et al., 2006). Livestock grazing affects watershed properties by altering plant cover and by the physical action of their hooves (Chaichi et al., 2005). In the highlands of Ethiopia, the traditional uncontrolled and free grazing system has caused severe degradation of the grazing lands (Gebremedhin et al., 2004). Land degradation reduces water productivity at field and landscape scales and affects water availability, quality and storage (Bossio et al., 2010). The strong link between land and water shows that every land use decision is a water use decision (Bossio et al., 2010). This implies that unless agricultural land (including grazing land) is managed properly, it is very unlikely to improve the use and management of agricultural water. The trade-offs between the needs for improving livestock productivity (to support economic development) and for sustaining resource management should be scrutinized to keep them in a state of compatibility (Bartley et al., 2010).

Investing in agricultural water for food security is a high priority in the Nile Basin (Peden et al., 2007). Although water is crucial for animal production, its utilization competes with other uses including crop production. Water accounting provides a means to assess water use across scales, and to better understand the denominators of the water productivity (Molden et al., 2003). The task in water accounting is to estimate the flows across the boundaries of the domain during the specified time period (Molden et al., 2003). In doing so, it helps to better understand the wider dimension and complexity of water uses in a given domain. Such exercise enables to explore alternative options and the scope for improving the use of this scarce resource that has already been put under pressure.

A conceptual framework was developed by Peden et al. (2007) for assessing livestock water productivity that helps identify options for reducing water depletion, increasing livestock production, and enhancing ecosystem services associated with animal production. In Ethiopia, farmers grow different crops and manage livestock differently according to their suitability to the areas or market values (Haileselassie et al., 2009). These management
differences have implications for water productivity and healthy ecosystem functioning. It is, thus, imperative to evaluate livestock productivity from the perspective of water use efficiency to help comprehend strategies that are useful for increasing overall water productivity and, from the perspective of grazing resource management to improve its sustainability. The specific objectives of the present study were to:

- provide insights on the methodology of livestock water productivity (LWP) estimation using the water footprint approach and relate it to the life cycle assessment (LCA) framework,
- assess LWP from empirical evidences across different land-use mosaics of the mixed crop/livestock production systems in Gumara watershed,
- investigate the impact of collective management of communal grazing land on lessening the problem of land degradation and sustaining pasture production, and
- identify the determinant factors influencing sustainable use and productivity of the natural pasture ecosystem pertaining to collective management of communal grazing lands.

1.4 Outline of the thesis

The thesis comprises six chapters. The first part (chapter 1) deals with general introduction to give background information about topics of the thesis including its specific objectives. It reports on the importance of agriculture to the economy of Ethiopia and describes the impacts of agriculture in general and livestock production in particular on the natural resource base. Chapter 2 addresses the first objective of the study that deals with underpinnings of the conceptual basis of livestock water productivity in mixed crop-livestock farming systems. It attempts to refine the methodological approach in estimating livestock water productivity combining the life cycle assessment and the water footprint concepts. Chapter 3 presents results of a monitoring study carried out to determine livestock water productivity across spatial scales in Gumara watershed of north western Ethiopia. It identifies potential alternative options for improving livestock water productivity in the contexts of the study area. Chapter 4 describes the impact of collective management of communal grazing lands on vegetation attributes and hydrological properties of the scenario in question. It reveals the extent of vulnerability of freely open communal grazing lands to severe land degradation.
Chapter 5 explores factors that affect condition of a pasture of a common hold kept under collective management. It explains the relationship between good pasture condition and relevant explanatory factors that influence productivity of pasture. Chapter 6 presents general discussion of the thesis. It synthesizes results of the whole thesis and corroborates it with other similar works elsewhere. It describes the drawn conclusions and recommendations of this study that are pertinent to future development and research concerns of similar situations.

References


Chapter 2

Increasing Livestock Water Productivity under Rain Fed Mixed Crop/Livestock Farming Scenarios of Sub-Saharan Africa: A Review

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Abstract

Although water is a renewable natural resource, it has become insufficient at the global level. Unless the current efficiency level of water use can be increased, the trend of water shortages will become more serious. Among agricultural activities, livestock production is mostly considered an intensive water consuming operation although the knowledge and information related to livestock-water interaction appears to be limited in scope. The present review focused on the livestock-water interaction with the following objectives: 1) to strengthen the current understanding of the concept of livestock water productivity and relate it to life cycle assessment analysis framework; 2) to provide insights on the methodology of livestock water productivity estimation using water footprinting approach 3) to assess the potential integrative intervention options towards improving livestock water productivity pertinent to the contexts of rain fed mixed farming. The concept of water accounting for livestock production is reviewed to reflect feasible options for improving animal productivity, income, livelihood and ecological benefits per unit of water input, especially the practical implications of these options for the rural poor in Sub-Saharan Africa. Utilising the rain fed mixed farming endowment as a relatively less competitive water scenario is also emphasised. In line with the intention for increased livestock water productivity, the likelihood of its negative impact on the environment and possible mitigating methods are outlined.

Key words: Livestock water productivity, sub-Saharan Africa, life cycle assessment, water footprint, mixed farming system

2.1 Introduction

Livestock production has a prominent position in satisfying the diverse needs of humans ranging from the provision of natural animal food products (highly nutritious) to rendering the associated benefits of economic, social, cultural and ecological domains (Thomas et al., 2002). Furthermore, livestock is considered an inflation-proof asset that can be converted into cash in difficult times for the poor livestock keepers in developing countries (Thomas and Sumberg, 1995). In Sub-Saharan Africa (SSA), the livestock component of mixed farming is highly significant in ensuring food security and reducing poverty (Thornton and Herrero, 2001; Thomas et al., 2002). The statistics indicate that approximately 144 million people (in
SSA) located within mixed-farming systems often manage to draw their livelihoods from livestock (Thornton et al., 2002). However, livestock productivity is usually low because of inadequate feeding, ill health (ACIAR, 2003), less capital input, depleted natural resources, low genetic potential of local breeds and limited access to improved technological options.

Currently, the demand for livestock products in developing countries has increased by 6% to 8% per annum (ACIAR, 2003), which exceeds that of cereals (Steinfeld et al., 2006). The rising demand for livestock products has occurred following the rise in incomes that trigger an accelerated desire to eat nutritious foods (Delgado et al., 1999). While attempting to satisfy the increasing and changing demands for animal food products, keeping sustainability of the natural resource base (soil, water, air and biodiversity) at the same time is a key issue confronting the agriculture (Steinfeld, 2004), particularly in view of the present climate change and concern over animal welfare. Fresh water resources are fixed in abundance, yet the loss of water in both rain fed and irrigated agriculture systems often amounts to more than 70% (Wallace, 2000), highlighting the need for improving water use efficiency.

Although the largest part of fresh water is left for agricultural use (Wallace, 2000; Steinfeld, 2004; Molden et al., 2010), there is an increasingly growing demand and competition for this finite water resource required by municipal and industrial sectors for other indispensable uses. Among agricultural activities, livestock production is widely considered an intensive water consuming activity (Molden et al., 2010) but with a wide variability of potential for improvement (Peden et al., 2007). Globally, livestock farming is responsible for approximately 20% of the evapo-transpiration (ET) in agriculture (de Fraiture et al., 2007), and this share is expected to considerably rise in an attempt to fulfil ongoing increments of demand for animal products. In addition, climate change may also induce rainfall reduction and alteration of its distribution pattern to cause frequent droughts in tropical regions (Zhang et al., 2007) and intra-seasonal dry spells (Rockstrom et al., 2002), which cause SSA to be vulnerable because its rain fed agriculture constitutes more than 95% of the agricultural land use (Rockstrom et al., 2004). These scenarios underscore the need for improving water management in rain fed agriculture to secure the water required for food production and to build resilience for coping with water scarcity (Rockstrom et al., 2010). Thus, improving the productivity of water in livestock production may substantially contribute to reducing future agricultural water needs. Capitalising on rain fed agriculture is a worthwhile consideration to
lessen the competition for scarce water resources. Moreover, it may boost the potential for increasing water use efficiency of the rain fed system from its present low level of utilisation (less than 15% of rainfall) in field conditions of Africa (Rockstrom, 1999).

Knowing that the challenge of water scarcity will continue in the years to come, it is worthwhile to consider every option for optimising the use of water. There is limited knowledge on livestock-water interactions (Peden et al. 2007; Descheemaeker et al. 2010) and the limited available information largely refers to industrial livestock production systems. A conceptualised livestock-water interaction is the focus of the present review in the context of rain fed mixed farming systems of SSA. Therefore, the objectives of this review were 1) to strengthen the current understanding of the concept of livestock water productivity and relate it to life cycle assessment (LCA) framework, 2) to provide insights on the methodology of livestock water productivity estimation using water footprinting approach, and 3) to assess the potential integrative intervention options for improving livestock water productivity.

2.2 Understanding livestock - water interactions

The provision of water is critically important in all animal production systems because most livestock have to drink at least every other day to remain productive and have to drink every few days to survive (King, 1983). As the production level intensifies, the need for water by a productive animal increases. Thus, water constraints severely affect the productivity of livestock. King (1983) stated that the greatest threat to life on land is the danger of dehydration. In a tropical ruminant, 99% of all the molecules in the body are water (King, 1983), which forms approximately 65% to 80% of the body weight of the animal (Lillywhite and Navas, 2006).

Animals obtain their water not only from drinking but also from their feed, metabolic processes within the animal and other sources. While access to adequate water is essential for livestock production, drinking water is only of minor significance (50 l/day for a TLU) in terms of livestock water budgets in a farming system or watershed as compared to the amount of water depleted for feed production, which can reach 5,000 l/day for a TLU or 100 times that amount directly consumed (Peden et al., 2003). Nonetheless, the daily drinking water requirement of livestock and its regular provision should not be neglected. The metabolic
function of water in the animal body is a highly determinant factor for maintaining the normal physiological process and healthy production state of the animal despite its small proportional amount as indicated above.

In arid areas with annual precipitation below 600 mm, most common crops do not have good yields, and isohyets near this magnitude delineate the natural limit between animal and crop production (Wilson, 2007). In such environments, raising livestock represents the only feasible agricultural activity under rain fed conditions for utilising the extensive natural grasslands of marginal areas in the world, which are estimated to cover approximately 21 million km² (Mack, 1996). Consequently, the pastoral livestock system can be considered the best traditional strategy in utilizing this scarcely available water, which is normally obtained from erratic rainfall sources that would have otherwise remained non-beneficial (Cook et al., 2009).

2.2.1 Water accounting for livestock production

In the past, the growth in agricultural production has heavily relied on increasing water withdrawals for farming (Humboldt Forum for Food and Agriculture, 2010). In the face of the present trend of critical water deficit for satisfying multiple uses (Molden et al., 2007; Descheemaeker et al., 2010; Rockstrom et al., 2010), the growth of future food production is highly influenced by water shortage unless the efficiency of its use is dramatically increased in all respects (Wallace, 2000). It is thus necessary to have a clear description of the water input depletion in the course of agricultural production to arrive at appropriate option for improving agricultural water management (Bastiaanssen et al., 2008).

2.2.2 Livestock Water Productivity (LWP)

With regard to water productivity, its implication goes beyond the direct effect of simply increasing total farm outputs and farm income (Bossio et al., 2010; Namara et al., 2010). Because water productivity plays a pivotal role in improving land productivity, increasing labour productivity, safeguarding the ecosystem, encouraging the use of more inputs, providing employment opportunity and fostering equitable economic growth (Harrington et
al., 2009), it needs to involve and intersect the complex matters associated with social, economic, organisational, policy and technical issues (Amede et al., 2009).

Water productivity is generally defined as output per unit of water depleted in the production process where the output can be measured in physical terms or values. It is considered to serve as a partial measure of productivity (Harrington et al., 2009) because of its limitation in accounting for all types of benefits. With the present empirical formula of water productivity, it is widely variable in space and time scale even in areas with apparently similar agro-ecologies (Harrington et al., 2009). It is more useful to emphasize on selective priority areas where profound increases in water productivity are possible (Molden et al., 2010). The identified scenarios include the following areas where: 1) poverty is high and water productivity is low; 2) competition for water is high due to its scarcity; 3) high returns from additional water use can make a substantial difference; and 4) water-driven ecosystem degradation occurs, such as falling groundwater tables and river desiccation. SSA is of particular concern because the intended changes can be comprehended with the application of appropriate interventions. The progress can be evaluated by monitoring the extent of improvement in water productivity.

The determination of LWP followed the concept of water productivity as described by Peden et al. (2009). LWP is a ratio of total benefits in terms of outputs and services obtained from livestock per total water depleted in livestock production. Wide variations have been noticed in reported values of LWP (from case studies in Ethiopian highlands) such as 0.4 USD$^\dagger$ m$^{-3}$ volume of water by Haileselassie et al. (2009) against 0.07-0.09 USD m$^{-3}$ by Mekonnen et al. (2011) for similar subsistence based mixed farming systems. This may indicate that there is a strong need to refine and standardize the methodology for estimating LWP. The numerator takes the total sum of benefits obtained from livestock over the complete period of productive herd life including their insurance value. The denominator represents the amount of water depleted for producing feeds, consumed by the animals (expressed as evapo-transpiration), and for drinking over the entire lifetime of the herd being assessed based on the water foot printing concept (Hoekstra et al 2009) and applying the frame of LCA (Beauchemin et al.

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$^\dagger$ USD=United States Dollars
To represent this relationship, a computational model was adapted from Peden et al. (2009) and modified as follows:

\[
LWP = \frac{\sum_{i=1}^{n} (O_i \times P_i) + \sum_{j=1}^{n} SC_j - \sum_{j=1}^{n} M_j}{\sum_{k=1}^{n} ET_k + \sum_{j=1}^{n} D_j + \sum_{l=1}^{n} S_l + \sum_{m=1}^{n} DGm}
\]  

(1)

Where LWP= Livestock water productivity (USD m\(^{-3}\)), O\(_i\)=quantity of the \(i^{th}\) livestock output or service type obtained over the productive life span, P\(_i\)=local market price (USD) of the \(i^{th}\) output or service type, SC\(_j\)=stock capital (USD) of a breeding herd/flock of the \(j^{th}\) livestock species towards the end of productive life span, M\(_j\)=loss of monetary value (USD) due to mortality of the \(j^{th}\) livestock species, ET\(_k\)=water depleted (m\(^3\)) in evapo-transpiration to produce \(k^{th}\) feed type consumed by livestock species kept at the farm over the productive life span or until off take being assessed using water-foot printing concept in LCA frame, D\(_j\)=drinking water consumed (m\(^3\)) by the \(j^{th}\) livestock species kept at the farm over the productive life span or until off take being assessed using water foot printing concept in LCA frame, S\(_l\)=water used (m\(^3\)) in \(l^{th}\) service type such as cleaning of barn, milking parlour and milk utensils, DG\(_m\)=degraded/contaminated in the process of livestock production in \(m^{th}\) water source like dipping and spraying in veterinary services.

### 2.2.3 LCA and water foot printing

Agriculture today must follow a sound path to sustain the environment and the ecology. It is expected to increasingly maintain public values e.g. positive landscape image and appropriate animal welfare (Haas et al., 2001). Emphasizing on fresh water resource use and its allocation, Koehler (2008) reported the need for assessing the use of agricultural water by applying the LCA framework. LCA is a method that can be applied to compile inventory and evaluate agricultural production system for assessing its impact on natural resource management in a defined system boundary (Haas et al. 2001). To estimate LWP at farm level, LCA within the boundary of cradle to farm gate, enables us to enfold the entire herd life in accounting for water. It invokes the whole continuum from birth/growing period to end of the productive age of a herd.
The water footprint of a product is conceptualized as the amount of freshwater used to produce the product, measured over the full supply chain. Hoekstra and Chapagain (2008) have shown that visualizing the hidden water use behind products can help in understanding the global character of freshwater and in forming the foundation for a better management of the globe’s freshwater resources. Truncating the boundary of the water footprinting to a livestock farm gate, the volume of water consumed by livestock can be quantified from birth to end of productive age or off-take in the breeding cycle. The water footprint accounting is based on the LCA frame of livestock production. It considers the subsequent growth stages of livestock as: i) birth to weaning, ii) weaning to maturity and iii) production to culling. Nutrient requirement of an animal varies depending on its growth and productive stage and hence quantifying the feed demand over lifespan of the animal must take care of all this.

The water used for producing animal feeds comprises the majority of the physical water needed for determining the extent of LWP (Molden et al., 2007; Peden et al., 2007; Peden et al., 2009). To calculate ET and crop water requirements, the CROPWAT model of FAO (1998) and the Penman-Monteith equation (FAO 2005) are employed. Of all the forms of water depletion, transpiration is preferable (Peden et al., 2009) for its contribution towards increasing biomass production, thereby improving the nutrition of animals, which is the most serious limitation to increasing livestock productivity.

In mixed farming systems, the utilization of crop residues as animal feed is currently a prominent practice. In these systems, farmers appreciate the nutritional values of crop residues and hence they play a role in choosing the type or variety of crops. Considering market price of grain and crop residue as a partitioning factor helps to allocate the total ET between the two components.

### 2.2.4 Livestock outputs and services

The production goal of a farm dictates the type of livestock output. For instance the output of a dairy farm is majorly milk, and of a cow-calf beef ranch is meat. In typical mixed crop/livestock farming systems of SSA, livestock have multi-functions and give many outputs and services. Ordinarily, a smallholder farmer keeps mixture of livestock species such as cattle, sheep/goat and equine. It needs to model the herd structure of a farm and quantify the
different outputs and services of each livestock species by age class over the productive lifetime of a herd or until off-take time. Using manure for replenishing soil fertility and draught oxen for land cultivation have considerable values in such system. Keeping livestock in the mixed farming of SSA also has the merit of asset accumulation and insurance, which this to be considered in the valuation like the case quantified by Bebe (2003). Each output or service needs to be converted into monetary value. The monetary unit is more convenient and comprehensible for combining the values of diverse benefits as they are derived from multiple livestock species and are variable in terms of quality. Animal mortality is a serious problem in livestock production scenarios of SSA where livestock diseases are rampant. It is necessary to account for the monetary loss due to livestock mortality in determining the value of LWP.

2.3 Strategies to enhance LWP

Increased LWP reverses land degradation and safeguards environmental resilience in addition to improving food security and livelihoods (Descheemaeker et al., 2010). The volume of water needed to produce 1 kg of meat or milk is estimated to range from 3,000 l to 15,000 l (Molden et al., 2007) depending on the type of husbandry, the type of feedstuff, the processing system and the conversion efficiency of animals. Improvement in LWP can be realized by adjusting each of these factors. Research results have shown that proper management can improve the return from water by more than two-folds (Oweis, 1997). Various experiences reveal that there is considerable scope for increasing livestock productivity in both physical and economic water productivity (ILRI, 2006; Peden et al., 2007; Molden et al., 2010). Strategies to enhance LWP include improving feed components, improving grazing management, enhancing animal productivity, improving water management, strengthening livestock marketing, improving animal health, and reducing negative environmental impacts, such as water pollution. The compatibility of the intervention and its environmental friendliness to the specific local context should be considered with caution, as the adoption of a well-proven technology can often be stalled by the coevolving changes that entail intensive labour demand, gender inequality, additional cost, mode of utilisation and cultural implication. Thus, increasing water productivity demands thorough understanding of the biophysical, socio-economic and environmental
aspects at field, farm and basin scale (Amede et al., 2009; Descheemaeker et al., 2010; Molden et al., 2010).

