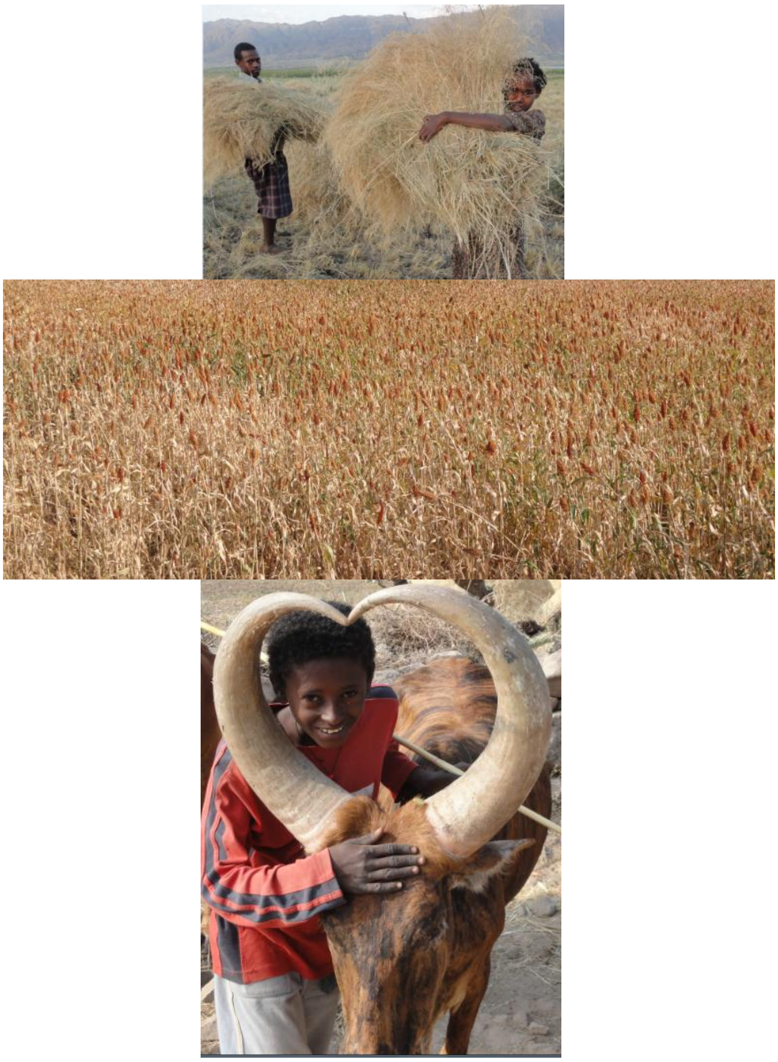
MSc Thesis Plant Production Systems

Crop residue management and farm productivity in smallholder crop-livestock system of dry land North Wollo, Ethiopia



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Crop residue management and farm productivity in smallholder crop-livestock system of dry land North Wollo, Ethiopia

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Dedication

My mother W/ro Yemenzwork Abebe and my father Ato Terefe Diressie were determinant for my education at my early school times. During my study abroad my wife, W/ro Almaz Abebe, shouldered the entire responsibility of taking care of our children and heading the family. The feeling of loneliness and difficulties in caring kids together with teaching responsibility was really challenging for her; but the stress reduced due to dedicated support of Hasabe Terefe and Kasech Terefe to the extent that Hasabe decided to stop searching for job and earn her living. Instead, she devoted her time to care our two children. She tolerated many difficulties and challenges to ensure the happiness of our kids. My son, Yoseph Hailu and my daughter Edlawit Hailu, also missed the love of their father in their infant stage. Though the pain of missing them is extremely high for me, I have tolerated it knowing the objective of my study; but they only know that their father is not around them when they need him. In GOD’s will, all efforts bear successful fruit. Thanks to God who gives us the strength to tolerate challenges and bless our paths. Therefore, with pleasure, I dedicate this Thesis to my beloved family.