2.3.1 Improving feed resources and grazing management

As LWP is a function of both livestock outputs and water input, there is a need to consider avenues for reducing water input without compromising outputs to improve efficiency of livestock production and increase profit. Providing feed to animals is a major cost input in almost any animal production system (Archer et al., 1999; Sherman et al., 2008), and it is also the main route of water depletion in the LWP model. Generally, animals in developing countries are fed either native grasses or agricultural by-products, which are comparatively low in digestibility and thus result in greatly decreased rumen efficiency (RuMeth International, 2001). These diets with caloric intake levels that barely fulfil maintenance requirements differ substantially from those used in developed countries. The low level of production per livestock unit is the result of seasonal variations in available feedstuffs, limited basic nutrient supplementation and lack of improved production practices at the farm level. Therefore, animals are less productive than their genetic potential. For sustaining livestock productivity, it is crucial to determine the critical balance between pasture availability and pasture requirement of grazing stock (Hamilton et al.; 2008), which allows substantial productivity gains by meeting production targets and product quality specifications (Bell et al., 2008).

In mixed-farming systems, crop residue serves as a crucial single fodder source in response to a continual diminishing of pastureland resulting from its conversion into arable land, regardless of fertility status (Delve et al., 2001; Blümmel et al., 2009). For instance, in India, crop residue on a dry matter basis covers 44% of the countrywide total demand (Blümmel et al., 2009), and the use of crop residue mostly coincides with critical feed shortages during periods of dry spells. Nevertheless, the nutritive value of crop residues is usually low as compared to that of planted fodders (Blümmel et al., 2009). Unfortunately, the intuitive attempt of livestock for increasing their intake to compensate for its low nutrient content is also limited in this case. Thus, to enhance the role of crop residues in improving LWP, it is necessary to consider various options for improving the feeding value of crop residues by employing appropriate treatments (Blümmel et al., 2009) or incorporating nutritive quality as
a desirable trait in the crop variety improvement program (Blümmel et al., 2003). However, a contentious concern arises with regard to the competitive use of crop residue either as animal feed or as a soil fertility ameliorating input. Therefore the negative impact of using crop residue as a feed source can be considered negligible only if this practice is offset by its utilisation for ameliorating soil fertility and its role in reducing soil erosion.

The dependence on fibrous low-forage-quality natural pastures is considered to be insufficient to produce quality meat from elite lambs or finishing cattle required by the present market (Dowling et al., 2006). This requires the inclusion of nutritious feed ingredients in the daily diet of animals to enhance their productivity. However, the real challenge for the poor smallholder farmers in SSA is that they cannot afford or gain access to supplementary feeds of higher nutritional value from urban markets. Instead, the farmers grow multipurpose trees and forage legumes with the intention of improving diet quality and providing additional dietary nitrogen as supplements to the poor quality basal diets (Getachew et al., 1994; Ebro et al., 1995). Tarawali et al. (2001) combined several findings related to dual-purpose crops, especially legumes, which offer the potential to increase the available fodder from a limited land base. Growing improved forage crops, particularly forage legumes, as fodder banking, ley farming, intercropping and relay cropping, have proven to alleviate protein shortfalls encountered by livestock and to enrich the soil with nitrogen (Thomas and Sumberg, 1995; Mohammed Saleem, 1998). The outcome of this type of intervention may result in an improvement of livestock productivity through increasing digestibility and utilisation efficiency of the basal feedstuffs (Dowling et al., 2006).

### 2.3.2 Enhancing animal productivity

Most cattle in developing countries are maintained by small-scale producers without the benefit of improved management practices (RuMet International, 2001). This lack of innovation results in the livestock yielding far less than their genetic potential. It has been reported that SSA accounts for 14% of the world’s livestock resources but produces only 2.8% of the global meat and milk (Otte and Chilonda, 2002) because of low productivity. With the present trend of natural resource scarcity and an increasingly vulnerable environment, it is critically important that growth in efficiency rather than in numbers should
be the dominant factor in the effort to meet the demand for future livestock products (Cunningham, 1999).

Archer et al. (1999) indicated that a genetic variation exists in feed conversion efficiency of growing cattle, suggesting that it may be possible to decrease feed intake of growing cattle without affecting growth performance. Improvement in feed efficiency can then improve the overall livestock production system and also reduce methane production (Archer et al., 1999; Sherman et al., 2008). Hence, one of the keys to efficient livestock production is to maximise the potential conversion of forage into animal products (Millar et al., 2009), where its implication entails increased livestock water productivity. Improving the genetic base of livestock through crossbreeding for managing them under better nutrition may substantially contribute in increasing LWP (Sahlu, 2007). However, the report by Gebreselassie et al. (2009) argued that no significant improvement in LWP is found when using crossbred dairy cows compared to local cows.

### 2.3.3 Improving animal health care

Livestock production is often jeopardised by rampant disease in the tropics. In SSA, the majority of animals are traditionally raised under extensive free-roaming management systems with no specialised input into housing care, nutrition or disease prevention (Mukasa-Mugerwa, 1996). Consequently, poor livestock health remains one of the main bottlenecks to livestock development in the region. For instance, the overall direct losses due to livestock mortality in SSA have been estimated at USD 2 billion per year (FAO, 1985). Furthermore, substantial revenue is lost annually because of the failure of many potential producers to meet the sanitary requirements of lucrative export markets (Mukasa-Mugerwa, 1996). Disease epidemics often coincide with changes in climatic conditions, such as drought, early rains and other output-reducing events (Otte et al., 2004), which aggravates the incidence of loss in livestock production. Therefore, strengthening the operational efficiency of the public veterinary service continues to be necessary in boosting livestock production as a whole (Holden et al. 1996). At the same time, promoting the privatisation of veterinary services may help deliver better veterinary services, particularly for a domain that is shifting toward more commercialised operations and the treatment of individual animals (de Haan and Bekure,
Because animal health care is a base for all other inputs to yield a desired return, optimising the veterinary service would then contribute towards increasing LWP.

2.3.4 Drinking water provision and water management

The water requirement of livestock varies in different species and breeds of livestock and depends on the ecological zones in which the production system takes place (King, 1983). Animals drink water primarily to replace lost fluid rather than in anticipation of future needs. The maximal amount an animal can drink at one visit to a watering point varies with the degree of dehydration of the animal and the time spent near water. Under tropical conditions, animals use 5% - 30% of their total body water pool per day (King, 1983). The daily drinking water requirement of tropical indigenous ruminant livestock is estimated at 5 L for small ruminants and 30 L for large ruminants (King, 1983) accounting for the capacity of the animal to meet the daily requirement and the amount the animal can drink on one visit. The water taken in by the animal needs to be retained for some time in the gut, and the release of water occurs slowly to prevent hypotonic solutions passing into the bloodstream until salts have been added (King, 1983), which determines the water intake of an animal. Because drinking water is one of the main causes of physical contact between the livestock and body of water, constructing a watering trough for the separate provision of drinking water to livestock minimises the incidence of water pollution coming from the livestock. To decrease the incidence of watering point-associated land degradation caused by livestock, pragmatic methods of allocating watering points across grazing lands, supported by continual monitoring of drinking to allow a timely decision are required.

2.3.5 Strengthening livestock marketing

In the rural livestock farming of SSA, smallholding production systems operate with rudimentary production technologies and are not adequately market-oriented (Solomon et al., 2003; Barret, 2008). The main driver of such traditional production is to secure subsistence livelihoods, which are characterised by low levels of productivity (Barret, 2008). The transition from the low productivity of semi-subsistence agriculture to high productivity of commercialised agriculture has been a core theme of the development and agricultural economics for more than half a century (Timmer, 1988). For this type of transition in
livestock businesses, marketing becomes the most important segment to promote the production and productivity of livestock (Shafiq and Kakar, 2006). Market infrastructural and institutional links will improve the access of producers to potential markets where they could supply more volumes with higher shares of the end market price (Solomon et al., 2003; Cadot et al., 2006). However, putting the infrastructural requirements in place requires significant investments (Barret, 2008). Therefore, improving access to markets in order for the rural smallholder farmers to benefit from the rapidly growing demand for livestock products is one option that policymakers must consider (Lapar et al., 2003). Acquiring access to markets alone is not enough because farm households must also have access to productive technologies and adequate private and public goods to produce a marketable surplus (Barret, 2008). Having better access to information and market would help smallholder farmers to improve their livestock production towards supplying quality products whereby this ultimately benefits consumers (Solomon et al., 2003).

2.3.6 Institutional and policy factors

In many areas of SSA with higher rainfall and mixed-farming practices, population densities of both people and animals are normally high. In these areas, water sources are common used for multiple purposes. Secure land tenure, be it communal or individual, is among the factors that lead to better water use and, incidentally, to the conservation of other resources (Wilson, 2007). The acceptance of new technology is affected by institutional factors, policy factors (Amede et al., 2009a; Wilson, 2007), ease of fitting into the existing farming complex (Gebremedhin et al., 2003) and the impact on the environment (Steinfeld et al., 2006). Because livestock innovation is a social process, institutional commitments are essential in promoting water productivity principles and practices (Amede et al., 2009b).

2.4 Impacts of livestock on environment

Currently, the quick rises in demand for animal food products in developing countries are placing unprecedented stress on the resources used in livestock production (Delgado et al., 1999; Steinfeld, 2004). Livestock production is blamed for its strong association to land degradation, water pollution, green house gas emission and the erosion of biodiversity (de
However, the negative role attributed to livestock is frequently a result of other pressures and distorted policies (de Haan et al., 1997; Boyazogulu, 1998).

Land degradation is considered a major threat to future agriculture in SSA because it reinforces poverty (Steinfeld, 2004). The impact is substantiated by the reports of case studies on the trends of soil erosion in the highlands of Ethiopia, showing that land degradation can reduce per capita incomes of the residing people by 30% (FAO, 1986). Livestock production is believed to be among the key causes of land degradation (Hurni, 1988; Mwendera et al., 1997a; Mwendera et al., 1997b; Tadesse, 2001; Steinfeld, 2004). Grazing systems set the direct interface between livestock and land, water and biodiversity, which represent a significant part of the natural resources of the earth (de Haan et al., 1997). Livestock grazing inflicts change on watershed ecosystem by altering the plant cover and causing physical damage (Blackburn, 1983). The mechanical pulverisation effect on the soil and the denudation of the vegetation cover eventually lead to serious land degradation (Tadesse, 2001). The tradeoffs between the need to improve livestock productivity and the desire to sustain natural resources should be scrutinised to keep them compatible (Bellaver and Bellaver, 1999).

Ruminant livestock are labelled as significant contributors to global warming through the emission of greenhouse gases such as nitrous oxide (N\textsubscript{2}O) and methane (CH\textsubscript{4}) (Schils et al., 2007). In Europe, emissions from ruminant livestock account for 55% of the total agricultural emissions (Freibauer, 2003). These gas emissions are assumed to be higher in developing countries because of the higher number of livestock and the dominant use of fibrous and less digestible feedstuffs. The goal of lowering these agriculture-related greenhouse gas emissions in Europe (to an approximate 10% reduction level by 2004) was achieved through a strategy targeted at reducing livestock population (Schils et al., 2007). This perhaps entails a shift in human food habits towards vegetarianism at least in the developed world where the concern or awareness of dietary health has already been developed. The use of higher concentrate proportions in the diet of ruminants or an increase in the digestibility of forages may contribute to reducing methane emissions (RuMeth International, 2001).

In rural areas, agricultural activities result in surface water and groundwater pollution (Zhang et al., 2009). Water is vulnerable to contamination from livestock farms. A case report shows
that drinking water was contaminated by effluents from livestock agriculture causing illness of local people in Canada (Burton, 2009). In SSA, water sources are commonly used for multiple uses. Hence, the extent of the problem from water contamination would be worse in the rural areas of SSA, leading to an increased risk of human health. The challenge of water pollution from a nitrate source further compounds the problem (Hooda et al., 2000). To address this problem, a convenient device for isolating the access to livestock drinking water must be developed.

It is plausible that grazing alters the botanical composition of a pasture. De Haan et al. (1997) indicated that heavy grazing for a longer period causes the disappearance of desirable plant species and the subsequent dominance of other, less desirable, herbaceous species. The same report showed that the total absence of grazing also reduces biodiversity in some cases because a thick canopy of shrubs and trees develops, and results in overprotected plant communities that are susceptible to natural disasters. However, previous studies illustrated that moderate grazing maintains watershed conditions and utilises the feed resource base for optimal return (Blackburn, 1983).

In general, livestock production with good management can also make a positive contribution to the natural resource base by enriching soil quality, keeping plant biodiversity and others (Cunningham, 1999). Therefore, policies and technologies that favour good management need to be identified and implemented to overcome the negative environmental impact in an attempt to satisfy the increasing demand for livestock products.

2.5 Implications of LWP on rain fed mixed crop/livestock farming

Smallholder farming in SSA occurs in diverse conditions of soil, climate and socio-economic structure. The development of these systems is strongly affected by the limited availability of key resources, like land, plant nutrients, cash and labour (van Wijk et al., 2009). In mixed farming systems, the ways of utilizing these resources and the decisions of farmers pertaining to the allocation of the resources have immense implications to the farm livelihood (van Wijk et al., 2009). Hence, there is a wide variation in level of development of the mixed farming systems across the world depending on their specific contexts (resource use efficiency,
productivity of the integral components, sustainability of the agro-ecological system and socioeconomic/governance complexes).

The evolutionary trend of mixed farming systems has shown that as the pressure on land increases, herds are restricted to smaller grazing areas during the cropping season to avoid crop damage (Powell and Williams, 1995), which poses nutritional problems for the livestock and increases the risk of overgrazing. During dry seasons when low-lying areas are transformed into irrigated gardens, traditional grazing lands may become inaccessible, giving few alternatives for livestock that otherwise have to depend on aftermath grazing and crop residues. Strategies directed at raising the productivity of a specific mixed farming system need to consider the stage of development of the target area and the nature of the crop/livestock interactions (Jagtap and Amissah-Arthup, 1999).

Under crop residue grazing, animals remove greater amounts of biomass and nutrients disproportionate to the manure return (Powell and Williams, 1995). This nutrient removal by livestock may lead to the spread of animal voiding in the landscapes, which is usually concentrated around watering points, resting places and along trekking paths (Stoorvogel and Smalling, 1990). As a result, nutrient balance has become negative for many farming systems in SSA. Increasing population pressures on fixed land resources of poor soil fertility have turned the arable lands to barely provide the basic food needs (Wilson, 2007). The present and future trends of water availability prove that rain fed agriculture will continue to have a significant role in securing food and livelihoods of an increasing world population (Rockstrom et al., 2010). However, supporting rain fed agriculture with supplemental irrigation schemes by enforcing water harvesting and storage mechanisms becomes an indispensable necessity to mitigate terminal water stress that nowadays occurs more frequently (because of climate change). The integration of livestock with crop farming contributes to the optimal utilisation of farm resources (Harrington et al., 2009).

2.6 Conclusions

Satisfying the growing demands for livestock products while simultaneously sustaining the natural resource base (soil, water, air and biodiversity) is a key issue confronting the future farming practices. Alleviating malnutrition and food insecurity in developing countries will
require reducing the existing wide gap between actual and maximal yields. Improving productivity is the most plausible way to meet the demand for agricultural products.

Investigating the concept of livestock-water interactions and water accounting may help to better understand the wider dimension and complexity of water uses in a given domain. The in-depth understanding of these interactions and water accounting in LCA framework will help to explore alternative options for improving the use of this scarce water resource. Because LWP is a function of both livestock outputs and water input, there is a need to consider practical avenues for enhancing livestock outputs by combining them with water use efficiency in a manner more compatible to the specific local contexts.

Capitalising on rain fed agriculture may have a key role in lessening the competition for scarce water resources. Moreover, emphasis on virtual water trading would also contribute to increase water use efficiency from global perspective. Integrating crop and livestock in mixed farming systems is a better and more synergistic way of utilising farm resources. Livestock can make use of the crop by-products and a portion of the non-process water depletion (such as weeds and green biomass that grow along farm paths between crop fields) to convert this fibrous matter into useful animal products with higher food value, thereby contributing to increasing water productivity.

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Chapter 3

Assessing Livestock Water Productivity in Mixed Farming Systems of Gumara Watershed, Ethiopia

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Abstract

A monitoring study was carried out in Gumara watershed, upper Blue Nile basin, with an objective to evaluate livestock water productivity (LWP) using the framework of a life cycle assessment from cradle-to-farm gate boundary. Sixty two smallholder farmers were selected for the study implemented between November 2006 and February 2008. Data on crop and livestock productions, pertinent to assessing livestock water productivity, were collected in three different rain-fed mixed farming systems viz.; barley/potato based mixed farming (BPF), tef/finger-millet based mixed farming (TMF), and rice/noug based mixed farming (RNF). LWP was found significantly lower (p< 0.01) in RNF (0.057 USD m⁻³) than in TMF (0.066 USD m⁻³) or in BPF (0.066 USD m⁻³). Notably, water requirement per kg live weight of cattle increased towards lower altitude area (in RNF) mainly because of increased evapo-transpiration. As a result, 20% additional water input was required per kg live weight of cattle in RNF as compared to BPF in the upland. Crop water productivity (0.39 USD m⁻³) was evidently superior to LWP (0.063 USD m⁻³) across the mixed farming systems of Gumara watershed. But the prospect for improving LWP is likely to be enormous from its present low level for instance through keeping only the productive animals, increasing pasture productivity, improving the utilization of other feed sources and linking the production goal to market orientation. The intervention targeting at early off-take management proved to significantly increase LWP. This would also contribute to ease the imbalance between the existing high livestock population and the deteriorating carrying capacity of natural pasture.

Key words: Livestock water productivity, mixed farming systems, life cycle assessment, Gumara watershed

3.1 Introduction

Rain fed mixed crop/livestock farming is the principal production system in the highlands of Ethiopia. It is a complex system that combines crop and livestock production within the same management unit. More than 50% of the country’s population is engaged in this practice to support their livelihoods. Livestock production plays a pivotal role in sustaining the integral links required by mixed farming and in contributing to food security of the rural poor households. The links include provision of draught power for crop cultivation and manure for
replenishing soil fertility in return to utilization of crop residues as animal feed. Besides, livestock play a complementary role to earn immediate cash for purchasing agricultural inputs. However, the productivity of livestock in the traditional mixed farming system is very low (Mukasa-Mugerwa et al., 1989). Apart from this, it is often blamed to impact negatively on environment (Steinfeld et al., 2006). Gumara watershed is no exception to all these outcomes. It rather gets worse in response to cultivating steep slopes coupled with excessive livestock population that accentuate the problem of land degradation. This problem is overwhelmingly associated with poor green water management practices across the watershed.

Water is a key limiting factor to livestock production in the upper Blue Nile basin primarily by influencing the seasonal availability of feed resources. Livestock production is considered to be a relatively water intensive enterprise (Molden et al., 2010) regardless of the production type. The concern on water resource becomes more important than ever before in face of the present climate change (Zhang et al., 2007) aggravating water shortage, and the increasing trend of livestock production intensifying the competitive use of scarcely available water (Molden et al., 2010). To this effect, the efficiency at which water is utilized in the prevailing rain fed mixed agriculture determines the overall livelihoods of the rural poor households (Namara et al., 2010). It is, thus, imperative to evaluate livestock productivity from perspective of water use efficiency to help comprehend strategies that are useful for increasing water productivity and the realm of its multiple uses.

Livestock water productivity (LWP) is a concept (Peden et al., 2009) that has recently received attention of the CGIAR centres and the National Agricultural Research Systems. LWP is generally determined as a ratio of total benefits obtained from livestock per unit of water depleted in the production. Its implication underlines the need to identify intervention options that can lead to increased livestock productivity with more effective use of water resource and with reduced impact on the environment. To estimate LWP at a household level, considering Life Cycle Assessment (LCA) within the boundary of cradle to farm gate, enables us to enfold the entire herd life in accounting for water. LCA is a tool that can be applied to compile inventory and evaluate agricultural production system for assessing its impact on natural resource management in a defined system boundary (Haas et al., 2001). It invokes the whole continuum from birth/growing period to end of the productive age of a
herd. The objectives of the present study in the upper Blue Nile basin of Ethiopia were (i) assess LWP from empirical evidences across different land-use mosaics of the mixed crop/livestock production systems in Gumara watershed, and (ii) highlight the possible intervention options for improving LWP pertinent to the contexts of the study area.