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Abstract

Farmers at Chorie, North Wollo, are smallholders engaged in a mixed crop-livestock system. In Ethiopia, smallholder crop-livestock farming systems produce about 90% of the total grain production and keep 70% the livestock. Mixed farming systems also support two-third of the world population. Despite the importance of the system, the tradeoffs between food and feed productions are major constraints for system sustainability. The general objective of this study is to explore and analyze crop residue and manure management practices and their influence on farm productivity. Data on resource allocation and other socio-economic aspects were gathered using semi-structured questionnaire. Current biomass production, N content and digestibility of crop residues (teff straw and different parts of sorghum stover) and soil nutrient status of the area were studied from fields of sixteen farmers. Yield data were collected at normal harvesting period of the main cropping season by taking samples using quadrants of sizes $0.25m^2$ for teff and $1m^2$ for sorghum. Soil samples were performed using Edelman auger from the top 0-30 cm depth. Different varieties of teff and sorghum were sampled. Accordingly, from teff varieties, *Sikuar magna* produces higher grain (P=0.001) and both *Sikuar magna* and *Abat magna* produce higher straw (P=0.000) yields. However, *Tikurie* showed higher straw digestibility than *Abat magna*(P=0.040). From sorghum varieties, *Jigurtie* produces higher grain yield (P=0.000) whereas *Abola* produces higher stover yield (P=0.000). In N content, significant differences were observed at leaf sheath (P=0.023), middle and lower stem parts (P=0.014; 0.036 respectively); whereas, in digestibility, differences are only at lower stem parts (P =0.029). High percentage of maize and sorghum grains are used for home consumption but teff grain is used for sale. About 90% of teff straw, 74% sorghum and 81% of maize stovers are used for livestock feed as stubble grazing and stall feeding. Allocation of sorghum stover for fuel is high next to livestock feed. Manure sharing is about 46% and 28% for fuel and for fertilizer respectively; the remaining is left un-used. Nutrient contents and physical structures of arable plots are declining. To reverse this situation, farmers should retain about 70% of crop residues in the field; but retention should ensure incorporation into the soil. Scarcities of feed, fire wood, labor; gender of a household head and open access to crop residues are influencing factors for making decisions. Therefore, the study area needs strong interventions to: a) increase biomass production to satisfy the competing uses of crop residues, b) improve manure usage as fertilizer, c) enhance soil and water conservation practices, d) diversify alternative livestock feeds and energy sources, and e) introduce legal support for crop residues property right and for land renting/sharing agreements.

Key words: crop residue; feed; livestock; manure; soil fertility; farm type; main crop plots

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Abbreviations

AfricaNUANCES	Nutrient Use in Animal and Crop systems-Efficiencies and Scales
ANOVA	Analysis of variance
C	carbon
CEC	Cation exchange capacity
CROPSIM	Crop production SIMulator
dm	dry matter
FIELD	Field scale resource Interactions, use Efficiencies and Long term soil fertility Development
Fig.	Figure
Figs	Figures
FL	farmer group that have Fewer livestock and Larger crop lands
FS	farmer group that have Fewer livestock and Smaller crop lands
ha	hectare
ILRI	International Livestock Research Institute
Ivomd	Invitro organic matter digestibility
K	potassium
kg	Kill gram
km	kilo meters
LSD	Least Significant Difference
masl	meters above sea level
MATLB	MATrix LaBoratory (a numerical computing environment and fourth-generation programming language)
ME	metabolizable energy
Mj	Mega joule
ML	farmer group that have More livestock and Larger crop lands
mm	millimeter
MS	farmer group that have More livestock and Smaller crop lands
N	nitrogen
N-dm%	nitrogen content on percent dry mater basis
NIRS	Near Infrared Reflectance Spectroscopy
^{o}C	degree Celsius
P	phosphorus
PH	Scale used to measure acidity and alkalinity
Ppm	Parts per million
RF	Rain fall
SLP	System-wide Livestock Program
SOC	soil organic carbon

TLU	Tropical Livestock Units

Chapter 1. Introduction

1.1 Background information

Farmers at Chorie, North Wollo, are smallholders engaged in a mixed crop-livestock system. Small holder crop-livestock systems are dominant in Ethiopia. In the country, these systems produce about 90% of the total grain production (Anderson, 1987; Jagtap and Amissah, 1999) and keep about 70% of the livestock (Shitahun, 2009). One can see the potential of this smallholder crop-livestock integrated farming to provide food and feed to peoples' livelihood in the country. The systems also play significant role in other parts of the developing world. According to Herrero et al. (2010), mixed crop-livestock farming systems support the world's 1 billion poor people; they reported that two-third (2/3) of the global population live in small holder crop-livestock systems.