3.2 Materials and Methods

3.2.1 Study site

Gumara watershed was selected in the upper Blue Nile basin (Fig. 3.1) for undertaking the present study. The site is located in the north western part of Ethiopia having coordinates of 11°81'-11°85' N latitude, and 37°70'-38°02’ E longitude. Elevation of the watershed varied from 1780 m above sea level (asl) around the entry point of Gumara River into the Lake Tana to 3704 m asl towards the upper beginning source of the river at the base of Guna mountain. The surface area of the watershed is 1768 km² and produces a mean annual flow of 1229 m³ (Walle, 2008). The rainfall distribution follows a uni-modal pattern receiving it in June-September with average annual precipitation of 1492 mm in the uplands and 1378 mm in the ‘lowlands’ of the watershed (Fenta, 2009). The landscapes of the watershed encompass various topographic features ranging from rugged rolling mountain to vast flat lands, named as Fogera plain, towards Lake Tana that usually gets flooded during wet season. The soil type of the watershed is generally classified into five categories (Fenta, 2009) out of which the luvisols dominate the upland while the veritsols dominate the ‘lowland’.

3.2.2 Farming systems

The prevailing agricultural production system in Gumara watershed is subsistence based mixed crop-livestock farming. Human and livestock pressures are high relative to the resource base of the watershed and consequently out-migration takes place to other highland or lowland areas. There is an acute shortage of arable land that has led to expansion of production on marginal and fragile lands including steep slopes (Tamene and Vlek, 2008).
The crop types grown in the watershed area are quite diverse depending on the agro-ecological conditions. Given the various mosaics of the mixed crop-livestock farming complex to persist in the watershed, three distinct scenarios of mixed farming practice, on which the present study has focused, were identified and described as follows:

1) Rice/noug based mixed farming (RNF):- It occupies the vast plain area of Fogera adjacent to Lake Tana (Fig. 3.1). It covers approximately 20% of the watershed and situated at an altitude between 1780 m and 1850 m asl. It experiences flooding of the entire plain every year during the rainy season. It is warmer for most of the year having an average daily temperature of 18.6°C. Farmers often allocate much of their croplands for growing rice (*Oryza sativa*). Maize (*Zea mays*), noug (*Guizotia abyssinica*), tef (*Eragrostis tef*) and finger millet (*Eleusine coracana*) are also grown on fields that have less standing water in the rainy season. Farmers exercise double cropping to make use of the residual moisture by relaying chickpea (*Cicer arietinum*) and grass pea (*Lathyrus hirsutus*) after an early maturing landrace.
of tef known as ‘bunigne’. With the advent of stronger market links, more farmers are currently engaged in vegetable production (onion-Allium cepa, tomato-Lycopersicon esculentum and garlic-Allium sativum) during the dry season using irrigation from Gumara river giving the opportunity for some farmers to practice triple cropping. Cattle (Bos indicus) are the most preferred livestock species kept by every farm household. Farmers also keep equines particularly donkeys (Equus asinus) and mules for transport services. The major feed resources are crop residues and aftermath grazing. Higher livestock density is a major problem and feed shortage becomes critical during the rainy season due to flooding. Livestock health problem such as trypanosomiasis is a serious concern. The present low livestock performance is a manifestation of the complexity of the problems in livestock production of the study area.

2) Tef/finger millet based mixed farming (TMF):- This category represents the largest (about 60%) part of the watershed. The altitude ranges from 1851 m to 2,400 m asl. It has cool to moderately warm weather conditions. The area is typically characterized by rugged terrain and rolling mountains. Within short distance, there exists a wide ecological variability and hence more diverse crops are grown here by a household. Fragmented stone covers are typical features of the croplands. Tef and finger millet are grown as major crops. Wheat (Triticum durum), maize, sorghum (Sorghum bicolor), barley (Hordeum vulgare), faba bean (Vicia faba), field pea (Pisum sativum), linseed (Linum usitatissimum), noug and potato (Solanum tuberosum) are also grown based on the choice of farmers depending on the rotational need and crop preference. Alike the crop diversity, different livestock species viz. cattle, horses (Equus caballus), donkeys, mules, sheep (Ovis aries) and goats (Capra hircus), are kept by farm households in their order of importance. Equine are usually used as pack animal for transporting humans and agricultural produces across the prevailing rugged terrain. The major feed resource bases are crop residues, grazing lands and aftermath grazing. This farming system suffers from problems of severe soil erosion, land degradation, overutilization of communal grazing land, feed shortage, poor health care and low livestock performance.

3) Barley/potato based mixed farming (BPF):- It represents about 20% of the watershed area on an elevation between 2401 m and 3700 m asl. It is cool upland with mean daily minimum temperature of 2.8°C (Fenta, 2009). The terrain is rugged and characterized by undulating
chains of mountains. The major crops grown include barley and potato. Triticale has become a famous and major crop since its recent introduction by GTZ in the late 1990’s. Pulses such as faba bean and field pea are grown as rotational crops. Farmers traditionally relay barley after potato or early maturing barley variety locally named as ‘kinkina’ to utilize terminal moisture of the wet season. Farmers keep mixed livestock species such as sheep, cattle and equine. Unlike the other two farming complexes, the use of horses and mules for ploughing cropland is a common practice in this system. The major feed resource comes from grazing land crop residues are used to supplement animals during dry season. Fragmented stone cover on croplands is a common scene like that of TMF system. Poor soil fertility as a consequence of soil erosion, land degradation, declining land holding, feed shortage, fasciolosis (particularly in sheep) on wet bottomlands and low livestock performance are the major farm problems challenging the farming community.

3.2.3 Determination of LWP

LWP was assessed at a household level across different farming systems in the Gumara watershed covering 2-3 peasant associations (PAs) of 1000-1500 smallholder households per PA in each of the three farming systems, depending on their size. Again from each PA, 10 households were selected on a random basis. The sample farmers were then stratified into three wealth categories (resource-poor, -medium and -rich’ farmer) based on the perception of their peer colleagues in relation to the households’ relative income, herd size, land holding and annual crop harvest (Table 3.1). A total of 62 farmers were monitored between November 2006 and February 2008 to collect pertinent data on crop and livestock production using recruited enumerators. The determination of LWP followed the procedure as detailed out by Alemayehu et al. (2012) in the frame of LCA as bounded by cradle to farm gate (Beauchemin et al., 2010).
Table 3.1. Key features describing wealth categories of farm households in Gumara watershed area.

<table>
<thead>
<tr>
<th>Describing feature</th>
<th>Wealth category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor (23)†</td>
</tr>
<tr>
<td>Land holding (ha)</td>
<td>0.5</td>
</tr>
<tr>
<td>Herd size (TLU)</td>
<td>1.3</td>
</tr>
<tr>
<td>Total annual grain harvest (ton)</td>
<td>0.5</td>
</tr>
<tr>
<td>Annual additional income (USD)</td>
<td>150</td>
</tr>
</tbody>
</table>

†: Number in parenthesis indicates total number of households in the respective category; TLU: tropical livestock unit equivalent to 250 kg live weight; USD: US dollar.

3.2.4 Determination of water use

The major water requirement for livestock production is often related to produce animal feed (Peden et al., 2009). In all the three scenarios of the mixed farming systems, crop-residues are used as a key strategy for feeding livestock in dry season. To quantify the amount of crop-residue produced by each farm household, we estimated grain and crop-residue yields of the different crops grown by farmers using a 1x1 m² quadrat. For estimating the size of cropland allotted for each crop type, the area was measured using a tape.

To arrive at the total water account for livestock production during the whole productive herd life time, we estimated the total nutrient requirement of all animals in terms of metabolizable energy (ME) demand for maintenance (NRC, 2000; Nsahlai et al. 1997; NRC, 2007), growth/weight gain (NRC, 1985; Rosemary et al., 2002), lactation (NRC, 2001) and work (NRC 2007).

Knowing the energy content and quantity of crop residues produced by a household, we estimated the amount of pasture required to meet the nutrient demand of the livestock on an annual basis. To determine the volume of water used in producing each crop type and pasture, we used CROPWAT model (FAO, 1998) that employs the Penman-Monteith equation for estimating the reference evapo-transpiration (ETo) as described by Allen et al. (1998). The crop evapo-transpiration (ETc) was determined by multiplying ETo with the crop coefficients using specific data (meteorological data, cropping pattern and soil data) inputs required by CROPWAT8 computer program.
The water requirement \( (m^3 \text{ ha}^{-1}) \) of each crop and pasture was then calculated from the accumulated ETc in mm day\(^{-1}\) over the complete growing period. We partitioned the total ETc of cereal and pulse crops into the grain and crop-residue components based on their respective local market values (Singh, 2004). We estimated drinking water consumed by different livestock species and age class as described by FAO (1986) over the period of their productive life or until off take. Water required for cleaning barn, animals, utensils and others was not estimated in this study. We also did not estimate degraded water because of the complexity to quantify it.

### 3.2.5 Benefits from livestock

In mixed crop/livestock production systems, livestock are kept for their multi-functionality. To assess the multifaceted benefits obtained from livestock in accounting for LWP, we quantified the various livestock products and services rendered over the herd’s productive life time including their insurance value (C/F Bebe, 2003). The estimated benefits were finally converted to monetary values based on their respective market prices to combine them all together.

**Livestock outputs**

Livestock outputs in terms of milk production and live animal off take were assessed over the entire life time of a herd or flock. Milk production of a cow was estimated from lactation yield and the total number of parities. Lactation yield of a cow was determined from the present monitoring study. The estimate for total number of calving during the productive life time of cows was taken from literature reports on local cattle breeds (Mukasa-Mugerwa et al., 1989). It was assumed that each offspring, not required for herd replacement, was raised at the farm until off take time usually at an age between 2-4 years for sale or slaughter. Similarly for small ruminants, total number of parity over life time was taken from other reports (FAO, 1991) and lamb or kid raising takes place until 1 year of average off take age.

**Draught use**

Work performance of draught animals for tillage, threshing and pack transport has been monitored by recording the number of working hour in a day and total work days in a year. The cumulative services were estimated over the productive life span. It was converted into
USD monetary value by multiplying the number of work days with the local rate for hiring a pair of oxen or equine on daily basis. The same procedure was followed for equine service as pack.

**Manure and urine**

In valuation of manure, its nutrient content under smallholder farm management conditions was averaged to be 16.1, 3.6 and 16.8 g kg\(^{-1}\) DM for N, P and K, respectively (Lupwayi et al., 2000). Urine contains 0.9% N and 0.5% K on a wet basis while P content is reported as trace level (FAO, 1992). We estimated the output of urine over the herd life or until off take using a daily average rate of 31 ml kg\(^{-1}\) body weight (FAO, 1992). Manure output was estimated at a rate of 3.3 kg for cattle and 2.4 kg for small ruminant and equine per day per TLU (C/F Haileselassie et al., 2009). We considered the nutrient price of inorganic fertilizer (Mekonnen et al., 2011) for estimating monetary value of manure and urine to serve as soil amelioration input.

### 3.2.6 Statistical analysis

General Linear Model of SAS (2002) was employed to analyze the data. For testing effects of the independent factors on response variables, the statistical model used in the analysis was

\[
Y_{ijk} = \mu + F_i + W_j + (F*W)_{ij} + E_{ijk}
\]

where; \(Y_{ijk}\) = response variable such as LWP, water use; \(\mu\) = the overall mean, \(F_i\)=\(i^{th}\) farming system, \(W_j\)=\(j^{th}\) wealth status of smallholder farmers, \((F*W)_{ij}\)=interaction between farming system and wealth status, and \(E_{ijk}\)= error term.

The interaction effect in the model was not found significant (p>0.05) in all the cases and hence was left out. A group t-test procedure was run to compare means of LWP between early off-take (at 2 years of age) and late off-take (at 4 years of age) in SAS (2002). A separate analysis was also carried out to test the effect of livestock species on dry matter and metabolizable energy intakes, and LWP.
3.3 Results

3.3.1 Livestock performance

Small ruminants had a lower (p<0.01) daily dry matter intake per kg of metabolic body weight than both cattle and equine (Table 3.2). Hence, the ME used per kg of metabolic body weight in a day was significantly lower (p<0.001) in small ruminants than in cattle reflecting its lower metabolic rate. The proportion of cattle in the total TLU kept by a household tended to inversely relate with altitude as this being manifested by a higher number of cattle in RNF than in BPF system (Table 3.3). Of all the livestock outputs, larger returns (USD TLU⁻¹ year⁻¹) were obtained from manure use as fertilizer and sale of live animals. The return from draught power use was also considerable, making about 14% of the total livestock values. The benefit from milk production in monetary terms seemed to be the lowest although its contribution in improving the nutritional diet of the poor rural family mainly of the children is invaluable. Nonetheless, mortality incidence was found to reduce the total return from livestock production by up to 30% on average in a year (Table 3.3).

Table 3.2. Live weight and daily feed consumption of livestock species kept by smallholder farmers in Gumara watershed.

<table>
<thead>
<tr>
<th>Livestock type</th>
<th>Live body weight±se (kg)</th>
<th>Intake DM±se (g kg⁻⁰.⁷⁵ lwt )</th>
<th>Intake ME±se (KJ kg⁻⁰.⁷⁵ lwt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>195.7±2.1</td>
<td>82.8±1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>637.5±7.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Small ruminant</td>
<td>20.3±2.4</td>
<td>71.5±1.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>550.9±8.8&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Equine</td>
<td>152.7±2.5</td>
<td>92.3±1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>711.0±9.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>F-test</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

DM: Dry matter of the feed; ME: metabolizable energy of the feed; lwt: live weight of animal; se: standard error; **: significant at 1%; means with different superscript letters in a column are significantly different at the indicated significance level.
Table 3.3. Livestock holding and values of livestock outputs at a household level in three mixed farming systems.

<table>
<thead>
<tr>
<th>Farming system</th>
<th>Livestock holding (TLU)</th>
<th>Livestock value (USD TLU⁻¹·year⁻¹)</th>
<th>Mortality loss (USD year⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SC</td>
<td>Sale, Milk, DP, Manure, Total</td>
<td></td>
</tr>
<tr>
<td>BPF</td>
<td>5.9 (61)††</td>
<td>21.6†, 60.7*, 18.2, 21.6*, 59.9</td>
<td>182.0†</td>
</tr>
<tr>
<td>TFF</td>
<td>6.6 (76)</td>
<td>21.7*, 59.9*, 16.4, 27.6*, 59.9</td>
<td>185.5†</td>
</tr>
<tr>
<td>RNF</td>
<td>5.6 (95)</td>
<td>18.1b, 32.3b, 13.9, 25.5ab, 62.6</td>
<td>152.4b</td>
</tr>
<tr>
<td>Average</td>
<td>6.0</td>
<td>20.5, 51.0, 16.2, 24.9, 60.8</td>
<td>173.3</td>
</tr>
<tr>
<td>F-test</td>
<td>**</td>
<td>** ns * ns * ns</td>
<td></td>
</tr>
</tbody>
</table>

††: number in parenthesis represents percent share of cattle in TLU; TLU: tropical livestock unit equivalent to 250 kg live weight; USD: US dollar; SC: stock capital of the breeding herd/flock, sale: income from sale of live animal; **: significant at 1%; *: significant at 5%; ns: not significant; means with different superscript letters in a column are significantly different at the indicated significance level.

3.3.2 Water productivity

In Gumara watershed, smallholder farmers cultivated diverse crops owing to heterogeneity in farm conditions and spreading the risk of crop failure. Combining the benefits of these crops together in monetary terms, RNF showed a higher CWP (p<0.01) with a value of 0.46 USD m⁻³ of water than both BPF and TMF (Table 3.4). In contrary, LWP was rather found significantly lower (p< 0.01) in RNF (0.057 USD m⁻³) than in TMF (0.066 USD m⁻³) or in BPF (0.066 USD m⁻³). This showed that water requirement per kg live weight of animal increased towards lower altitude area implying more water loss in RNF. As a result, 20% additional water input was required to sustain a kg live weight of cattle in RNF as compared to BPF in the upland. CWP was evidently superior to LWP across the mixed farming systems of Gumara watershed. However, integration of the two enterprises led to a better water productivity of the rain fed system than either in separate. Wealth status of a household appeared to affect both crop and livestock water productivities (Table 3.5). Only ‘rich’ farmers were able to attain both higher CWP and LWP.
Table 3.4. Least squares means of crop water productivity, LWP and water used to sustain a kg live weight of livestock over the entire herd life time under three different mixed farming systems.

<table>
<thead>
<tr>
<th>Farming system</th>
<th>N</th>
<th>CWP± se (USD m$^{-3}$)</th>
<th>LWP± se (USD m$^{-3}$)</th>
<th>Water use±se (m$^3$ kg$^{-1}$ lwt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPF</td>
<td>23</td>
<td>0.33±0.01$^c$</td>
<td>0.066±0.002$^a$</td>
<td>42.4±1.9$^a$</td>
</tr>
<tr>
<td>TMF</td>
<td>27</td>
<td>0.38±0.01$^b$</td>
<td>0.066±0.002$^a$</td>
<td>42.7±1.7$^a$</td>
</tr>
<tr>
<td>RNF</td>
<td>12</td>
<td>0.46±0.01$^a$</td>
<td>0.057±0.003$^b$</td>
<td>50.6±2.5$^b$</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.39±0.01$^a$</td>
<td>0.063±0.003$^b$</td>
<td>45.2±2.0</td>
</tr>
</tbody>
</table>

F-test

N: number of sample households; CWP: economic crop water productivity; LWP: livestock water productivity; USD: US dollar; lwt: live weight of animal; se: standard error; **: significant at 1%; *: significant at 5%; ns: not significant; means with different superscript letters in a column are significantly different at the indicated significance level.

Table 3.5. Least squares means of CWP, LWP and water use per kg live weight over the entire life of a herd by wealth status of smallholder farmers in Gumara watershed.

<table>
<thead>
<tr>
<th>Farmers’ resource endowment</th>
<th>N</th>
<th>CWP$^2$± se (USD m$^{-3}$)</th>
<th>LWP± se (USD m$^{-3}$)</th>
<th>Water use (m$^3$ kg$^{-1}$ lwt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>23</td>
<td>0.37±0.01$^b$</td>
<td>0.060±0.003$^b$</td>
<td>46.8±2.1$^{ab}$</td>
</tr>
<tr>
<td>Medium</td>
<td>23</td>
<td>0.38±0.01$^b$</td>
<td>0.058±0.002$^b$</td>
<td>48.0±1.9$^{b}$</td>
</tr>
<tr>
<td>Rich</td>
<td>16</td>
<td>0.43±0.01$^a$</td>
<td>0.072±0.003$^a$</td>
<td>40.9±2.2$^{a}$</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.39±0.010</td>
<td>0.063±0.0030</td>
<td>45.2±2.10</td>
</tr>
</tbody>
</table>

F-test

N: number of sample households; CWP: economic crop water productivity; LWP: livestock water productivity; USD: US dollar; lwt: live weight of animal; se: standard error; **: significant at 1%; *: significant at 5%; means with different superscript letters in a column are significantly different at the indicated significance level.

A cattle herd management that pursued early off-take practice increased LWP by 28% over that of late off-take practice (Table 3.6). The amount of water used per kg live weight of animal over its entire life time was much lower (reduced by more than 50%) in early off-take scenario than in late off-take. Contrasting the income from sale of animals per TLU, early off-take gave a higher return than late off-take.
Table 3.6. Means of LWP, income from sale of live animal and water use to sustain a kg live weight of cattle over the entire herd life time under two off-take managements.

<table>
<thead>
<tr>
<th>Off-take type</th>
<th>N</th>
<th>LWP± se (USD m⁻³)</th>
<th>Sale income± se (USD TLU⁻¹)</th>
<th>Water use± se (m³ kg⁻¹ lwt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>62</td>
<td>0.09±0.0030</td>
<td>272.2±2.3</td>
<td>13.2±0.6</td>
</tr>
<tr>
<td>Late</td>
<td>62</td>
<td>0.068±0.001</td>
<td>265.3±1.2</td>
<td>29.6±1.0</td>
</tr>
<tr>
<td>Mean</td>
<td>62</td>
<td>0.079±0.002</td>
<td>268.7±1.7</td>
<td>21.4±0.8</td>
</tr>
<tr>
<td>t-test</td>
<td>***</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

N: number of sample households; LWP: livestock water productivity; USD: US dollar; lwt: live weight of animal; se: standard error; **: significant at 1%.

3.4 Discussion

3.4.1 LWP and its methodology

Water productivity is a crucial instrument to gauge the extent of water used for agricultural production and to work towards its efficient use because water has become a very scarce resource over time in the respective farming systems (Molden et al. 2010). The growth of future food production is increasingly constrained by water unless the efficiency of its use is dramatically increased in all respects (Wallace, 2000). Regarding its application to livestock production, building on the concept of LWP as first developed by Peden et al. (2009) serves the purpose to clearly understand the interaction between livestock and water including its implication to the production environment (e.g. degraded water). Estimating LWP is a complex exercise as it requires data on life time performance of a herd and conversion of all livestock utilities to monetary values using contemporary price index. Hence, caution must be taken when comparing LWP values across regions or countries because of variability in production targets (e.g. milk, meat, dual purpose, or multiple functions in mixed crop/livestock farming system) and in market prices of livestock outputs and services.

In the methodology of quantifying the amount of water used for feed production, it is necessary to estimate the feed requirement by different livestock species and age class as well as sources of feed in a given production system. Because it covers more than 95% of the water portion required in livestock production (Peden et al., 2009), a proper estimation of the feed requirement/consumed by livestock is very important in order to arrive at a reliable
value of LWP. In the present study, the feed requirement of a given animal was assessed based on its nutritional needs of maintenance requirement under the specified production scenario, growth or weight gain, reproduction, lactation and work service being all these sorted out with a stage in the life cycle and sex of the animal. In Ethiopia, smallholder farmers do not keep performance records for their animals. This creates limitation of data on the performance of a herd over its life time and hence it necessitates relying partly on secondary data to assess LWP in this study.

In Gumara watershed, LWP ranged from 0.03 to 0.1 USD m\(^{-3}\) across spatial horizons. These figures appear to be lower as compared to that of CWP (0.2-0.6 USD m\(^{-3}\)) obtained from the same domain. The implication is that the intrinsic feature of livestock production makes the enterprise to be more water intensive. The reasons for this are complex and context specific. However, the necessity for an animal to first pass through a long growing period in its life cycle (retarded growth at early age due to poor management in the present study area) to reach at productive age is worth mentioning as one of the main reasons for the lower LWP. Contrary to CWP, LWP was lower in RNF than in BPF or TMF. The reason could be associated with ET and livestock management. RNF area has warmer climate and hence the ET required for both pasture and crop productions was higher than in the cool uplands of the study area.

In agreement with our results, Haileselassie et al. (2011) reported LWP estimates of 0.03-0.12 USD m\(^{-3}\) for Indo-Ganga basin and Breugel et al. (2010) calculated 0.01-0.13 USD m\(^{-3}\) for different farming systems in the Nile Basin. Similarly, Mekonnen et al. (2011) and Descheemaeker et al. (2011) also showed comparable values of LWP for water stressed environments of northern Ethiopia with a narrower range between 0.07 and 0.09 USD m\(^{-3}\). However, the reports by Gebreselassie et al. (2009) and Haileselassie et al. (2009) found much higher estimates of LWP ranging between 0.25-0.39 USD m\(^{-3}\). This divergence might have arisen from methodological differences where LCA approach was applied in the present study and it might also be from using intensively managed crossbred dairy cows at experimental station in the former report. The likelihood for improving LWP in Gumara watershed is presumed to be higher provided that appropriate interventions are employed. In supporting this view, Molden et al. (2010) indicated that areas where poverty is high and
water productivity is low are among the priority areas where substantive increase in water productivity is possible.

3.4.2 Livestock outputs and services

Manure application for sustaining soil fertility is featured as a key ecosystem component in nutrient cycling models of agricultural systems (Murwira et al. 1995). Currently, the Ethiopian government has paid more attention than ever before to extend the use of compost (from manure and biomass) by smallholder farmers. In the present study, it has been observed that manure and draught power, in serving as crop inputs; make the largest share of the total values obtained from livestock component. The higher value of draught power in TMF might be associated with the need for intensive tillage to make a fine seedbed for small seeded cereals like tef. It can, thus, be noted that the overriding reason to keep livestock as an integral part of the mixed farming system is to meet the necessary inputs required for crop production. This puts a challenge on the intention to improve livestock outputs per animal while farmers would like to keep more animals to support crop production (for ploughing, compacting, threshing) although the available feed resource is limited.

In the tropics, livestock productivity is highly reduced by poor husbandry practices coupled with animal health problems. In this study, we monitored an incidence of mortality at a rate of 10% in equine, 14% in cattle and 20% in small ruminants, affecting mainly young stock. Consequently, its cumulative effect on reducing the benefits (in monetary value) from a herd reached as high as 35% in the present study. Agreeing with these results are those of Gizaw et al. (2010), who reported mortalities among sheep of 17-26% under traditional management practices of smallholder farmers in Ethiopia. So, interventions that target at improving livestock health would considerably contribute to increasing productivity of livestock and water. Feed utilization efficiency of livestock seems to correlate with LWP. Cattle had more LWP than equine (Table 3.7) since they provide more valuable products than equine in addition to their better digestion efficiency (Udén and Van Soest 1982) when utilizing low-quality feedstuffs of the type commonly available in the study area.
Table 3.7. LWP and water use to sustain a kg live weight of different livestock species over their life time (Least squares means).

<table>
<thead>
<tr>
<th>Livestock species</th>
<th>N</th>
<th>LWP±se (USD m⁻³)</th>
<th>Water use±se (m³ kg⁻¹ lwt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>62</td>
<td>0.077±0.002ᵃ</td>
<td>37.6±5.0ᵇ</td>
</tr>
<tr>
<td>Small ruminant</td>
<td>50</td>
<td>0.053±0.002ᵇ</td>
<td>37.9±5.7ᵇ</td>
</tr>
<tr>
<td>Equine</td>
<td>44</td>
<td>0.037±0.002ᶜ</td>
<td>143.2±5.9ᵃ</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.057±0.002</td>
<td>67.4±</td>
</tr>
<tr>
<td>F-test</td>
<td></td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

N: number of herds/flocks; LWP: livestock water productivity; USD: US dollar; lwt: live weight of animal; se: standard error; **: significant at 1%; means with different superscript letters in a column are significantly different at the indicated significance level.

3.4.3 Livestock off-take

Off take time of livestock posed significant influence on LWP. Prolonging the off take time of those animals not required for replacement to about 4 years of age or above would unnecessarily add the cost of their maintenance resulting in lower LWP. Nowadays in Ethiopia, consumers are more concerned about the quality of meat and hence, livestock traders prefer buying younger animals from producers so as to sell them at a better price. Negassa and Jabar (2008) illustrated the need for incentivizing smallholder farmers to induce the supply of young animals to market and this in turn contributes to alleviation of overstocking problem in the highlands of Ethiopia.

3.5 Conclusions

LWP was generally found lower in Gumara watershed although it showed spatial and household variation. But the prospect for improving LWP is likely to be enormous in light of the present growing aspiration pursued by the Ethiopian government to fuel agricultural development in the country for instance through keeping only the productive animals, improving health care to reduce mortality and morbidity, increasing pasture productivity, improving the utilization of other feed sources and linking the production goal to market orientation. The interventions targeted at early off-take management proved to substantially increase LWP and this would contribute to ease the imbalance between the existing high livestock population and the deteriorating carrying capacity of natural pasture.
Acknowledgement

The authors would like to thank the CGIAR Challenge Program on Water and Food (CPWF) for financially supporting this study. We extend our gratitude to the International Livestock Research Institute (ILRI) and the Ethiopian Institute of Agricultural Research (EIAR) for their full support to the execution of the field work. Finally, our gratitude goes to the farmers in the study area for their participation and resource commitment.

References


Chapter 4

Collective Management on Communal Grazing Lands: Its Impact on Vegetation Attributes and Soil Erosion in the Upper Blue Nile Basin, North-western Ethiopia

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Abstract

Collective action, on communal grazing land, has evolved in the highlands of north-western Ethiopia to mitigate the problems of feed shortage and land degradation due to overgrazing. The exercise is liked by farmers for improving the availability of natural pasture during the long dry season when other feed sources get depleted. However, large portions of the communal grazing lands are still managed under free grazing throughout the year. This study was undertaken in Maynet village in the upper Blue Nile basin, north-western Ethiopia, to assess the impacts of three different types of grazing land management (GLM) and two slope gradients (<10%; 15-25%) on aboveground herbaceous biomass yield, ground cover, species richness, runoff, soil loss and soil bulk density of grazing lands. The GLMs include a) freely open communal GLM, b) restricted communal GLM - collective management of communal grazing land locally named as ‘yebere sar’ and c) private holding GLM. Stocking density was more than carrying capacity of grazing lands across all GLMs. However, the extent of overstocking problem was exceptionally severe in freely open communal GLM. The interaction between GLM and slope was significant (P<0.05) for runoff, soil loss and runoff coefficient. The average runoff coefficient was close to 50% in freely open communal GLM on steeper slopes (15-25%). Freely open communal GLM on steeper slopes resulted in consistently highest cumulative runoff and soil loss amounting to 491mm and 32t/ha per year, respectively. Polynomial regression analysis showed that quadratic relationship (r² = 0.87) existed between soil loss and runoff. But, soil loss was close to nil when runoff did not exceed 2mm per rainfall event. As expected, restricted communal GLM appeared to reduce surface runoff by more than 40% and curb the rate of soil erosion by more than 50% compared to freely open communal GLM. Its vegetation cover persisted above 70% throughout the year, meeting the threshold level recommended to keep surface runoff and soil loss to minimum. Reducing the problem of overstocking and pasture resting in August-November are important components to improve ground cover and aboveground herbaceous biomass yield, which in turn reduce land degradation on grazing lands.

Key words: grazing land management; overstocking; ground cover; resting pasture; land degradation
4.1 Introduction

Throughout the world today, natural resource depletion is among the major problems facing human beings (WWF, 2010; UNEP, 2011). However, there are great differences in the abilities of countries to cope with the problem of sustained use of natural resources (Hurni, 1997). Of all the regions in the world, sub-Saharan Africa (SSA) that embraces least developing countries suffers most from accelerated soil erosion (Lal, 1990; Fleitmann et al., 2007). In Ethiopia, land degradation is a core problem threatening sustainability of the traditional agricultural system (Zeleke and Hurni, 2001; Hagos et al., 2002; Nyssen et al., 2009) on which more than 80% of the population relies for its livelihood (EPCC, 2008). Its negative impact has contributed to the country’s overarching problem of protracted impoverishment and increasing social stress (Hurni, 1993; Demelash and Stahr, 2010). In assessing the cost of land degradation in Ethiopia, the annual loss due to erosion and soil nutrient reaches 80 million USD which amounts to 3% of the agricultural gross domestic product (Bojô and Cassells, 1995).

In Ethiopia, agricultural land degradation is associated with the unsustainable exploitation of the land resource (Nyssen et al., 2004; Bewket and Teferi, 2009) and is believed to arise partly from the existing land tenure system (Gebremedhin et al., 2002; Tenaw et al., 2009). The land tenure system of Ethiopia assigns the entire land ownership to the government while the people have a use-right of various forms (Ahmed et al., 2002). It recognizes communal ownership of grazing lands respecting customary use right (but no functional policy towards its sustainable utilization) that are mostly subjected to free grazing management. Despite the challenge of ecological degradation persisting in the country, farmers’ engagement in successful land conservation practice is limited (Shiferaw and Holden, 1999; Demelash and Stahr, 2010), with the exception of Konso area in southern Ethiopia where contour terracing (stone terracing) is practiced on hill slopes (Beshah, 2003). In northern Ethiopia, community based soil and water conservation measures have also been implemented since late 1980’s and its impact evaluation demonstrated encouraging results (Descheemaeker et al., 2006; Nyssen et al., 2009). Nonetheless, the ever increasing rural population continues to negatively change the land use system (such as cultivation on steep slopes, clearing of vegetation and overgrazing) in most part of the country, provoking accelerated soil erosion (Hurni et al., 2005; Shiferaw, 2011). The expansion of crop cultivation has pushed livestock grazing to
patches of marginal and steep sloping common holds (Mwendera et al., 1997; Tamene and Vlek, 2008). Yet, livestock numbers continued to increase despite the dwindling of pastureland (Mengistu, 2006). This situation has inevitably turned most pasturelands into degraded land due to overgrazing (Tadesse et al., 2002).

Grazing impacts vary naturally in space and over time due to the normal variability of climate, vegetation, intensity and duration of livestock presence (Mwendera, 1996). Trends of the impacts are partly influenced by farmers’ management decisions and partly by natural variations in landforms (Mwendera and Mohamed Saleem, 1997). The key to sustainability of grazing lands is thus managing vegetative cover, not only to provide feed for grazing livestock but also to hold soil in place, to filter water, and to recycle nutrients (Mwendera et al. 1997). In some villages of the upper Blue Nile basin, there is an innovative local experience of collective management on common hold natural pastureland that attempts to solve the problems of feed shortage in the dry season and grazing land degradation. On selected communal pasturelands- locally named ‘yebere sar’, farmers put restricted grazing management in place using judicious by-laws developed by the community itself. However, large portions of the communal grazing lands are still in open/unrestricted grazing system. Literature on the concepts, socio-economic contexts, institutional and governance perspectives of collective action including its effectiveness in common hold resource managements have been well developed (Agrawal, 2001; Gebremedhín et al., 2004; McCarthy et al., 2004; Poteete and Ostrom, 2004; Benin and Pender, 2006). The present study intended to explore the impact of collective management on biophysical attributes of communal grazing lands. The specific objectives were a) to assess above ground herbaceous biomass yield and ground cover of these pastures, b) to quantify the amount of runoff and soil loss in response to different grazing managements, and c) to learn lessons from local experiences of collective management having significance to policy implication.
4.2 Materials and methods

4.2.1 Description of study area

The study was carried out at Maynet village, from December 2006 to November 2007, in Farta district representing a typical upland ecology of the Blue Nile basin, north-western Ethiopia. The study site is located with coordinates of 11°44' N latitude and 38°06' E longitude. It is situated at an elevation of 2800 meters above sea level. The rainfall distribution follows a uni-modal pattern; rains fall in June-September (Fig. 4.1) and the average total annual precipitation is 1532mm.

![Figure 4.1. Monthly rainfall and mean (minimum and maximum) daily temperature of the study area in year 2007.](image)

Precipitation peaks in July and August when more than half of the total annual rainfall is received. The coefficient of variation for rainfall in the study area indicates rainfall variability is lower in the wet season than in the dry season (Zewdie, 2010). The mean annual potential evapotranspiration is 1217mm (Zewdie, 2010). It is cool upland with the mean annual minimum and maximum daily temperature of 9.6°C and 22.7°C, respectively. The terrain is rugged and characterized by undulating chains of mountains. The dominant soil type is Luvisol (Fenta, 2009) and the major crops are barley (*Hordeum vulgare*) and potato (*Solanum tuberosum*). Pulses such as faba bean (*Vicia faba*) and field pea (*Pisum sativum*) are grown as rotational crops. Different livestock species namely, cattle (*Bos indicus*), sheep (*Ovis aries*),
goats (*Capra hircus*), horses (*Equus caballus*), donkeys (*Equus asinus*) and mules are kept by the farming community. Sheep are the dominant livestock species in the study area. The use of horses and mules for ploughing cropland is a common practice in the area to cope with oxen shortage. Human and livestock pressures are high relative to the available resource base of the study area and consequently out-migration takes place to other places (ATWLZ, 2007). In Farta district, the average landholding of a household is 0.9 ha (Demeke, 2003). There is an acute shortage of arable land that has led to the expansion of crop production on marginal and fragile lands including steep slopes (Tamene and Vlek, 2008).

Three distinct types of grazing land management (GLM) exist in the study area. These GLMs are: i) freely open communal GLM, ii) restricted communal GLM, and iii) private holding GLM. Freely open communal grazing land is unrestrictedly open for every farmer to use it with all kinds of his animals. Selective grazers like sheep and equine freely graze on open communal grazing land without any restriction (Table 4.1). But, restricted communal grazing land is permitted for oxen and new born calves until weaning age. Lactating cows are also allowed to graze for only one month during their first postpartum periods. Only two mature oxen or horses/mules from each member household are eligible for grazing. Restricted communal grazing practice covers around 275 km² in eastern side of Farta district and has stayed for long time, perhaps more than a century. Restricted communal grazing land is located either adjacent to freely open communal grazing land or enclosed by cropland and river bank. Each of restricted communal grazing lands has identified members to have use-right and this being recognized by local governance. The management and utilization of such grazing land is governed by local by-laws established by the members themselves. It is often rested in August – November and in May – June while freely open communal grazing land is always put under continuous grazing pressure (Table 4.1). Guarding of restricted communal grazing land is performed either by members in rotation or by hiring a guard. Private holding grazing land is a pastureland kept by a household for private use mainly to make hay. It is normally located near homestead compound, and is rested in the wet season between July and October.
Table 4.1. Grazing duration, resting pastureland and dominant grazer species across different types of grazing land management (GLM).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Restricted communal</th>
<th>Freely open communal</th>
<th>Private holding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazing duration (days/month)</td>
<td>12</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Daily grazing time (hour)</td>
<td>2</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Resting season</td>
<td>August –November; May – June</td>
<td>No resting</td>
<td>July–October</td>
</tr>
<tr>
<td>Dominant grazer species</td>
<td>Oxen</td>
<td>Sheep and equine</td>
<td>cattle</td>
</tr>
</tbody>
</table>

4.2.2 Study design

We considered three types of GLM (freely open communal GLM, restricted communal GLM, and private holding GLM) and two slope gradients (<10% and 15-25%) in order to assess their effects on vegetation attributes and water erosion. The two slope gradients were chosen because they are commonly found across all the three GLMs. The sites have been randomly selected from many villages in the surroundings having similar landscapes and ecological settings.

4.2.3 Livestock density and carrying capacity

Animal sizes vary and forage requirements change with the size of the animal. Tropical Livestock Unit (TLU) is commonly taken as a standard equivalence of an animal with 250 kg live-weight (Jahnke, 1982). Stocking density of each grazing land was estimated as the number of animals grazing on specific pasture land at a particular point in time (expressed as TLU/ha). Carrying capacity is the maximum stocking rate possible which is consistent with maintaining or improving vegetation or related resources (McLeod, 1997). Carrying capacity of grazing land (expressed as TLU/ha) was estimated as described by De Leeuw and Tothil (1990). In estimating carrying capacity, use factor of the pasture was taken to be 50% (Werner and Urness, 1998). Given the mixed crop-livestock production system of the study area, crop-residue and aftermath grazing was estimated to cover 40% of the annual feed requirements (Keftasa, 1987) of the available livestock. The total annual herbaceous biomass
removed by livestock was estimated to reflect grazing intensity in different GLMs. This estimate was made using daily grazing hour spent on each type of grazing land and daily dry matter intake of animals taken as 2.5-3% of their live weights (De Leeuw and Tothill, 1990). Daily grazing hour of livestock in the Ethiopian highlands is estimated at 8 hours on average to obtain the maximum voluntary daily intake (Smith, 1997).