Crop-livestock integrated farming is complex and dynamic with many interacting biophysical resources (Mark et al., 2009) and socio-economic factors. Productivity and sustainability of a system depends on appropriate decisions on resource allocations on to the different sectors and efficient use of available resources. Key resources that can form constraints for crop-livestock systems include land, livestock, feed, labor, soil nutrients, cash and market (Giller et al., 2006; 2009). Decisions on these resources are influenced by a number of factors such as rainfall, tenure security, household endowments (Di Falco et al., 2010), gender, as well as short term and long term needs of households. Since the most responsible person to make decision is the head of the household, gender of the head of the household is an important factor for resource allocation.

In the study area, Chorie, there are households headed by different genders (male or female). Males are the dominant decision makers on land management activities, selection of crop varieties, management of crop residues and livestock activities. Females in male headed households do not make decision independently; sometimes they decide jointly with their husband. Female headed households depend on decisions of family members (son/daughter if available) or land tillers/shareholders. When female headed households rent out their crop land, the renter do not worry about fertility management of rented plots aiming at short-term benefits. Likewise, lands given for share are managed after all land activities are performed for the private plots so that there is a delay in the timing of land preparation, weeding and harvesting activities for the shared plots. Delayed land activities also influence the type of crop to be planted which determines the yield at the end. As a result of these, productivity and sustainability of rented/shared plots is at risk.

Different varieties of teff (*Eragrostis teff*), sorghum (*Sorghu bicolor* L. Moench) and maize (*Zea mays* L.) are grown in the area. The availability of alternative varieties increases farmers' flexibility to respond to climate, market and social variations (di Falco et al., 2010). For example, farmers at Chorie village, plant *Bunign* (early maturing teff variety) if they expect food shortage at September and October. Otherwise, they plant market demanded variety “*Sikuar magna*”. Variety selection for sorghum depends on rain fall. High yielding varieties (*Abola* and *Jigurtie*) require longer periods to mature. They can be planted if there is sufficient rain in April and May. The low yielding but early maturing variety *Wedhakir* is used as an alternative if there is failure of rain in these months. Mostly, teff grain is used for sale whereas, sorghum and maize grains are used for home consumption. Residues from both teff, sorghum and maize crops are mainly used for livestock feed. Moreover, sorghum stover is also used as energy source for cooking in the house.

In the northern part of Ethiopia, where there is pasture land, 45% of livestock feed is derived from crop residues (Berhanu et al., 2002). However, in areas where there is limited pasture land, crop residues account over 90% of total livestock feed including stubble grazing and stall feeding (de Leeuw, 1997). Farmers at Chorie, have no pasture or grass land for their livestock year round feed supply. Their pasture area is common reserve for selective grazing (high value livestock like a milking cow or an ox) at severe feed shortage in the rainy season (in the period when farmers have exhausted the stored straw/stover and green fodders are not ready yet to fill the gap). Hence, crop residues form the single most important feed source for farmers in the area. Crop residues are also highly demanded livestock feed in other parts of the developing world, especially in semi-arid zones (Latham, 1997; Adrian, 1997; Powell and Williams, 1993).

At Chorie, farmers cut the residues close to soil surface during crop harvesting, separate the grain by threshing, transport it to homestead and store for later use. The part of crop residue left in the field is subject to repeated grazing during the prolonged dry season (November to June; but livestock get sufficient amount of feed by grazing on crop residues only up to February). The main reason for using crop residues for livestock feed is because of the limited availability of range land and the existing livestock types. Farmers at Chorie keep cattle, sheep, goat, camel and donkey; sometimes farmers own composition of two or three livestock types but most of the time they have only one type. Few farmers own small ruminants such as sheep and goat, and pack animals such as camel and donkey. Sheep and goat normally obtain their feed from grazing on pasture lands throughout the year. The decreased number of these animals could be due to shrinkage of pasture lands as a factor of increasing land cultivation due to human population increase.

The dominant livestock owned by farmers at the study area is local bread cattle (*Raya breed*). According to Rufino (2008), cattle are also the main livestock type in other African smallholder crop-livestock systems. Cattle have the ability to digest low quality feeds and roughages (Williams et al., 1997). They graze stubble in the field after main crop harvesting and also feed in stall the stored residues (mainly in the months March to August with increasing order).

This research is part of the SLP-ILRI (System wide Livestock Program- International Livestock Research Institute) research project entitled "Optimizing livelihood and environmental benefits from crop residues in smallholder crop-livestock systems in sub-Saharan Africa and South Asia: regional case studies". In Africa the project conducts research at South Africa, West Africa and East Africa. Kenya and Ethiopia are the East Africa countries for the project. In Ethiopia there are two sites: Nekemte (western Ethiopia) and Kobo (North-Eastern Ethiopia); at each site eight villages are selected. This thesis explores farming system at Chorie village, one of the eight selected villages at Kobo site. The village is one of the two near-near (near to market- near to road access) villages. In the village, farmers settled on higher slopes following the contour of the mountain. Their main arable plots are far from home. Majority of the farmers own less than 1.5 ha of land.

In the study area, farmers depend on crop residues for their livestock feed through direct grazing in the field and in stall after livestock clear stubbles and when crop lands are planted. However, they do not apply soil fertility inputs such as manure or chemical fertilizer to the main arable plots. In crop-livestock farming, nutrient cycling of crop residues in to manure (Harris 2002; Zingore et al., 2007a; Samaddar, 2008) governs system sustainability but farmers in the study area do not sufficiently use manure for soils while they total depend on crop residue for their livestock feed. Furthermore, they use sorghum stover as energy source for cooking. This practice without soil amendment strategies resulted in severe soil fertility degradation. This report presents investigation of current biomass production and crop residue and manure management practices of farmers at Chorie village, North Wollo, Ethiopia. Furthermore, it describes factors that are influencing farmers' decisions, and indicates the long-term impacts of current practices on soil fertility and land productivity status.

1.2 Research questions

1. How important are crop residues and manure for farm productivity in smallholder crop-livestock system?
2. What is the current crop residue and manure management practice of farmers at Chorie village? Are there differences among farm types or not?
3. What are influencing factors for farmers' decisions on resource allocation?
4. How important is the influence of current crop residue and manure management practices on future land productivity?

1.3 Objectives

General objective:- the general objective of this research is to explore and analyze how crop residues and manure management practices influence farm productivity in smallholder crop-livestock farming systems.

Specific objectives:-the specific objectives of this research are:

- To review literatures on the role of crop residues and manure in a mixed farming system
- To characterize the farming system (crops and livestock) of Chorie village
- To quantify biomass production, analyze N content and digestibility of crop residues
- To understand farmers' resource allocation, decision making processes and influencing factors for decision makings
- To assess long-term impact of crop residues and manure management practices on land productivity

Chapter 2. Literature review

2.1 Role of crop residues as livestock feed

According to Zingore et al. (2007a), livestock have multiple functions in the economy of smallholder farms in sub-Saharan Africa. To mention few of the benefits, they are major capital investment, play significant role in food security through products such as milk and meat; they provide labor for land cultivation and threshing, and they add nutrients to soils through manure (Tangka et al., 2000; Herrero et al., 2010). Furthermore, livestock play significant role in recycling nutrients from pasture lands and grazing stubbles to arable plots. The economic and social values of livestock ensure their importance in the mixed production system. However, feed shortage due to land use changes from grazing/pasture lands to crop lands caused by population growth (Anderson, 1987; Berhanu et al, 2002; Harris, 2002; Ebanyat et al., 2010) limits the number and type of livestock. The problem forced farmers to shift their feeding strategy from pasture/range source to crop residues.

Crop residues are considered as by-products in crop production activities but they are vital source of livestock feed in the mixed crop-livestock system (Williams et al., 1997). Crops provide residues (straws/stover) and un-marketable surpluses to feed livestock. This role may not be significant in places where there is range land that livestock can get considerable amount of feed. However, since crop-livestock farming system is historically created due to increased human populations (Harris, 2002), in the process, range lands are converted to crop lands; and thus, major feed sources for livestock are becoming crop by-products such as the residues. Livestock, especially large ruminants, convert these materials into high value products: milk and meat for human consumption and dung/manure which can be returned back to the soil. Nevertheless, over use of crop residues for livestock feed could result in declining productivity of the farm due to extreme nutrient export from arable plots.