4.2.4 Ground cover, aboveground herbaceous biomass yield and species richness

Ground cover, aboveground herbaceous biomass yield and species richness were determined along three parallel 50m transects (25m transects on private holding pastureland due to its smaller size). These measurements and samples were taken every 5m along each transect. We considered transects as replicates. Aboveground herbaceous biomass yield was determined by clipping at ground level using a 50x50 cm$^2$ quadrat. Since freely open communal grazing land is always subjected to heavy grazing pressure it seemed unlikely to obtain harvestable herbage biomass at any time. To estimate aboveground herbaceous biomass yield from freely open communal grazing lands, additional plots were fenced along the transect line (from August to October 2007) at same time when the other two GLMs undertook resting pasture. A composite vegetation sample (500g on fresh-weight basis) was kept from each transect and dried in an oven at 65°C for 72 hours to determine its dry matter content. Ground cover is the percent of ground surface covered by vegetation (Elzinga et al., 1998). We estimated ground cover from each 5m along the transect using a plot estimate technique (20x50 cm$^2$ quadrat), and a ground cover ranking class or scale (Daubenmire, 1958). Ground cover data were taken twice, one after end of the wet season in October and one in late dry season in May. Species richness is defined as the number of species per site (Hoare, 2009). To determine species richness, all vascular species were counted from 5 plots on private holding and 10 plots on other pastureland types along each transect using a 100x100 cm$^2$ quadrat.

4.2.5 Runoff and soil loss

To measure runoff and soil loss, a net 4 x 2 m$^2$ plot was demarcated on each type of grazing land, and slope using galvanized iron sheet (50 cm wide of which 20 cm were inserted into the ground to prevent lateral flow of runoff) with a gutter at the lower end of each plot. A total of 18 plots were used to measure runoff and soil loss using three plots as replicates on
each of GLMs and slope gradients. A 200 litre capacity barrel was fixed in a ditch with its open top at ground level to collect the runoff coming from the whole surface of a plot as directed by the gutter. This barrel size was chosen to collect the whole runoff from the experimental plot and to overcome overflowing incidence. When heavy rain fell, runoff and sediment measurements were taken soon after the event to avoid overflowing. A standard non-automated rain gauge (graduated cylinder with a funnel attached to it) was installed at the study site of central place to record the daily rainfall at 8:00 O’clock in the morning. Runoff and sediment measurements were taken following each rainfall event that produced runoff on the plot. These measurements were taken the next day at 8:00 AM and made way clear for the following day. The runoff was determined using a dipstick where five readings were taken at a time from each barrel. The volume of runoff was later estimated from a regression equation ($R^2=0.98$) developed using separate 34 data points. Runoff coefficient was computed as the ratio of runoff and the corresponding rainfall both expressed as depth (Critchley and Siegert, 1991). To determine the sediments, a 1000 ml sample was taken from each barrel at each runoff event after thorough mixing to bring all the sediments into suspension. In a laboratory, a total of 828 samples were filtered through Whatman® filter paper of known weight that retained particles greater than 1.2 µm. At Holetta Agricultural Research Center, the filtered materials were dried in an oven at $105^0$C for 24 hours and weighed to determine soil dry weight. All plots were accessible to livestock grazing early in the wet season until the usual closure time in the mid rainy season.

4.2.6 Bulk density and soil moisture

Soil samples were taken using Kopecky’s rings (100 cm$^3$) of core samplers at 0-5cm soil depth to determine moisture content and bulk density. The samples were taken to the soil laboratory at Holetta Agricultural Research Center where they were oven dried at $105^0$C for 24 hours. The bulk density was determined from the equation (Kubik and Nozdrovicky, 2005):
$\rho_b = \frac{m}{v}$

Where: $\rho_b$ - bulk density of soil, m- mass of the dried soil sample from Kopecky’s ring determined by weighing, v- volume of the soil sample given by the geometrical dimensions of the Kopecky’s ring.

4.2.7 Statistical analysis

Prior to parametric data analysis, a normality test was run using PROC CAPABILITY procedures of SAS (SAS, 2002). The data on aboveground herbaceous biomass yield, runoff, soil moisture and bulk density were log transformed to ensure the assumptions of Gaussian distribution. Arc sine transformation was carried out on ground cover and runoff coefficient data to fit to normality assumptions. Lacking to pass normality test after log transformation, a nonparametric analysis was undertaken on soil loss data using aligned rank transform method (Higgins and Tashtoush, 1994) in ARTool software (Wobbrock et al., 2011). Sediment concentration was analyzed without being transformed after passing Kolmogorov-Smirnov test. A square root transformation was undertaken for species richness count data that follows a Poisson distribution. A 3x2 factorial design was used to analyze each data set and to see the interaction effect. The factors included three levels of GLM (freely open communal, restricted communal, private holding) and two levels of slope (<10%, 15-25%). The data on stocking density and carrying capacity was not analyzed due to lack of replications. In post hoc test, multiple comparisons of means were made using Tukey’s HSD method. Correlation analysis was run to see the strength of relationship between ground cover and hydrological responses. A quadratic relationship was established between runoff and soil loss using polynomial regression.

4.3 Results

4.3.1 Livestock density and carrying capacity

Stocking density of grazing lands ranged between 11 and 25 TLU/ha in the study area (Fig. 4.2). Stocking density of freely open communal grazing land seemed to be more than double
of restricted communal or private holding grazing lands. In contrary, carrying capacity of freely open communal grazing land was less by half than that of restricted communal and private holding grazing lands (Fig. 4.2). Annually, total biomass removed by livestock was estimated to be 1.6 t DM/ha in restricted communal, 2.1 t DM/ha in freely open communal and 2.3 t DM/ha in private holding GLMs (Fig. 4.2). The proportion of biomass removed from the total production amounted 46% in restricted communal, 58% in private holding and 80% in freely open communal GLMs.

![Figure 4.2. Stocking density, carrying capacity and amount of biomass removed by livestock in each type of grazing land management (GLM).](image)

### 4.3.2 Vegetation attributes

Vegetation attributes of grazing lands (namely ground cover, aboveground herbaceous biomass yield and species richness) across GLMs and slopes are given in Table 4.2. The interaction effect between GLM and slope was not significant for all vegetation attributes (P > 0.05). GLM had a significant (P < 0.05) impact on aboveground herbaceous biomass yield, species richness and ground cover. Although the interaction was not significant, aboveground herbaceous biomass yield seemed to be higher in private holding and restricted communal GLM on gentle slopes (<10%). Freely open communal grazing land had barely harvestable biomass at any given time of the year because of continuous grazing pressure posed on it. However, resting the ever freely grazed communal land in the rainy season (at same time
when other grazing lands were closed) readily improved its aboveground herbaceous biomass yield to a level comparable to restricted communal GLM. Restricted communal and private holding GLMs were superior in ground cover with values greater than 75% during the wet season. Ground cover tended to decline towards the late dry season. Species richness followed a similar trend like in ground cover although we found no statistical difference between restricted communal and freely open communal GLMs.

Slope had no significant (P > 0.05) effect on species richness and ground cover of grazing land while its influence on above ground herbaceous biomass yield was significant (P < 0.01). Grazing land on steeper slopes (15-25%) appeared to have lower herbage yield (Table 4.2) than on gentle slopes.

Table 4.2. Above-ground herbaceous biomass yield, species richness and ground cover of natural pasturelands under different types of grazing land management (GLM) and across two slopes in the highlands of north-western Ethiopia.

<table>
<thead>
<tr>
<th>Measured parameter</th>
<th>Restricted communal GLM</th>
<th>Freely open communal GLM</th>
<th>Private holding GLM</th>
<th>SEM³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;10% 15-25%</td>
<td>&lt;10% 15-25%</td>
<td>&lt;10% 15-25%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>slope</td>
<td>slope</td>
<td>slope</td>
<td></td>
</tr>
<tr>
<td>HBY (t DM/ha)¹</td>
<td>3.9ab 2.8bc</td>
<td>2.8bc 2.5c</td>
<td>5.2a 2.7c</td>
<td>0.3</td>
</tr>
<tr>
<td>SR (n)²</td>
<td>5.6ab 5.0ab</td>
<td>3.5b 4.0b</td>
<td>6.9a 6.0a</td>
<td>0.01</td>
</tr>
<tr>
<td>GCw (%)³</td>
<td>85.0n 76.4a</td>
<td>44.3b 42.7b</td>
<td>87.6a 78.3a</td>
<td>4.6</td>
</tr>
<tr>
<td>GCd (%)⁴</td>
<td>73.3a 70.0a</td>
<td>34.6b 31.2b</td>
<td>72.7a 68.4a</td>
<td>4.4</td>
</tr>
</tbody>
</table>

¹HBY – above-ground herbaceous biomass yield.  
²SR - species richness.  
³GCw - ground cover after end of wet season.  
⁴Gcd - ground cover towards end of dry season.  
⁵SEM - standard error of mean.  
Different superscript letters within a row indicate significant differences between mean values at least at 5% significance level.

4.3.3 Runoff and soil loss

Measured values of runoff, sediment concentration and soil loss as hydrological responses to GLM and slope factors are shown in Table 4.3. Effects of the independent factors and their interaction were found statistically significant (P < 0.05). The annual cumulative runoff and soil loss were highest in freely open communal GLM on steeper slopes (15-25%). However, these values were lowest in restricted communal and private holding GLMs on gentle slopes.
(<10%). Restricted communal GLM appeared to reduce surface runoff by more than 40% and curb the rate of soil erosion by more than 50% as compared to the widely practiced freely open communal GLM. Sediment concentration was considerably lower (P < 0.01) in restricted communal GLM particularly on gentle slopes. Runoff coefficient reached close to 50% in freely open communal GLM on steeper slopes where as it was below 20% in restricted communal and private holding GLMs on gentle slopes. Second order polynomial regression analysis showed that both the quadratic and the linear terms were significant (p<0.05) indicating the model accounts for a significant portion of the variation in the data. Generally, soil loss tended to have a quadratic relationship (r² = 0.87) with runoff. But, it was noted that soil loss was close to nil when runoff did not exceed 2mm per rainfall event (Fig. 4.3).

Table 4.3. Runoff coefficient, runoff, soil loss and sediment concentration under different types of grazing land management (GLM) and across two slopes in the highlands of north-western Ethiopia.

<table>
<thead>
<tr>
<th>Measured parameter</th>
<th>Restricted communal GLM</th>
<th>Freely open communal GLM</th>
<th>Private holding GLM</th>
<th>SEM²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;10%</td>
<td>15-25%</td>
<td>&lt;10%</td>
<td>15-25%</td>
</tr>
<tr>
<td>ROC (%)</td>
<td>17.0ᵃ</td>
<td>28.1ᵇ</td>
<td>16.1ᶜ</td>
<td>22.4ᵈ</td>
</tr>
<tr>
<td>RO (mm)</td>
<td>172.3ᵈ</td>
<td>284.2ᶜ</td>
<td>167.3ᵈ</td>
<td>255.9ᶜ</td>
</tr>
<tr>
<td>SL (t/ha)</td>
<td>6.1ᵇ</td>
<td>14.0ᶜ</td>
<td>6.4ᵇ</td>
<td>10.9ᵈ</td>
</tr>
<tr>
<td>SC (g/l)</td>
<td>1.8ᵇ</td>
<td>3.5ᶜ</td>
<td>4.9ᵇ</td>
<td>6.0ᵃ</td>
</tr>
</tbody>
</table>

* - the values for SL are medians;
¹ ROC = runoff coefficient.
² RO = cumulative surface runoff per year.
³ SL= annual soil loss.
⁴ SC= average sediment concentration per rainfall event.
⁵ SEM - standard error of mean.

Different superscript letters within a row indicate significant differences between mean values at least at 5% significance level.
4.3.4 Bulk density and soil moisture

The interaction effect of GLM and slope was significant (P <0.05) for soil moisture only. Soil bulk density was lower (P<0.05) in restricted communal and private holding GLMs compared to freely open communal GLM (Table 4.4). Soil moisture at 0-5 cm depth was highest (P<0.05) in restricted communal GLM on gentle slopes (<10%). Lowest soil moisture was recorded in freely open communal GLM on steeper slopes (15-25%).

Table 4.4. Soil moisture and bulk density (taken at 0-5 cm soil depth) under different types of grazing land management (GLM) and across two slopes in the highlands of north-western Ethiopia.

<table>
<thead>
<tr>
<th>Measured parameter</th>
<th>Restricted communal GLM</th>
<th>Freely open communal GLM</th>
<th>Private holding GLM</th>
<th>SEM$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;10% slope</td>
<td>15-25% slope</td>
<td>&lt;10% slope</td>
<td>15-25% slope</td>
</tr>
<tr>
<td>SM (%)$^1$</td>
<td>34.5$^a$</td>
<td>24.3$^{cd}$</td>
<td>26.8$^{bc}$</td>
<td>22.6$^{a}$</td>
</tr>
<tr>
<td>BD (g/cm$^3$)$^2$</td>
<td>0.82$^c$</td>
<td>1.02$^{ab}$</td>
<td>1.06$^a$</td>
<td>1.08$^a$</td>
</tr>
</tbody>
</table>

$^1$SM - soil moisture.  
$^2$BD - soil bulk density.  
$^3$SEM - standard error of mean.  
Different superscript letters within a row indicate significant differences between mean values at the indicated significance level.
4.4 Discussion

4.4.1 Stocking density and carrying capacity

Stocking density appeared to be much higher than carrying capacity of pasture across all GLMs, signifying overstocking problem. This problem is more pronounced in freely open communal GLM because of lack of control over its utilization. Consequently, freely open communal grazing land is exposed to overgrazing and land degradation. The proportion of biomass removed from a pasture relative to its yield potential reached about 80% in freely open communal GLM while it did not exceed 50% in restricted communal GLM, implying that a higher grazing pressure leads to pasture deterioration. The report by Norton (1998) also explained that the deleterious effects of high stocking rate of continuous grazing are manifest in the patches so affected, leading to localized changes in vegetation and soil which are not easily reversed. To rescue freely open communal grazing land in the north-western Ethiopia, it is crucial to firstly solve the present overstocking problem and secondly adapt improved grazing management strategy to avoid excessive defoliation and ensure adequate pasture resting.

4.4.2 Aboveground herbaceous biomass yield and species richness

The higher aboveground herbaceous biomass yield in private holding and restricted communal GLMs on gentle slopes (<10%) might be associated with combined effect of lower grazing pressure, resting pasture in the wet season and better soil fertility due to lower soil erosion. Concurring to this, Müller et al. (2007) reported resting pasture during wet periods is crucial for regeneration of the pasture and maintaining the productive integrity of the ecosystem. The report by Ash et al. (2011) also confirmed either conservative stocking with year-round grazing or a grazing system that includes wet-season resting will help maintain rangeland in a desirable state of ecological condition. However, other reports disclosed grasses also degenerate if over rested (Moore et al., 2006). There is a trade-off between biomass production of desirable quality and length of resting period. A competitive use of dung for fuel (picking it from a pasture field- which is a usual practice in the study area) instead of nutrient recycling to the pasture across all GLMs is expected to negatively affect aboveground herbaceous biomass yield. The work of Tadesse et al. (2002) revealed that
increased herbaceous biomass yield could be achieved by using animal dung solely for nutrient cycling purposes. The higher species richness in private holding GLM, particularly on gentle slopes, might be due to its positive association with the moderate aboveground biomass yield of 5.2 t DM/ha. Oba et al. (2001) also verified that optimum species richness corresponded to 400-500 g/m² biomass level that likely show a hump-back relationship in tropical conditions, too. Species richness of freely open communal grazing land was similar to restricted communal grazing land. Reports from Kenya agree with the present results showing no difference between exclosures and open grazing plots with respect to species richness (Oba et al., 2001).

4.4.3 Runoff, soil erosion and ground cover

Runoff and concomitant sedimentation occurred when the rainfall amount exceeded 3.8mm on grazing lands of steeper slopes (15-25%) and 4.5mm on gentle slopes (<10%). Severity of runoff and soil loss was aggravated under freely open communal GLM on steeper slopes. This might probably be associated with excessive livestock concentration on freely open communal grazing lands of steeper slopes during the wet season, in search of relatively drained site. In agreement to our results, Mwendera et al. (1997) reported that the combined effect of higher grazing pressure and land slopes increased runoff and soil loss. Bartley et al. (2006) showed that runoff and soil loss dramatically increase when ground cover is below 40% in tropical area. The present study also revealed a strongly negative correlation between ground cover and runoff or soil loss (Table 4.5). This suggests that freely open communal GLM (with ground cover below 35% in dry season) is typically having a higher risk of water erosion in the study area, since ground cover is the most significant factor determining the level of runoff and soil loss on a pastureland (Carroll and Tucker, 2000). The use of freely open communal grazing land particularly on steeper slopes triggered ecological damage and hence this calls policy attention to reverse the existing mismanagement and restore sustainable use of the ecosystem.

According to Sanjari et al. (2010), a grazing management that keeps ground cover of a pastureland at 70% (threshold level) or above sharply reduces runoff and soil erosion to a tolerable level. Similarly, restricted communal and private holding GLMs in the present study had a ground cover above the stated threshold level throughout the year particularly on gentle
slopes. In restricted communal GLM, good ground cover was maintained by regulating grazing and resting periods. The grazing period (from December - April and July) is arranged to coincide with ploughing time permitting 12-20 grazing days per month in the dry season and every day in July in the wet season. In dry season, grazing is exercised for two to three hours in the afternoon to control grazing intensity. Czegledi and Radacsi (2005) pointed out that overgrazing is not only a function of livestock number but is also a function of time. It leads to a deterioration of the grass cover and botanical composition due to trampling and selective grazing. Resting natural pasture in the wet season (August-November) for its re-growth and reseeding played a key role in maintaining good ground cover under restricted communal GLM. The subsequent restricted grazing practice helped to regulate grazing intensity and evenness of pasture use.

Table 4.5. Correlation coefficients of ground cover and hydrological variables.

<table>
<thead>
<tr>
<th></th>
<th>GCd</th>
<th>RO</th>
<th>SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCd</td>
<td>-0.842**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RO</td>
<td>-0.878**</td>
<td>0.980**</td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>-0.917**</td>
<td>0.972**</td>
<td>0.983**</td>
</tr>
</tbody>
</table>

1 GCd = ground cover percentage in dry season.  
2 RO = cumulative surface runoff in mm.  
3 SC = sediment concentration in g/lt.  
4 SL = annual soil loss in t/ha.  
** = p<0.01.

4.4.4 Bulk density and soil moisture

The higher soil moisture in restricted communal GLM on gentle slopes might be attributed to its waterlogged location in the landscape as compared to private holding GLM which is usually located on relatively drained site of a plateau, near homestead area. Evidently, soil moisture tended to increase in restricted communal and private holding GLMs on gentle slopes (with good ground cover) as compared to freely open communal GLM on either slopes, pointing to a better infiltration rate in the former ones. The highest record of soil bulk density in freely open communal GLM was due to increased soil compaction effect from intense livestock concentration coupled with continuous grazing. Tate et al. (2004) obtained similar results indicating greater soil bulk density at sites of more cattle concentration.
4.5 Conclusions

Grazing serves as the most important source of livestock feed in the highlands of north-western Ethiopia. However, the type of GLM and slope considerably affected vegetation attributes and hydrological properties of pasturelands. Freely open communal GLM aggravated the deterioration of ground cover and intensified the incidence of soil erosion on natural pasturelands. The adverse effect of this GLM is mainly due to overstocking problem and lack of pasture resting, the effect being accentuated on steeper slopes. To mitigate this problem, collective management experience of the study area (to regulate stocking rate and exercise restricted grazing) can be taken as a good example for improving vegetation attributes of communal grazing land and reducing the rate of soil erosion. However, letting freely open communal GLM to continue as usual appears to be disastrous to the pasture ecosystem. This exercise seems to have no future to support profitable livestock production and thus it needs to devise appropriate GLM with workable policy instruments for its implementation.

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The first author thanks the CGIAR Challenge Program on Water and Food (CPWF) for funding his PhD scholarship and the International Livestock Research Institute (ILRI) for awarding him graduate fellowship. We extend our gratitude to ILRI and the Ethiopian Institute of Agricultural Research (EIAR) for their full support to the execution of the field and laboratory works. We are grateful to the two anonymous reviewers for their immense contribution to improve the paper. Finally, our gratitude goes to the farmers in the study area for allowing us to use their grazing land resources.