Strategies to ensure sustainable productivity of mixed crop-livestock systems should focus on balancing the flow of nutrients between the crop and livestock sectors (Tittonell et al., 2008; Benjamin et al., 2010). This can be done by efficient use of manure for soil fertility management, substantial amount of crop residue retention in the field and additional inputs from outside of the field to replenish nutrients that are lost in the process. Maintaining soil fertility guarantees good crop biomass production and sustainable crop residues supply for livestock; hence sustaining the nutrient flow.

2.2 Crop residue allocation and trade-offs

Poor soil organic matter content and limited nutrient availability to crops are key problems to low agricultural productivity of sub-Saharan Africa (Schlecht and Hiernaux, 2004). The physical, chemical and biological properties of soils can be improved through addition of organic materials (Waswa et al., 2007). The level of organic matter or carbon in agricultural soils depends on additions from crop residues and manure, and losses from erosion and decomposition (Beauchamp and Voroney, 1994). Benjamin et al. (2010) identified that crops that produce more residues have greater potential for increasing soil organic carbon than crops which produce low crop residues. The finding is in line with Tittonell et al. (2008). According to their report carbon supply to soils is a factor of biomass yields, harvest index and the proportion of feed carbon retained in the manure. In crop-livestock mixed system where there is high percentage of crop residue allocation for feed, soil C maintenance is only from manure and root-C inputs.

Besides livestock feed and other uses like construction materials and energy supply, crop residues are extremely important to soils to improve its chemical and physical characteristics. They enhance soil structure, reduce soil erosion and improve water availability to plants (Latham, 1997; Tittonell et al., 2008). The work done by Hartkamp et al. (2004) in Mexico revealed that retention of small amount of crop residues (1.5t ha^{-1}) doubled maize yield even at low rain fall areas. The result shows 40% increase in soil water content whereas 50% and 80% decrease in surface and soil particles run off respectively.

Crop residues are also nutrient sources for soil fertility improvement. Crop residues represent about half of the nutrients exported through the main commodity production (Unger 1990, cited in Latham, 1997). Therefore, substantial amounts of crop residue retention increase soil fertility. The effect is high when combined with other nutrient sources like manure or inorganic fertilizer (Aggarwal et al., 1997). Addition of crop residues and farm yard manure improved N and P availability, soil water availability, soil organic matter content and enzyme activity compared to no residue treatments. Furthermore, their study showed higher mineral fertilizer use efficiency for crop residue applied plots. This soil fertility enhancement increased grain and straw yields.

The research done by Tittonell et al. (2008) also confirmed the importance of crop residues to increase fertilizer use efficiency in soil nutrient restoration activities. Application of basal fertilizer rate maintained initial soil C content on fertile fields where 70% of crop residues were retained. This was not possible on fields where 10% of crop residues were maintained. From these findings, one can appreciate the role of crop residues in sustaining soil fertility and productivity. However, Aggarwal et al. (1997) reported that the benefit from crop residues and manure in tropical regions may not be as evident as for temperate regions because of rapid oxidation in the area. Yet, crop residues are basic components of a number of agronomic technologies.

Effective soil and water conservation practices are possible when crop residues are adequately available (Unger et al., 1991; 1997). In dry land areas moisture and soil characteristics are major production limiting factors. Since crop residues have the potential to reduce soil degradation and improve water infiltration, they can be used as a strategic intervention to improve land productivity through effective soil and water conservation practices. Thus, crop residue allocation for livestock feed and for soil fertility measures are key management aspects to avoid negative trade-offs between the livestock and crop sectors in crop-livestock systems.