References


Chapter 5

Factors Affecting Pasture Condition of Collectively Managed Communal Grazing Land: A Case Study in the Upper Blue Nile Basin, Ethiopia

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Abstract

Grazing is the basis for the traditional livestock production and represents a considerable share of the agricultural land use. In north-western Ethiopia, collective management is practiced on communal grazing lands mainly to defer pasture for dry season use when other feed sources are depleted on one hand but oxen are required for cropland cultivation on the other. This study was carried out in Farta district, north-western Ethiopia, with an objective of identifying the determinant factors influencing sustainable use and productivity of restricted communal grazing land. Overall, the logistic model was significant (P<0.05) in explaining the dependent variables (legume proportion, nutritive value and ratio of carrying capacity to stocking rate) taken as proxies to pasture condition. Analysis of the maximum likelihood estimates showed that the dependent variables were significantly affected (P<0.01) by several explanatory variables included in the binary logit model. Soil fertility of a pastureland has direct effect on legume proportion of the pasture. Good soil fertility favours growth of legumes in a pasture sward and hence increases its proportion. The inverse relation of oxen number to nutritive value, in the present studies, might be explained by the increase in stocking rate. Increase in oxen number would cause heavy greazing pressure which this would eventually result in deterioration of the pasture probably due to the domination of less palatable grass species in the pasture sward. In the present study, dry matter yield was significantly influenced only by a single factor, i.e. pasture resting period. Extended pasture resting improves its resilience to grazing stress and it also gives the pasture a chance to accumulate more herbage biomass. It is, however, necessary to reconcile the yield increment with a possible deterioration of quality that might come from over maturity. Results of the present study showed that soil fertility, grazing intensity and pasture resting period are the key determinant factors to sustainable grazing management so long as rainfall distribution is normal.

Key words: legume proportion, nutritive value, grazing intensity, pasture resting, Farta district
5.1 Introduction

Livestock are the key elements in securing livelihoods of the rural population in Ethiopia. Grazing is the basis for the traditional livestock production and represents a considerable share of the agricultural land use. However, the available grazing resource is highly depleted (loss of fertile soil, decline in bio-diversity and in pasture productivity) presumably due to overgrazing. The traditional uncontrolled free grazing system is the principal means of utilizing common pool grazing resources but has caused severe degradation of most grazing lands (Mwendera et al. 1997; Gebremedhin et al., 2004). Free grazing exacerbates the seasonal shortage of pasture particularly towards dry season. As a consequence, livestock are subject to a shock of severe fluctuations in feed availability and hence production per animal is extremely low (Haile et al., 2009) although this is ascribed to many complex factors. Nowadays, improving the utilization of grazing land is a key management concern to restore and sustain the productivity of natural pastures and ultimately minimize land degradation.

In north-western Ethiopia, collective management is practiced on communal grazing lands mainly to defer pasture for dry season use when other feed sources are depleted on one hand, while oxen are required for cropland cultivation on the other. They also allow grazing on green pasture in the wet season when crop residue reserve is finished and all livestock are confined to limited place to avoid crop damage. A communal grazing land managed by collective action, from here afterwards, is referred as restricted communal grazing land and locally named as ‘yebere sar’ where its use and management is governed by local rules and regulations formulated by the community itself. The number of members of restricted communal grazing land varies from 10 to 200 households depending on the size of pasture closure. This practice is a traditional experience that has stayed for long time and farmers would like to continue pursuing it as a beneficial legacy. It is one of the few exemplary experiences of collective management that has successfully worked on communal grazing lands. The government encourages farmers to collectively manage communal grazing lands apart from recognizing the right to use it. The condition of pasture on restricted communal grazing land in terms of productivity and quality attributes varies in space and time (Gebremedhin et al., 2004) due to differences in management, environment, soil fertility, grazing pressure and animal species (Santos and Costa, 2002). The aim of good pasture management is to grow high quality pasture, the larger proportion of which is to be either
eaten or conserved without much wastage, and which can sustain for the maximum possible time. The present study was conceived to identify the determinant factors influencing sustainable use and productivity of restricted communal grazing land that help to sharpen a focus on key factors for improving the management and utilization of the pasture ecosystem.

5.2 Conceptual framework and theory

In north-western Ethiopia, farmers are known for ox-culture because crop production relies exclusively on animal power. In this system, grazing is an indispensable aspect of livestock production although the current grazing management systems are not sustainable (Yayneshet et al., 2009). Farmers have developed the experience of collective action to hold sustainable pasture management on some of communal grazing lands in Farta district, north-western Ethiopia. The collective management is enforced by abiding rules and regulations where its violation leads to a punishment. In fact, there is some sort of flexibility in modifying the rules and regulations (only when majority of the members felt it necessary) to cope with emerging dynamics in the system and the environment. Like that of village farmers in India to communally manage water for irrigation as described by Wade (1987), smallholder farmers of the present case study are also rational choice-makers to cooperate for village common pool grazing resource use and voluntarily comply with rules of restrained access to grazing.

Sustainability of natural pasture is influenced by a number of dynamic factors (Fig. 1). Native pastures are extremely variable in terms of quantity and quality of forage species as a function of space and time. Variability may be natural (normal changes on physiology, phenology, and plant growth associated to seasonal or even daily variations in environmental conditions), or induced by grazing (caused by animals) through the depression of available sources (O’Reagain & Schwartz, 1995; O’Reagain, 2001), the main challenge is to understand this natural variability and find ways to maximize productivity through adequate management.
Management actions must try to define strategies to maintain and/or sustain biological diversity, health and productivity of the pasture ecosystems at long term. In Farta district, farmers are accustomed to pasture deferment on restricted communal grazing land for dry season grazing. Pasture deferment in the tropics has advantages and disadvantages. The advantages are less uncovered soil, and consequently, the emergence of weeds decreases, allowing forages to recover and to reseed. On the other hand, it allows grasses to mature, deteriorating forage quality if deferment is too long. Management variables that have more influence on the plant response to grazing are: i) grazing time as to the opportunity of the plat...
to grow or re-grow; ii) frequency of de-foliation of the plant community; and iii) intensity of use or stocking rate, i.e. de-foliation level (Trlica and Rittenhouse, 1993).

The act of grazing is one of the most important forces changing the pasture environment. The effects of grazing on the ecosystems obviously depend on the number of herbivorous and their movement, as grazing is a hierarchic process, ruled by animal decisions (Trlica and Rittenhouse, 1993). Rook et al. (2004) also concluded that the main mechanism through which grazing animals influence pastures is their dietary selection, which in consequence creates and maintains the structural heterogeneity of pasture swards. The degree of animal dispersion influences the support capacity of the pastures, which in turn affects pasture conditions and animal production. Some management actions may help to improve grazing distribution, such as attracting animals to specific sites, placing water and salt troughs in strategic locations, reducing paddock size, dividing the herd in classes, and using some management strategies, such as rotational grazing (Schacht et al., 1996).

The sustainability of grazing system emphasizes the maintenance of productivity and stability. In general, pasture production in tropical countries tend to be less stable partly due to the higher weather instability, and also to larger contrast in the morphology and phenology of the hot climate species (O’Reagain and Schwartz, 1995). The management of natural pasture ecosystems aiming at sustainability and productivity depends on our ability to detect changes and to implement management responses at relevant special scale. Currently, planning and managing natural resources involve flexibility to respond to short-term changes. This type of planning can affect long-term sustainability when decisions are wrong. According to Danckwerts et al. (1993), economic, social and political changes probably have more influence on the decision-making of the producer than variations of the physical conditions and of the natural resources.

5.3 Research methodology

5.3.1 Description of the study area

The study was carried out from May 2011 to November 2011 in Farta district which represents an upland ecology of the upper Blue Nile basin in the north-western Ethiopia. The
The study site is located with coordinates of 11°44'–11°50' N latitude and 38°05'–38°08' E longitude. The altitude ranges from 2700m to 2900m above sea level. The rainfall has a unimodal distribution, stretching from June to September, with a total annual precipitation of 1532mm (Fenta, 2009). The terrain is characterized by rolling chains of hills. The rain-fed agriculture is dominated by barley-sheep based mixed crop/livestock farming. The major crop grown is barley followed by potato, faba bean, field pea and linseed. Triticale has become a popular crop since its recent introduction by GTZ in 1990s. There is an acute shortage of cropland due to the ever increasing human population expanding to marginal and fragile areas at the expense of grazing land. The average landholding of a household is less than 1ha (ERA, 2003). Mixed livestock species such as cattle, sheep and equine are kept by the farming households out of which sheep is the dominant one. Livestock play a significant role in the mixed farming by providing draught power, manure, food, and cash. The estimate of livestock density for the area ranges between 27-130 TLU/km² (CSA, 2008) implying that there is an overstocking problem (Alemayehu et al., 2012).

5.3.2 Survey

Four peasant associations (PAs) which practice collective management on communal grazing lands were selected for the present study. About 9-13 villages, depending on size of the PA, were randomly selected from each PA making up a total of 42 villages. Each village represents specific collective action on communal grazing land. Based on multistage sampling, about 140 smallholder farmers were selected to collect the desired data at a household level using a structured questionnaire. The information related to collective management of communal grazing land was gathered at village level by conducting group interviews.

To assess pasture condition of the restricted communal grazing land, proxy indicators such as legume proportion, digestibility and grazing pressure were determined for each village. A 50 x 50 m² quadrat was used to take a pasture sample by clipping the biomass above the ground level. The samples were taken along diagonal transect of the pastureland at interval of 20m. The clipped sample was decomposed into the components of grass, legume and weeds. Each component was weighed separately and was dried in an oven at 65°C for 72 hours to determine its dry matter yield. The legume proportion was thus estimated as the ratio of
legume component to the combined total biomass on dry matter basis. Composite samples of the grass and legume components were taken to determine in vitro digestibility of the pasture following Tilley and Terry (1963) method at Holetta Agricultural Research Center. Grazing pressure was considered as the ratio between carrying capacity of the pasture and the present stocking rate on the same pasture.

5.3.3. Dependent variables

The dependent variable is the condition of pasture under restricted communal grazing land management in some villages of Farta district. There are many established indicators of pasture productivity as reported in different literatures. Among which, dry matter yield, legume proportion, nutritive value and ratio of carrying capacity to stocking rate are considered as proxy indicators (Table 5.1) in the present study to help in identifying the underlying determinants of good pasture condition of collectively managed communal grazing lands. Dry matter yield of a pasture measures the extent of its productivity and determines carrying capacity of a pasture. A lower dry matter yield is normally a reflection of poor grazing land management. Legumes are an important source of nitrogen to pastures and enhance quality of the natural pasture. The lower limit of legume proportion in a pasture is set about 17% so as to qualify as good pasture (Lascano, 2000). The nutritive value of a pasture is a decisive factor to increase carrying capacity of the pasture and productivity per animal. An animal’s feed intake, and how well that feed is digested, determine the feed’s production performance (Getachew et al., 2004). Digestibility, implying the extent to which forage is absorbed as it passes through an animal’s digestive tract, varies greatly. Immature, leafy plant tissues may be 80 to 90% digested, while less than 50% of mature, stemmy material is digested (Ball et al., 2001). Digestibility usually provides a fairly reliable index of nutritive value because more digestible feeds are normally consumed to a greater extent than less digestible feeds (Khan et al., 2003). Hence, for a feedstuff to be considered as a quality feed, it should have digestibility value greater than 55% (Bell, 2006). Pastures should be managed to maintain a leafy canopy that is free of weeds and dead herbage and is grazed uniformly without many ungrazed patches (Adesogan et al. 2002). The proper amount and frequency of grazing are critical in maintaining productive pastures. Close and frequent grazing causes loss of vigor, reduction in density of desired species and higher risk of soil erosion. On the other hand, light uses favor buildup of excessive residue and promote
shedding to the under-storey vegetation. The critical factor to evaluate is how well the stocking rate agrees with the carrying capacity of the pastureland to warrant good pasture condition. So, the major requirement for successful livestock raising on natural pasture is not to exceed the livestock carrying capacity of the area, which is the number of animals the area can support in the long term (Timberlake and Reddy, 1986). If this capacity is exceeded, overgrazing results that can lead to environmental degradation. It is believed that socio-economic circumstances have a decisive role to influence management decisions of farmers on communal grazing lands. In the present study, we did not include educational status at community level, agricultural extension services and access to market in the model as we found them similar across the villages.

Table 5.1 Description of dependent variables used in the analysis of pasture condition managed in collective action, in north-western Ethiopia.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
<th>Concept</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter yield</td>
<td>Dry matter yield of a pasture biomass in t/ha</td>
<td>Pasture condition</td>
<td>Values of weight measurements expressed on dry matter basis</td>
</tr>
<tr>
<td>Legume proportion</td>
<td>Percent of legume in the total forage biomass on dry matter basis</td>
<td>Pasture condition</td>
<td>Dummy= 1 if legume proportion&gt;17, 0 otherwise</td>
</tr>
<tr>
<td>Nutritive value</td>
<td>Digestibility percentage of a pasture</td>
<td>Pasture condition</td>
<td>Dummy=1 if % digestibility&gt;55, 0 otherwise</td>
</tr>
<tr>
<td>Ratio of carrying capacity to stocking rate</td>
<td>Ratio of carrying capacity of a pasture to the existing stocking rate</td>
<td>Pasture condition</td>
<td>Dummy=1 if the ratio&gt;0.9, 0 otherwise</td>
</tr>
</tbody>
</table>

5.3.4. Independent variables

The independent factors that are presumed to explain the dependent variables can be numerous. But, we limited the variables to those that have direct relation to the collective management of restricted communal grazing land at village level (Table 5.2). The prevailing equilibrium view of pastureland (Milton et al., 1994) has been taken into consideration to set the hypothetical theory of restricted communal grazing land ecosystem.
The independent variables that are thought to affect pasture condition of restricted grazing land include size of freely open communal grazing land in a village, size of restricted communal grazing land, cropland size of a household (in provide alternative feed resource like crop residue), total number of oxen in a village being permitted to graze on restricted communal grazing land, livestock density of a village, pasture resting period and soil fertility status. Farmers can manipulate stock numbers but have no control over climatic influences (Lawrence et al., 1994). Farmers cannot control variable weather but they can study the weather patterns in their area to work their pasture accordingly. Obviously, the influence of agro-ecological condition (in terms of rainfall availability, ambient temperature, etc) on pasture productivity is critical. In the present study, this influence has been assumed to be uniform in the microclimate that bound the study area and hence was not included in the model.

The size of freely open communal grazing land has an influence on pasture condition of restricted communal grazing land. As its size gets smaller, the available grazing resource will be limited. This may lead to have frequent access to grazing on restricted communal grazing land thereby eventually impacting negatively on its pasture condition. The size of restricted communal grazing land can have either negative or positive impact on pasture condition depending on the type of grazing management. Cropland size is hypothesized to have a positive relationship to maintaining good pasture condition of restricted communal grazing land. Supply of more crop residues improves the availability of feed reserve for dry season use thereby lessening grazing pressure on restricted communal grazing land. Total number of oxen in a village permitted to graze on restricted communal grazing land determines the stocking rate. Whenever oxen number increases overstocking will occur impacting negatively on pasture condition. Again, pasture condition may deteriorate if number of oxen grazing on restricted communal grazing land is kept too low. But the chance for the latter situation to occur is very unlikely due to the apparent overstocking problem (Alemayehu et al., 2013). Livestock density in a village can impact condition of restricted communal grazing land. A higher livestock density may pose increased grazing pressure on restricted communal grazing land, that to have a negative effect on pasture condition. Plant vigour and longevity can be reduced if the plants are re-grazed before they have sufficiently recovered. If this process is continually repeated, a thinning or loss of the most desirable species occurs opening the ground cover for invasion of weeds or less desirable plant species. Timing of the plant’s
growing cycle in which grazing occurs also plays a significant role in plant growth and recovery rates. Hence pasture resting period must be sufficient and should take place at the right time of its growth cycle for a pasture to recover and regain good condition. On the other hand, letting a pasture to rest for too long period can negatively impact its condition. For a pasture to yield good biomass and ground cover, the soil should moderately be fertile and provide favourable growing condition.

Table 5.2 Summary statistics and hypothesized effects of determinant factors on pasture condition of restricted communal grazing land in the north-western Ethiopia.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Expected effect (+,-)</th>
<th>Statistics</th>
<th>LP</th>
<th>NV</th>
<th>RCS</th>
<th>DMY</th>
<th>Mean</th>
<th>SE (±)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of OCGL†</td>
<td>Total area of OCGL of a village in ha</td>
<td>+,+,-,+</td>
<td></td>
<td>2.8</td>
<td>0.45</td>
<td>0.1</td>
<td>15.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of RCGL‡</td>
<td>Area of RCGL in a village in ha</td>
<td>+,-,+,-,+</td>
<td></td>
<td>4.6</td>
<td>0.57</td>
<td>0.5</td>
<td>20.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cropland size</td>
<td>Average cropland holding of a household in a village in ha</td>
<td>-,+,-,+</td>
<td></td>
<td>0.9</td>
<td>0.04</td>
<td>0.3</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of oxen</td>
<td>Total number of oxen in a village permitted to graze on RCGL</td>
<td>-,+,-,+</td>
<td></td>
<td>179.3</td>
<td>14.75</td>
<td>44</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Livestock density</td>
<td>Total number of livestock per unit area in a village expressed as TLU/ha</td>
<td>-,+,-,-</td>
<td></td>
<td>143.4</td>
<td>15.71</td>
<td>33.1</td>
<td>582.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pasture resting period</td>
<td>Total number of days a pasture rests from grazing in a year</td>
<td>+/,-,+,-,+</td>
<td></td>
<td>223.9</td>
<td>4.15</td>
<td>150</td>
<td>270</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil fertility status</td>
<td>Dummy: 1 good as perceived by farmers ranking, 0 not good</td>
<td>+,+,+,+</td>
<td></td>
<td>0.5</td>
<td>0.08</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†OCGL- freely open communal grazing land, ‡RCGL- restricted communal grazing land. LP- legume proportion of a pasture, NV- nutritive value of a pasture, RCS- ratio of carrying capacity to stocking rate, DMY- dry matter yield of a pasture, SE- standard error, min-minimum value, max-maximum value
The relationship between good pasture condition and other explanatory variables were modelled using the logistic regression model. The threshold levels of legume proportion, digestibility and ratio of carrying capacity to stocking rate were determined (shown in section 5.3.3.) to reflect good pasture condition. The logit model follows the probability mass function and takes unobservable utility index, $Y_i^*$ as the latent variable. This index is determined by the explanatory variables in the regression implying that the larger the value of an index $Y_i^*$ means the greater the probability of an event occurring where in the present case refers to good pasture condition. The describing equation for this is given as follows:

$$Y_i^* = \beta X_i + \varepsilon$$  \hspace{1cm} (1)

Where $\varepsilon \sim \text{logistic (0,1)}$

Then $Y_i$ can be viewed as an indicator for whether this variable is positive:

$$Y_i = \begin{cases} 1 & \text{if } Y_i^* > 0 \text{ \ i.e. } -\varepsilon < \beta X_i, \\ 0 & \text{otherwise} \end{cases}$$

In this model the probability of observing a response (whether the pastureland is in good or not in good condition) is defined in terms of the level of the unobserved index $Y_i^*$; natural logarithm of the odds is used to transform the index $Y_i^*$ into a probability value. Model convergence status was checked to confirm whether convergence criterion satisfied to run the logistic model analysis. The logistic model was employed to analyse the data sets of legume proportion, nutritive value and ratio of carrying capacity to stocking rate. Ordinary least squares estimates (OLS) was used to analyse dry matter yield in a linear regression model. The distribution was first tested for its normality and the response variable, i.e. dry matter yield was found to assume normal distribution. Prior to the regression analysis, a collinearity test was made on the independent variables to filter out only those variables with no multicollinear relationship to one another.
5.4 Results

Logistic regressions explaining the determinant factors affecting pasture condition of restricted communal grazing land, in north-western Ethiopia, are shown in Table 5.3. Overall, the binary logit model was found fit in explaining the major portion of the variability in the dependent variables (legume proportion, nutritive value and ratio of carrying capacity to stocking rate) taken as proxies to pasture condition. Analysis of the Wald statistics showed that the dependent variables were significantly affected (P<0.01) by several explanatory variables included in the logistic model. The factors explaining legume proportion are different from that explaining other proxies. However, it was noted that both nutritive value and ratio of carrying capacity to stocking rate were explained significantly by common predicting factors. The explanatory variables did mostly take the expected signs.

Table 5.3 Logit regression coefficients of variables affecting pasture condition of restricted communal grazing land in north-western Ethiopia.

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>LP</th>
<th>Logit NV</th>
<th>RCS</th>
<th>OLS DMY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of OCGL†</td>
<td>0.0661</td>
<td>0.6337</td>
<td>0.0660</td>
<td>-0.01928</td>
</tr>
<tr>
<td>Size of RCGL‡</td>
<td>-0.0064</td>
<td>2.1685*</td>
<td>2.0641**</td>
<td>0.02906</td>
</tr>
<tr>
<td>size of cropland</td>
<td>-3.536†</td>
<td>-1.0045</td>
<td>-0.2110</td>
<td>-0.55043</td>
</tr>
<tr>
<td>Oxen number</td>
<td>-0.0022</td>
<td>-0.0560**</td>
<td>-0.0507**</td>
<td>0.00282</td>
</tr>
<tr>
<td>Livestock density</td>
<td>-0.0123</td>
<td>-0.00874</td>
<td>-0.00375</td>
<td>-0.00205</td>
</tr>
<tr>
<td>Pasture resting period</td>
<td>-0.0064</td>
<td>0.0563</td>
<td>0.0245</td>
<td>0.05221***</td>
</tr>
<tr>
<td>Fertility status of RCGL</td>
<td>4.2194***</td>
<td>11.8126*</td>
<td>2.7193</td>
<td>0.38756</td>
</tr>
<tr>
<td>Intercept</td>
<td>5.1111</td>
<td>-12.4499</td>
<td>-6.3015</td>
<td>-6.29490***</td>
</tr>
<tr>
<td>Log-likelihood functions</td>
<td>-109.496</td>
<td>-103.944</td>
<td>-116.256</td>
<td>ad-R²= 0.74</td>
</tr>
<tr>
<td>Model chi-square</td>
<td>23.8368</td>
<td>38.933</td>
<td>37.1502</td>
<td>-</td>
</tr>
</tbody>
</table>

†OCGL- freely open communal grazing land; ‡RCGL- restricted communal grazing land; OLS- ordinary least squares; LP- legume proportion of a pasture; NV- nutritive value of a pasture; RCS- ratio of carrying capacity to stocking rate; DMY- dry matter yield of a pasture; *significant at 10% level; ** significant at 5% level; *** significant at 1% level

A logistic regression analysis showed that of the seven determinant factors, only two were found to significantly influence legume proportion of natural pasture managed in collective action. These are fertility status of restricted communal grazing land with a positive influence and the average cropland size of a household in a village with a negative influence. Nutritive
value of a pasture was significantly influenced by three factors namely; size of restricted communal grazing land having positive effect, oxen number of a village having negative effect and fertility status of restricted communal grazing land having positive effect. Ratio of carrying capacity to stocking rate was significantly influenced by size of restricted communal grazing land with a positive effect and oxen number of a village with a negative effect. The ordinary least squares estimates (OLS) indicated that dry matter yield of restricted communal grazing land was significantly affected (P<0.01) only by a single factor, which is pasture resting period with a positive sign relationship.

5.5. Discussion

Soil fertility of a pastureland has direct effect on legume proportion of the pasture. Good soil fertility favours growth of legumes in a pasture sward and hence increases its proportion. Legumes are generally more sensitive than forage grasses to nutrient deficiencies and low soil pH (Caddel et al., nd; Botha, 2002). It must take into account what soil condition affects the coexistence of legume in the mixed pasture sward (Shwinning and Parson, 1996). Evidently, successful pasture legume production depends on maintaining adequate levels of the key nutrients in the soil, suitable pH and soil moisture (Botha, 2002). Size of cropland tended to have an inverse relationship with legume proportion. This might associate with a higher grazing intensity (more frequent grazing on restricted communal grazing land), leading to selective grazing on more nutritious patches of the pasture.

Nutritive value of a pasture was negatively affected by oxen number of a village, which refers to a stocking rate. The inverse relation of stocking rate to nutritive value, in the present studies, might be explained by the domination of unpalatable pasture species in response to an increase in stocking rate. In contrary, nutritive value appeared to increase with size of restricted communal grazing land. This might be due to less problem of overstocking and likely a management of higher grazing intensity. Sollenberger and Vanzant (2011) also reviewed that most studies report either no effect or positive effect of increasing grazing intensity on nutritive value of pastures. In such cases, the positive effect of increased grazing intensity on nutritive value occurs because as the sward canopies are grazed intensively over an extended period of time, average maturity of regrowth decreases and the leaf proportion of forage mass is greater due to shorter intervals between animal visits to individual patches.
Grazing intensity is a key management variable influencing the structure and composition of pastures (Dumont et al., 2007). A decrease in grazing intensity is assumed to favour biodiversity as a result of the increased heterogeneity of pastures (Grime, 1979). As expected, ratio of carrying capacity to stocking rate was considerably affected by oxen number of a village and size of restricted communal grazing land. The increase in oxen number increased the stocking rate which in turn resulted in a higher grazing pressure. A higher grazing pressure tends to result in deterioration of a pasture. In contrast, grazing pressure decreased as the size of restricted communal grazing land increased. Dry matter yield potential of a pasture is affected by a combination of factors including climate, pasture type and management. Improvement in pasture yield is the basis for increasing carrying capacity of a pasture, which helps to reduce problem of overstocking.

In the present study, dry matter yield was significantly influenced only by a single factor, i.e. pasture resting period. Resting a pastureland improves its resilience to grazing stress and helps to accumulate more herbage biomass. Extended resting of a pasture increases dry matter yield. It is, however, necessary to reconcile the yield increment with a possible deterioration of quality that might come from over maturity.

5.6 Conclusions

In some villages of Farta district, in north-western Ethiopia, smallholder farmers have long tradition of reserving part of a communal grazing land to manage it in collective action. Farmers are guided by well established local rules and regulations for maintaining collective management of communal grazing land. It has been observed that grazing management is the single most important factor affecting forage quality and production. Results of the present study showed that soil fertility, grazing intensity and pasture resting period are the key determinant factors to sustainable grazing management so long as the rainfall distribution is normal. These factors need to be manipulated depending on the specific pragmatic situation of the pasture ecosystem as it is dynamic and complex in nature. Our study implies that it is useful to develop a strategy (indicators) for assessing and monitoring pasture condition of communal grazing lands in order to make corrective decisions for sustainable pastureland management.
Acknowledgements

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References


Chapter 6

General Discussion
6.1 Introduction

Agriculture today must follow a sound path to sustain the environment and the ecology. Every agricultural activity has some impact on the environment (Atkinson and Watson, 1996). Livestock are crucial to fulfil key agricultural functions and besides the positive effects of livestock in an integrated mixed farming system, livestock are known to have negative effects on the environment causing land degradation, water pollution, greenhouse gas emission, and erosion of biodiversity (Steinfeld et al., 2006). More recently, researchers have called due attention to the substantial increments of feed, water and land requirements for ruminant production (Molden et al., 2010; Pelletier et al., 2010).

Nowadays, the concern on water resource has increased more than ever before in face of the growing human population (Wallace, 2000), the present climate change with its effect on rainfall (Zhang et al., 2007) and an ever growing demand on natural resources in aggravating water shortages. The evidence available indicates that livestock systems are large consumers of water in most basin systems of the world (Peden et al., 2009). Despite this fact and the importance of livestock products, livestock have often been neglected in water development and management arena (Peden et al., 2007).

Water is a constraint to livestock production in the upper Blue Nile basin, north western Ethiopia, primarily by influencing the seasonal availability of feed resources. The water deficit is caused by the long dry season in the study area. So, the efficiency at which water is utilized in the prevailing rain fed mixed agriculture determines the overall livelihoods of the rural poor households (Namara et al., 2010). Livestock production when linked to farm water management has direct influence on environment and sustainable use of grazing lands, this being affected by farmers’ management decisions and by natural variations in land forms (Mwendera and Mohamed Saleem, 1997). Management of grazing land and water use efficiency are interconnected. Unless a grazing land is managed properly, it is difficult to improve water management (Bossio et al., 2010). The aim of the present study was, therefore, to evaluate livestock productivity from the perspective of water use efficiency to help comprehend strategies that are useful for increasing water productivity and, to assess grazing resource management for improving sustainable use of grazing land. The specific objectives of the present study were to provide insights on the methodology of livestock water
productivity (LWP) estimation using the water footprint approach and relate it to the life cycle assessment (LCA) framework, to assess LWP from empirical evidences across different land-use mosaics of the mixed crop/livestock production systems in Gumara watershed east of Lake Tana in north-western Ethiopia, to investigate the impact of collective management of communal grazing land on lessening the problem of land degradation and sustaining pasture production, and to identify the determinant factors influencing sustainable use and productivity of natural pasture ecosystem pertaining to collective management of communal grazing lands.

6.2 Methodological approach

The emphasis of the present study was to assess livestock water productivity in the mixed farming systems of the Ethiopian highlands. Because feed production is the main route of water depletion in the process of livestock production, the succeeding step was to explore the impact of different grazing land management on pasture production and grazing land degradation. Improving management of grazing land increases pasture productivity, which helps to enhance livestock water productivity. After knowing the impact of grazing land management, determinant factors to good pasture production were identified to help in decision making for improving productivity of grazing land.

The uses of water in agricultural production systems are multiple and often simultaneous in space and/or time (Peden et al., 2009). The measurement of water flow through all uses within basin provides a basic integrating measure of the relative activities of different agricultural sectors within the basin as described by Molden et al. (2003). It is thus necessary to have a clear description of the water input depletion in the course of agricultural production to arrive at appropriate option for improving agricultural water management (Bastiaanssen et al., 2008).

LWP is a ratio of total benefits in terms of outputs and services obtained from livestock per total water depleted in livestock production (Peden et al., 2007). Conventionally, the relationship between livestock and water is associated with drinking water requirements and voluntary intake while in fact most of the water used by livestock is lost through evapotranspiration in producing the feed (Blümmel et al., 2009). It has been noticed that reported
values of LWP generally show very wide difference beyond what is expected even for similar agro-ecological conditions and farming systems (Haileselassie et al., 2009; Mekonnen et al., 2011). This might probably be ascribed to a difference in methodological approach and it is thus felt that there is a need to refine and standardize the methodology for estimating LWP (Chapter 2). Scholars have pointed out the need to emphasize on fresh water resource use and its allocation in agriculture by applying the LCA framework (Haas et al., 2001; Koehler, 2008). LCA is a method that can be applied to compile inventory and evaluate agricultural production system for assessing its impact on natural resource management in a defined system boundary (Haas et al. 2001). To estimate LWP at farm level, LCA and water foot printing within the boundary of cradle to farm gate, enables us to enfold the entire herd life in accounting for water (Chapters 2 and 3). It invokes the whole continuum from birth/growing period to end of the productive age of a herd. Truncating the boundary of the water foot printing to a livestock farm gate, the volume of water consumed by livestock (for drinking and feed production) can be quantified from birth to end of productive age or off-take in the breeding cycle.

The methods of estimating water productivity in general and livestock water productivity in particular contain large assumptions about both the numerator and denominator (Cook et al., 2009). In selecting measurable inputs and production, methods of the livestock water productivity are partial and do not acknowledge all benefits and costs of complex water consuming systems (Cook et al., 2009). For instance, non-marketable values associated with water use, such as livelihood support and values derived from ecosystem services, are normally not accounted for (Turpie et al., 2008), and hence undermines the estimation of livestock water productivity. Water accounting for crop residue (when utilized as animal feed) is a contentious concern where some say the water is primarily required to produce the grains and pods (Peden et al., 2007) while others emphasize farmers consider the value of crop residue as animal feed in selecting what crop variety to grow (Haileselassie et al., 2009). However, there is no clear methodology to follow in partitioning the proportion of water accounted for the grain and crop residue.

The present study was just one component of a bigger LWP project led by the International Livestock Research Institute (ILRI) in collaboration with the national agricultural research systems of Ethiopia, Sudan and Uganda to represent different farming systems in the Nile.
basin. The study identified Gumara watershed as a hotspot representing rain fed mixed crop-livestock production system in the upper Blue Nile basin, north western Ethiopia, for studying the interactions between livestock and water with its implications to pastureland ecosystem management.

After refining the conceptual basis for assessing LWP, a longitudinal monitoring study was launched in Gumara watershed to collect on-farm livestock and crop production data at a household level, pertinent to achieve the second specific objective of the present study (Chapter 3). The collected data addressed three distinct mosaics of mixed crop-livestock farming systems, i.e. a) rice-noug based mixed crop-livestock farming (RNF), b) tef-finger millet based mixed crop-livestock farming (TMF), and c) barley-potato based mixed crop-livestock farming (BPF). To assess LWP, we quantified the various livestock products and services rendered over the herd’s productive life time including their insurance value (C/F Bebe, 2003). Converting the benefits to a monetary value based on local market prices was necessary to create a comparable assessment base. For quantifying the amount of water used in livestock production, we estimated first the feed requirements by different livestock species and age class as well as sources of feed in a given production system. Hence, the water required for production of feeds was estimated using the CROPWAT model (FAO, 1998). The water used for drinking over life time was also estimated for different livestock species and age class as described by FAO (1986). The study helped to evaluate LWP spatially across different agro-ecological conditions within Gumara watershed. LWP was also assessed across wealth categories of smallholder farmers in the watershed. We considered how livestock off-take management strategies influence LWP.

A full-fledged field experiment was run at Maynet village of Farta district in north western Ethiopia, to study the effect of collective management of common hold pasturelands and other contemporary grazing managements on vegetation attributes and hydrological properties of communal grazing lands (Chapter 4). The study site is situated at an altitude of 2800 m above sea level representing a typical cool upland ecology of the Blue Nile basin. Three types of grazing land management (GLM) that commonly exist in the study area were considered under two slope gradients (<10% as gentle slope; 15-25% as steeper slope) to assess their effects on vegetation attributes and water erosion. The GLMs are i) restricted communal GLM- supported by collective management, ii) freely open communal GLM-
unrestrictedly open for every one to use it with all kind of animals, and iii) private holding GLM- for a private use mainly for making hay. Above ground herbaceous biomass yield was determined by clipping at ground level using 50 x 50 cm² quadrat along three parallel transects, where the transects were considered as replicates. Ground cover, as a percent of ground surface covered by vegetation (Elzinga et al., 1998), was estimated along each transect line using a plot estimate technique and a ground cover ranking class (Daubenmire, 1958). Species richness was determined by counting all vascular species along each transect using a 100 x 100 cm² quadrat. Runoff and soil loss were measured from a total of 18 plots each demarcated using galvanized iron sheets with three replications on each of GLMs and slope gradients. Soil bulk density was determined as described by Kubik and Nozdrovicky (2005). The various data sets were subjected to statistical analysis using a design frame of 3x2 factorial arrangement either in parametric or non-parametric method.

Condition of pasture on collectively managed grazing land varies in space and over time due to the normal variability in climate, vegetation and grazing management. To identify the key factors influencing sustainable use and productivity of restricted communal grazing land as controlled by collective management, a cross-sectional study was carried out in Farta district, north western Ethiopia (Chapter 5). About 9-13 villages were randomly selected from each of the four representative peasant associations (locally named as kebele), making up a total of 42 villages. Based on multistage sampling, about 140 smallholder farmers were selected to collect the desired data at a household level using a structured questionnaire. Required explanatory variables at village level were also collected using group interviews and from secondary data sources. Proxy indicators such as herbage dry matter yield, legume proportion, digestibility and ratio of carrying capacity to stocking rate were determined for each village to assess pasture condition of restricted communal grazing lands. The relationship between good pasture condition and other explanatory variables were modelled using logistic regression models.
6.3 Findings

6.3.1 Assessment of LWP

Livestock are important asset in the mixed crop/livestock production systems because of their multi-functionality. They serve many roles such as providing diverse animal products, giving draught power services (vital driver to crop production), providing manure for nutrient cycling, sourcing as immediate cash income and helping for accumulation of capital.

Water productivity can serve as a yardstick to appraise the extent of water depleted for agricultural production and thus help to device strategies for improving its efficient use. The concern is obviously because water has become a precious resource particularly in arid regions of the world (Qadir et al., 2003) and is also under growing pressure for its competitive but necessary uses (Molden et al. 2010). Regarding its application to livestock production, a concept of LWP has recently been developed by Peden et al. (2007) to clearly understand water accounting for livestock production including its implication to the production environment (e.g. degraded water).

In the present study, LWP showed a spatial variability across agro-ecologies and farming systems. It also varied between farmer’s wealth groups. LWP was significantly lower in RNF-rice/noug based farming system (0.059 USD m$^{-3}$) than in TMF- tef/finger millet based farming system (0.069 USD m$^{-3}$) or in BPF- barley/potato based farming system (0.074 USD m$^{-3}$). Results of this study exhibited that the volume of water required sustaining a kg live weight of animal increased towards lower altitude area (about 20% additional water) implying more water loss in RNF (Table 3.4). LWP increased towards relatively resource rich group of farmers showing better availability of feed resources (e.g. grass hay, more crop residues, others) and this makes animals to perform better than in the other wealth groups. The values of LWP obtained in the present study are in agreement with reports of Haileselassie et al. (2011) for the Indo-Ganga basin in India, Breugel et al. (2010) for the Nile basin, Owoyesigire et al. (2008) for the Nakasongola area in Uganda and Mekonnen et al. (2011) for the Lenche Dima watershed in Ethiopia.
Results of a group t-test analysis (SAS, 2002) revealed that an early off-take practice (at age of 2 years) increased LWP by more than a quarter (28%) over a late off-take practice (at age of 4 years). Extending the off-take time of those animals not required for replacement beyond 2 years of age would unnecessarily add the cost of their maintenance resulting in a lower LWP. In monitoring the incidence of mortality, we observed that the rate of livestock mortality ranged between 10% in equine and 20% in small ruminants, affecting mainly young stock. Consequently, it has posed a substantial impact on LWP.

6.3.2 Impact of GLM on vegetation attributes and hydrological properties

Carrying capacity of pastureland, in its most basic definition, determines the maximum livestock or wildlife population that a habitat or ecosystem can support on a sustainable basis. In fact, carrying capacity cannot be defined independently from livestock production and grazing land management objectives (McLeod et al., 2004) and thus should take both ecological and economic situations into account. In livestock grazing systems, livestock density affects vegetation production and condition which reduces the vegetation to a sub-climax (Vetter, 2005). It is, therefore, up to the herders and local support institutions to help balance the regeneration of the pastures and the grazing pressure of the livestock to either make it or break it. Carrying capacity is often taken as a scientific standard to judge whether a given pastureland is overgrazed or not. In the present study, livestock density rose above carrying capacity of the natural pasture across all types of GLM, implying overstocking problem (Chapter 4). Nonetheless, the gap was exceptionally very wide in freely open communal GLM (Fig. 4.3) since its access is unlimited to everyone in the village and is exposed to a free ride by few individuals. Subsequently, the likelihood of open communal grazing lands to face overgrazing problem and severe land degradation is higher. This particular study could not detect significant interaction effect between GLM and slope on vegetation attributes of natural pastures. However, above ground herbaceous biomass yield inclined to be higher in private holding and restricted communal GLMs at gentle slopes (<10%). This was so perhaps because of its association mainly to less grazing pressure and pasture resting management, and with relatively less soil erosion incidence at gentle slopes. Moreover, we assessed that both restricted communal and private holding GLMs had greater than 75% ground cover, meeting the threshold level required for soil protection as
recommended by Sanjari et al. (2010). In agreement to this, McIvor et al. (1995) also demonstrated how runoff and soil movement are related to cover levels on grazing lands.