There are different ways of balancing the trade-offs. Unger et al. (1997) suggested alternative crop residue management practices such as: 1) selective residue removal, 2) substituting crop residues to animal feed by high quality forages, 3) practicing alley cropping of nitrogen fixing plants at field margins/hedges, 4) more effective use of waste lands, 5) improving the balance between feed supplies and animal populations, and 6) using alternative fuel sources. These alternatives require inter-disciplinary and integrated approaches based on realities existing under local circumstances. The extent of feed shortage and or seasonal biomass production determines degree of selective residue removal from fields. Technology availability, accessibility, land size and tenure system may be the frontier bottlenecks to substitute crop residues with high quality livestock feed and so on. However, the farming system cannot be sustainable unless farmers are determinant to allocate appropriate amount of crop residues and manure and other fertilizers to improve the fertility of their soils (Benjamin et al., 2010).

Therefore, exhausting local resources and synthesizing situations from different point of views are needed to design the best appropriate technological combinations to improve allocation of crop residues for various needs. Single technology may not solve crop residue trade-offs; equally important is the fit of technologies to farming system (Rufino, 2008).

2.3 Method of crop residue application/retention

Different views are reported on the method of crop residue retention practices: direct application on the soil (Samaddar et al., 2008) and application after composting (Abegaz et al., 2007). Abegaz et al. (2007) argue that the C:N ratio of crop residues is high and direct application can result in negative effect on soil productivity due to N immobilization during the process of decomposition. However, composting requires labor for collecting, preparation of peats and re-distribution. It is unlike that composts will be evenly distributed throughout crop fields as the practice of farmers is evident in manure application (Zingore et al., 2007b). Hence, composting crop residues and re-distribution may result in nutrient gradients such that more nutrients near to compost peats and less nutrients to marginal fields. On the other hand crop residue retention alone may not ensure soil organic matter supply because; in some places they might be exposed to wind erosion, communal grazing and or free collection for fuel in addition to N immobilization. This needs a practice that ensures even distribution and proper incorporation of crop residues in the soil.

One way to do this may be burring crop residues by early tillage. In Ethiopian farming, tillage operation is done mostly after crop residues are cleared from arable plots and when rainy months are approaching with the objective to increase water infiltration and storage through trapping run off and reducing evaporation (Temesgen et al., 2008). In the study area there is no tillage schedule to incorporate residues in to the soil. Having many research findings on the role of crop residue retention in improving soil nutrients and physical characteristics, can residue retention alone ensure their availability as an organic input to the soil? To what extent are retained residues incorporated in to the soil?

Zeleke et al. (2004) reported that incorporation of crop residues by tillage operation improved rain water use efficiency and soil tilth. Since crop residues are vulnerable for free grazing and collection to fuel, at Chorie, tillage need to be scheduled as early as possible before they disappear from the farm. Early tillage operation following crop harvest may trap residues at the place where they are produced. The practice could give more benefit to farmers that have few or no livestock than those who have more livestock. Since nutrients are freely exported from poor farmers and accumulated to rich farmers who own more livestock through free grazing, farmers who have no or few livestock are the losers in the system. Hence, early tillage practice may give guarantee to poor farmers (who are unable to buy fertilizer and do not have access to manure) to return nutrients back to their soil. Early tillage also allows incorporation of weeds and grasses while they are relatively green which probably have better benefit than their effect after drying. It becomes apparent that early tillage still have negative trade-offs for livestock feed from stubble grazing. However, it may also influence farmers to limit the number of livestock to available resources and avoid over exploitation of nutrients and environment degradation as a factor of competition for communal resources.

2.4 Effect of manure management strategies to whole farm nutrient flow

Cycling of biomass through livestock excreta is an important linkage between livestock and soil productivity (Powel and Williams, 1993; Rufino, 2008) in crop-livestock mixed farming system. Manure is a corner stone to improve the chemical and physical characteristics of soils in smallholder crop-livestock integrated systems (Harris, 2002). Manure can improve soil pH, cation exchange capacity, water holding capacity, and soil structure. Nutrients from manure are released slowly over the growing season and have residual effect to the next crop. Studies reveal that farmers in sub-Saharan Africa have the knowledge about the role of manure in supplying nutrients to soils and improving its fertility, but they lack sufficient quantity to cover all of their plots and labor to distribute over fields. Manure production can be increased by increasing herd size, but this is not possible for the current smallholder farmers because of droughts (Zingore et al., 2007a) and feed shortage due to range land shrinkage (Ebanyat et al., 2010). Manure application is therefore concentrated around homesteads as a result of small quantity to cover all plots and labor constraints for distribution.

Farmers in the study area do not apply manure to their main arable plots. This could be influenced by their settlement location which creates inconveniencies to transport manure and lack of knowledge regarding manure management and uses. Villagers live following a raised mountain belt far from their main crop plots. Previous studies reported that farmers apply more manure and other organic inputs on close to home plots than on distant plots (Zingore, 2006; Zingore et al., 2007a; b; Bationo et al., 2007; Okumu et al., 2011). As a result of this preferential land management, soil fertility decline was observed as plots are more distant from the homesteads. However, it is not only the physical distribution of manure that matters, but also low quality in its nutrient content can create low effect in improving soil fertility.

Manure storage and handling practice of smallholder farmers of sub-Saharan Africa is poor; conditions that allow excessive aeration have high potential for ammonia loss (Powell and Williams, 1993; Nzuma et al., 1997; Rufino, 2008). These researchers suggest developing manure management options to minimize nutrient losses and enhance manure quality. Rufino (2008) showed considerable reduction in manure mass and N losses by covering the manure heap with polythene film. Farmers can use locally available covering materials or shades to improve manure storage conditions. Farmers may be discouraged by their manure application practice because of the weak effect of local manure in restoring the productivity of degraded soils. However, combination of poor quality manure with small amount of mineral fertilizer may give attractive response in the short term and more balanced build-up of soil C and nutrient stock in the long term (Tittonell et al., 2008; Giller et al., 2011).

Chapter 3. Methodology

3.1 Study area selection

The study area, Chorie, is selected by SLP-ILRI. The village is among the eight villages for the project work at Kobo site. Parameters to select villages were access to market and access to road. Accordingly, the project selected two villages near-near, two villages near-far, two villages far-near and two villages far-far (from market and road). Chorie village is geographically located at 12^{0}10’57.0’’ North latitude, 39^{0}39’65.9’’ East longitude (Fig. 1) and 1460 masl altitude; can be reached after driving 588 km from Addis to Kobo (north east of Addis Ababa) and additional 3 km drive towards the east departing from Kobo.

Annual averages of rain fall and temperature for the area are 82.7mm and 27 ^{0}C respectively (Tsegaye, personal communication). The dominant soil for the main crop plots is black vertisol. There are no trees or shrubs around crop lands but different Acacia spices are found around homesteads. Total human population of the village is about 515 in 103 households. The main crops grown in the area are teff, sorghum and maize. Farmers are totally dependent on rain fall for their farm activities (Annex 1).

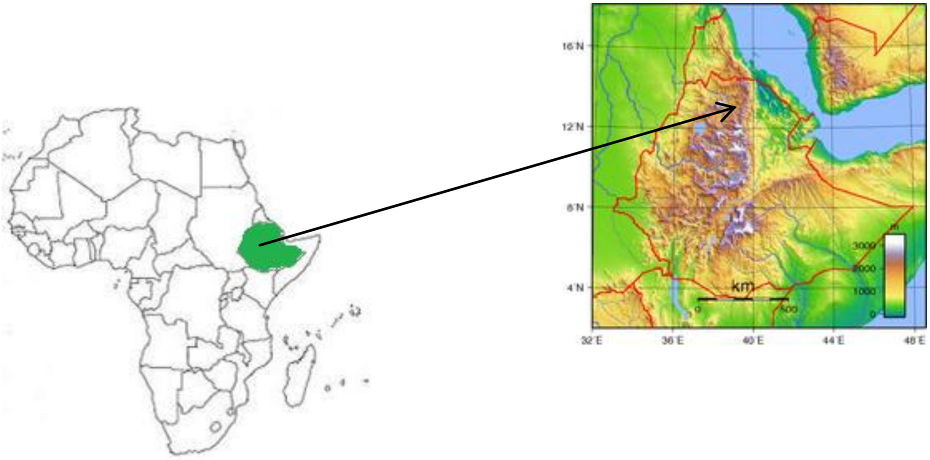


Fig. 1. Geographical location of Chorie, North Wollo, Ethiopia.