Livestock grazing effects on infiltration, runoff, erosion, on-site water use and consequent downstream water impacts are of great concern particularly in the highland agriculture (Mwendera and Mohamed Saleem, 1997). Surface runoff and soil loss on grasslands are altered by grazing management, surface conditions, and by the type and amount of vegetation cover (Haan et al., 2006; Bartley et al., 2010). Results of non-parametric analysis showed that severity of runoff and soil erosion was greatest in freely open GLM at steeper slopes (Chapter 4), since the interaction between GLM and slope was significant (Table 4.3). The reason might partly be associated with more grazing pressure at steeper slopes towards the rainy season due to the tendency of herders to keep their livestock at a relatively drained ground, which is steep in slope. Concurrent with the present results, Mwendera et al. (1997) reported that there is the risk of soil erosion rates exceeding tolerable limits when grazing pressure is heavier on pasturelands with greater than 6% slopes. Although the problem of overgrazing is complex in its dimension, it can be mitigated through collective management interventions as the present empirical results indicate that restricted communal GLM alone reduced runoff by more than 40% and curbed soil loss by more than 50% compared to freely open communal GLM. The implication to the mixed farming systems of the Ethiopian highlands is that reducing the present stocking rate by bringing down the livestock holding at a household level is a prerequisite in order to realize improved grazing land management in the entire system.

6.3.3 Factors affecting good pasture condition of communal grazing lands managed in collective action

Sustainable use of a pasture generally involves two basic processes, which are plant growth and re-growth on one hand and its consumption by animals on the other. The trade-offs in sustaining good pasture condition and increasing benefits from livestock grazing is of a practical challenge that needs to be resolved to secure livelihoods of the herdsmen and the environment in the long run. Production is only achieved when feed intake is in excess of maintenance requirements and a relatively small increase in feed quality will lead to a large increase in production (Vallentine, 2001). In chapter 5, the study focused on exploring what
determinant factors are affecting pasture condition in collective management of communal grazing land of north western Ethiopia, to help in formulating a practical implementation strategy for improving pasture productivity. Logistic regression analysis is often used to investigate the relationship between ordinate/discrete response variables and a set of explanatory independent variables. In this study, a binary logit model was used and found the model is fit to explain the dependent variables (dry matter yield, legume proportion, nutritive value and ratio of carrying capacity to stocking rate) taken as proxies to pasture condition.

Soil fertility of restricted communal grazing land significantly affected the legume proportion of a pasture. Legumes are generally more sensitive than forage grasses to nutrient deficiencies (Botha, 2002). Therefore, one has to understand what soil condition affects the competitive growth of legume in the mixed pasture sward (Schwinning and Parson, 1996; Baba et al., 2011), besides the type of grazing system. The nutritive value of a pasture was significantly influenced by the size of restricted communal grazing land, total oxen number in a village and soil fertility. The inverse relationship observed between oxen number and nutritive value might probably be associated with the dominance of unpalatable pasture species in response to a higher grazing pressure. Ratio of carrying capacity to stocking rate was also significantly influenced by the size of restricted communal grazing land and oxen number in a village. The ordinary least squares estimates (OLS) showed dry matter yield was affected most by pasture resting period. Since dry matter yield is inversely related to quality attributes (De Leeuw and Tothill, 1990), it needs to reconcile the two components so as not to increase the quantity at the very expense of nutritional quality. Improved grazing land management likely results in good pasture condition where this in turn will increases carrying capacity and livestock productivity. Maintaining good pasture condition keeps healthy ecosystem services so long as optimum stocking rate is maintained. This helps to enhance livestock water productivity through improving the feeding systems, and perhaps through lowering mortality and morbidity of animals.

6.4. Implications, future research and development needs

There is an increasing interest for sustainable forms of livestock production systems which will provide a balance relationship between environmental, socio-cultural and economic factors (Nardone et al., 2004). The present study demonstrated that overstocking is the main
problem in the highlands of Ethiopia (Chapter 4) that has resulted in deterioration of the available grazing lands. In addition to this, free access to communal grazing land is the root source of mismanagement on common hold grazing resource (Haileselassie et al., 2009). The continuing expansion of crop cultivation into grazing lands has not only decreased communal grazing land but also has affected the overall ecosystem services particularly breeding ground of peculiar birds. On the other hand, livestock grazing has been pushed to patches of steep slopping areas where the effect of livestock on the environment is downward spiral. To mitigate this problem, there should be a clear cut land use policy that enhances efficient use of the existing natural resource base to the right choice of agricultural enterprise in order to ensure its sustainability. To come up with an appropriate land use policy instrument, it is necessary to carefully investigate social perceptions and local institutional settings that will have huge impact on the success rate of the new change to make.

Because of the intricacies and variability of the animal-forage-land biological system, the management of grazing lands may require as much art as science to make continual adjustments as needed (Vallentine, 2001). The concept of grazing management implies decision making. In the highlands of Ethiopia, the ever increasing rural population demanded croplands to expand and this in turn required livestock number to increase for providing sufficient draught power. But, the challenge is grazing land resource is in a decreasing trend despite the increasing number of livestock. This has put a pressing pressure on natural resource management leading to severe land degradation. Besides, the unsolved question on the equitable use of communal grazing land resource complicates the problem of land degradation. The reality at the ground reveals that the existing livestock density must be reduced to a number that the available feed resource base can adequately support them for a long-term. This entails an investigation on practical mechanisms to reduce stocking rate in the highlands of Ethiopia, which requires supportive and sound initiative of livestock holding policy. A reduction of the stocking rate is expected to result in oxen shortage that will have a negative effect on crop cultivation. Researchers may need to look at other alternatives such as introduction of simple machinery, suitable for ploughing croplands at smallholding scale. The other option is the need to explore appropriate conservation agriculture that has relatively lower farm power requirements for cropland preparation.
To improve pasture productivity of grazing land, it is necessary to follow appropriate grazing land management. The present results (Chapter 4 and 5) demonstrated that checking on grazing pressure and resting pasture during growing season improved pasture production and reduced the rate of soil erosion substantially. So long as communal grazing land exists, the management and utilization of this grazing resource needs to be changed and be regulated to reverse the downward spiral of land degradation and to restore healthy pasture ecosystem. This can be possible only when the community in question is involved in the decision making process and being supported by local institutions for the implementation. The present study clearly pointed out the significance of local institutions and role of by-laws to uphold restricted grazing land management on selected common hold grazing resources of north-western Ethiopia. It is therefore very important to investigate the socio-economic circumstances of a target group in order to accommodate the diverse situations of small holder farmers in promoting the desired innovation (Waters-Bayer and Bayer, 2009) and also to smooth out inequalities (Amede et al., 2009) in an attempt to improve communal grazing land management.

6.5 Conclusions and recommendations

The present study assessed LWP in the mixed farming systems of the Ethiopian highlands. It seems that LWP is lower than crop water productivity within the same management unit. Among the millennia of factors affecting LWP, empirical results of the present study showed that livestock mortality considerably reduced LWP. It is, thus, important to minimize the incidence of mortality in a herd or flock through improving feeding and health care managements since it makes huge contribution in enhancing LWP.

Early off-take practice increased LWP by more than a quarter over that of late off-take counterpart. This practice manages the extra animals, not required for replacement to the breeding herd, at younger age when their maintenance requirement is lower. They also leave the herd when they have more preference in the market. Early off-take practice has a positive implication on easing the competition on scarcely available feed resource base of the farm. It is recommendable to encourage farmers to adapt early off-take practice by providing them required extension services including better market linkage.
LWP tended to increase towards a livestock species that are kept to provide multiple outputs and services. To this effect, cattle had a higher LWP than equine or small ruminants. Besides, cattle have better digestion efficiency when utilizing low quality feedstuffs like crop residue which is commonly available in the mixed farming systems of the highlands of Ethiopia. The efficiency in feed utilization contributes to increase LWP.

Type of grazing land management had significantly affected vegetation attributes and hydrological properties of communal grazing lands. Overstocking problem was evident in freely open communal grazing land. This situation has exposed freely open communal grazing land to overgrazing that has resulted in deterioration of the pasture. Grazing land degradation was severe on steeper sloping areas. The ongoing mismanagement of communal grazing land reduced its carrying capacity (by lowering its production potential) in addition to losses of its fertile soil and biodiversity. The overall impact of overstocking management seems to ultimately reduce LWP.

Results of the present study demonstrated that collective management of communal grazing land has positively contributed to a sustainable use of common hold pastureland by regulating grazing pressure and pasture resting period. Resting pasture during its growing period helps the pasture to be more resilient to grazing effects and restore its vegetation. It is noteworthy to investigate on local institutions and perceptions of smallholder farmers on the mechanisms, how open communal grazing land can be managed appropriately to ensure its sustainable use and the possible ways of reducing livestock holding per household.

References


Summary

In the highlands of Ethiopia, livestock fulfil the fundamental functions required by the mixed crop-livestock farming systems. Besides, they provide valuable products significantly contributing to livelihoods of the farming community. One of the limiting factors to livestock production, in north western Ethiopia, is access to water resource. Given the rain-fed agriculture prevailing in this area, the seasonal water scarcity during the long dry season severely affects availability of feeds. Worsening the situation, overstocking problem continues to be an additional challenge leading to overgrazing and degradation of communal grazing lands. Of all agricultural activities, livestock production is generally considered as water intensive system. It is, thus, imperative to evaluate livestock productivity from the perspective of water use efficiency to help comprehend strategies that are useful for increasing water productivity and, from the perspective of grazing resource management to improve its sustainability. The specific objectives of the present study were to:

- provide insights on the methodology of livestock water productivity (LWP) estimation using water footprint approach and relate it to life cycle assessment (LCA) framework,
- assess LWP from empirical evidences across different land-use mosaics of the mixed crop/livestock production systems in Gumara watershed,
- investigate the impact of collective management of communal grazing land on lessening the problem of land degradation and sustaining pasture production, and
- identify the determinant factors influencing sustainable use and productivity of natural pasture ecosystem pertaining to collective management of communal grazing lands.

To achieve the above stated objectives, a set of studies were carried out in Gumara watershed representing the upper Blue Nile basin, north western Ethiopia. To refine and standardize the methodology for determining LWP, an extensive literature review was made on the concepts of LWP relating it to life cycle assessment (LCA) and water footprint. After refining the concept and methodological approach on LWP, an on-farm monitoring study was conducted in Gumara watershed to collect farm data from crop and livestock productions that were required for estimating LWP across different agro-ecologies and mixed farming systems. The watershed was clustered into three distinct mosaics of mixed crop-livestock farming systems namely; rice-noug based mixed crop livestock farming (RNF), tef-finger millet based mixed...
crop-livestock farming (TMF), and barley-potato based mixed crop-livestock farming (BPF). Livestock outputs and services including their benefit as insurance were quantified over the herd’s productive life time. The water required for production of feeds and crop residues was estimated using CROPWAT model. The water used for drinking over the herd’s life time was also estimated for different livestock species across their age classes. LWP was thus evaluated across different categories of mixed farming systems to assess its spatial pattern.

To study the impact of livestock grazing management on pastureland ecosystem, a field experiment was undertaken at Maynet village in Farta district, north western Ethiopia. Three types of grazing land management (GLM) that commonly exist in the study area were considered under two slope gradients (<10% as gentle slope; 15-25% as steeper slope). The GLM treatments were; a) restricted communal GLM- supported by collective management, b) freely open communal GLM- unrestrictedly open for everyone to use it with all kinds of his animals, and c) private holding GLM- limited to a private use by a household mainly for making hay. Above ground herbaceous biomass yield, ground cover and species richness were assessed across three parallel transects on each GLM and slope. Runoff and soil loss were measured from each plot demarcated by galvanized iron sheet and replicated three times across each type of GLMs and slopes.

To identify the key factors influencing condition of natural pasture under collective management, a cross-sectional study was carried out in Farta district. This study involved 42 villages to collect data at community level using group interviews and 140 smallholder farmers to collect data at household level using structured questionnaire. Proxy indicators for condition of a pasture like dry matter yield, legume proportion, digestibility, and ratio of carrying capacity to stocking rate were determined from restricted communal grazing land of each village. Logistic regression model was used to establish the relationship between good pasture condition and selected explanatory variables.

LWP was significantly (P<0.05) different between clusters of mixed farming systems. It was found highest in BPF (0.074 USD m$^{-3}$) and lowest in RNF (0.059 USD m$^{-3}$). This result implied that about 20% additional water is required to sustain a kg live weight of an animal towards the lower altitude area mainly because of higher water loss through evapotranspiration. LWP appeared to increase towards wealthier group of farmers. A group t-test
analysis showed that early off-take management regime (at age of 2 years) increased LWP by 28% as compared to that of late off-take management regime (at age of 4 years. Hence, extending off-take time beyond 2 years of age for livestock not required as replacement simply adds unnecessary cost in their maintenance and ultimately lowers LWP.

Results of the present study in chapter 4 indicated that overstocking problem was severe in freely open communal GLM exceeding much more than ten times of carrying capacity of the communal grazing land. This situation exposed the grazing land to overgrazing and land degradation. In another scenario, we observed that restricted communal and private holding GLMs maintained greater than 75% ground cover, which meets the threshold level required to combat soil erosion. The main reasons for this improvement are related to less grazing pressure and pasture resting managements. A non-parametric analysis showed that soil loss and runoff was greatest in feely open communal GLM at steeper slopes. This might be because of higher grazing pressure on steeper plots during the rainy season in an attempt to keep livestock on relatively drained site. Overgrazing problem on open communal grazing lands can be mitigated through extending collective management intervention as the present empirical results prove that restricted communal GLM suppressed runoff and soil loss by about 50% bringing it down to a tolerable level. Outputs of the logistic regression analysis (Chapter 5) showed that condition of a pasture in collective management is strongly influenced by soil fertility, total number of oxen in a village, pasture resting period and availability of alternative feed resources like crop residue. This study recommends that it is useful to develop key indicators for assessing and monitoring pasture condition of communal grazing lands that help in devising practical and appropriate strategies for improving pasture management and grazing systems.
Zusammenfassung


- versorgen Sie Einblicke auf der Methodik des Viehbestandswassersproduktivität (LWP) Schätzung, die Wasserfußabdruckannäherung benutzt, und erzählen Sie ihm Lebenszykluseinschätzung (LCA) Rahmen,
- schätzt LWP von empirischen Beweisen über verschiedene Bodennutzungsmosaiks von der gemischten Ernte/Viehbeständen Produktionssystemen in Gumara Wasserscheide, Untersuchen Sie den Schlag der gesamter Leitung des Gemeindestreifenslands auf Vermindern des Problems der Landsabbau und Unterstützungsweidenproduktion, und
- identifiziert die Bestimmungsfaktorfaktoren, die sustainable Gebrauch und Produktivität der natürlicher Weide Ökosystem beeinflussen, betreffend gesamte Leitung von Gemeindestreifenländern.

Um das über erklärte Ziele ein Satz von Studien zu erreichen, wurden in Gumara Wasserscheide ausgeführt, die das obere Blaue Nil Becken vertritt, Norden westliches Äthiopien. Zu raffinieren und die Methodik zur Bestimmen von LWP zu standardisieren, wurde eine umfangreiche Literaturnachprüfung auf den Begriffen des LWP Erzählens es zu Lebenszykluseinschätzung (LCA) und Wasserfußabdruck gemacht. Nachdem den Begriff


Um die Schlüsselfaktoren zu identifizieren, die Bedingung der natürlicher Weide unter gesamter Leitung beeinflussen, wurde ein böse-zerlegbares Studium in Farta Bezirk ausgeführt. Dieses Studium hat 42 Dörfer verwickelt, Daten an Gemeinschaftshöhe zu sammeln, benutzend gruppiert Interviews und 140 smallholder Landwirte, Daten an

LWP war bedeutend (P<0.05) verschieden zwischen Haufen von gemischt bewirtschaftend Systeme. Es wurde am höchsten in BPF (0,074 GEBRAUCHTEN m-3) und am niedrigsten in RNF gefunden (0,059 GEBRAUCHT m-3). Dieses Ergebnis hat besagt, dass ungefähr 20 % zusätzliches Wasser erfordert wird, ein Kg zu stützen, lebt Gewicht eines Tiers nach dem unteren Höhengebiet hauptsächlich wegen höheren Wassersverlustes durch Evapotranspiration. LWP ist erschienen, nach wohlhabenderen Gruppe von Landwirten zu vermehren. Eine gruppen t-Prüfungsanalyse hat jenes frühe Aufnahmeleitungsregime (an Alter von 2 Jahren) hat vermehrt LWP durch 28 % im Vergleich dazu des spät Ab-Aufnahmeleitungsregimes vorgezeigt (an Alter von 4 Jahren. Deshalb Ab-Aufnahme Zeit über hinaus 2 Jahre des Alters für Viehbestand nicht erfordert aus, während Ersetzung einfach hinzufügt, dass unnötige Kosten in ihrer Wartung und letzten Endes LWP herunterlässt.

beweisen, dass eingeschränkt Gemeinde GLM runoff und Erdenverlust durch ungefähr 50 %
Bringen es hinunter zu einer erträglichen Höhe unterdrückt hat. Ausgaben der logistischen
Regressionsanalyse (Kapitels 5) haben jene Bedingung einer Weide in gesamter Leitung stark
wird beeinflusst von Erdenfruchtbarkeit, gesamte Zahl von Ochsen in einem Dorf, Weide
ruhend Periode und Verfügbarkeit des alternativen Futters Ressourcen wie Erntenrückstand
gezeigt. Dieses Studium empfiehlt, dass es nützlich ist, Schlüsselanzeiger für Schätzen und
Überwachungsweidenbedingung von Gemeindestreifenländern zu entwickeln, die beim
Ausdenken praktische und passende Strategien für Verbessernweidenleitung und
Streifensysteme helfen.
Autobiography

Mengistu Alemayehu Asfaw, the youngest child in the family, was born in September 1965 to his mother Mrs. Mulunesh Woldegiorgis and father Mr. Alemayehu Asfaw at Koffele-Arsi, 275 Km south of Addis Ababa, in Oromia Region. He started schooling at 7 of his age at Koffele Lutheran Missionary Elementary School. After successfully passing the Ethiopian School Leaving Certificate Examination (ESLCE) in 1983, he joined the then Alemaya University of Agriculture.

In July 1987, Mr. Asfaw graduated with a B.Sc. in Agriculture (Animal Sciences) and was employed by the Institute of Agricultural Research (IAR). He was stationed at Melka Werer Agricultural Research Center and served for six years in Feeds and Nutrition Research Division as Assistant Research Officer. In October 1993, he joined the graduate school of the then Alemaya University of Agriculture to do his Master of Science in Animal Production and graduated in 1997. Right after his MSc degree, he was transferred to Holetta Agricultural Research Center (HARC) where he has served for 13 years at various responsibility levels. He coordinated Animal Power Research program at a national level and participated in many other livestock research undertakings. Mr. Asfaw has also served as a Center Director for Holetta Agricultural Research Center before proceeding to Humboldt University of Berlin to pursue his PhD study in the Department of Animal Sciences under the fellowship of the International Livestock Research Institute with a fund grant from the CGIAR Challenge Program on Water and Food (CPWF). Upon completion of his doctoral degree, he will return to HARC and share responsibilities with other colleagues to undertake applied research on livestock and feed resources.

List of publications

Published journal articles


Submitted, under review


To be submitted


Working documents

8 Agricultural Constraints identification survey for research and development options in M2-5 sub-agro ecological zones.

9 Participatory farming systems characterization and intervention options for Sekota Woreda, Wag Himra zone
MSc thesis

Conference proceedings
16 Mengistu Alemayehu 2004. The genetic resources perspective of equines in Ethiopia


22 Mengistu Alemayehu, Jon Verhaeren, Mesfin Asfaw, Aster Yohannes and Gemechu Kebede 2000. Survey of people arriving at and departing from markets in the three


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