3.2 Farmer selection

Farmers were selected based on their wealth status using herd and land size as a main parameter for wealth classification. Cattle are the most important wealth indicator in sub-Saharan Africa (Zingore et al., 2007a); other important asset is land. Farmers that have relatively **F**ewer livestock and **S**maller land size are grouped under farm type FS; those with **F**ewer livestock and **L**arger land size in farm type FL; those with **M**ore livestock and **S**maller land size in farm type MS; and those with **M**ore livestock and **L**arger land size in farm type ML (Fig. 2). There were five female headed and eleven male headed households.

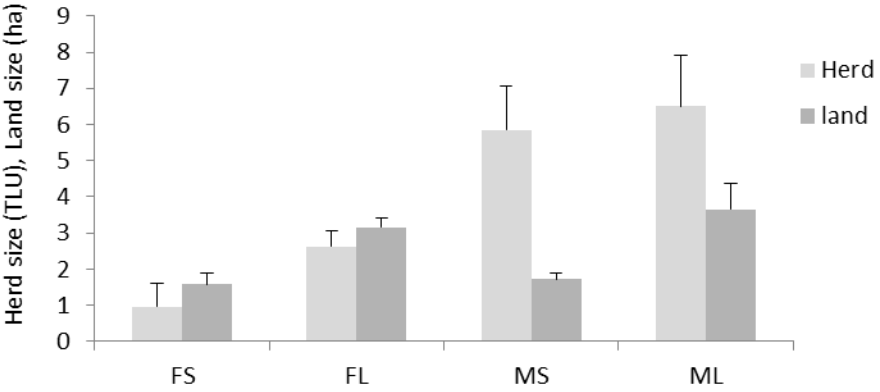


Fig. 2. Average herd and land sizes owned by different farm types.
FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

3.3 Plant sampling and analysis

Since farmers' plant crops by broadcasting, sampling following rows was not possible. To sample a defined area for later conversion in to hectares, quadrants were used for teff and sorghum crops. For teff crop 0.5m x 0.5m (0.25m^2) quadrant was used whereas for sorghum 1m x 1m (1m^2) quadrant was used (Njie and Reed, 1995).

Teff sample was collected by throwing the quadrant randomly by walking a certain distance diagonally in the field. Walking distance was estimated by observing the dimension of the field and five samples per plot were collected. Fresh weight for total biomass was measured at spot using field balance (spring salter). Dry weights were measured at Kobo agricultural research sub-center after drying them under the sun.

Throwing quadrant over sorghum crop was not possible because of the plant's height. Instead, one side open quadrant was prepared to insert it from the side. After inserting the quadrant, the open side was closed by the same sized moveable piece to ensure accurate sample area. Protecting knots are welded on tip of the two sides of the quadrant after 1 m length so that the closing side cannot move beyond the limit. Five representative samples per plot were collected by walking a certain distance diagonally within the crop. Total biomasses was split in to head, leaf blade, leaf sheath, stem and fresh weights for these different parts were measured on spot (Njie and Reed, 1995). After taking fresh weights, samples of similar parts were bulked per plot and sub-samples were taken for further measurements and analysis. Sub-samples of stover and grain yields were measured at Kobo agricultural research sub-center laboratory after threshing grains and drying stovers under the sun. The weight of threshed panicle was added to stover weight to evaluate grain and stover productivity of sorghum varieties.

Chemical analysis for the residues and grains of both crops were done at ILRI laboratories. Grinding samples and scanning using NIRS (Near Infrared Reflectance Spectroscopy) was done at ILRI-Addis, Ethiopia; and NIRS results were sent to India for estimation of nutrient contents using standard calibration models. “NIRS is an accepted method by international standards committees to carry out many constituents of various tissues of many plants [...] [including] grains and fibers” (Batten, 1998). Samples were crushed to pass 1 mm sieve (Njie and Reed, 1995), dried overnight at a temperature of 60^0C and filled in caps for scanning by the NIRS machine.

NIRS results for teff and sorghum residues are estimated using mixed feed global calibration model, teff grains (seed and flour) are predicted using millet grain and flour calibration model, and sorghum grain (flour) is predicted using millet flour 195 calibration model (Jean, personal communication).

3.4 Soil sampling and analysis

Soil samples were taken from all plots owned by the four farm types. The type of crop grown on a plot was recorded during sampling. Sampling was performed using Edelman auger from top 0-30 cm depth. Representative samples were taken from 3-5 points per plot depending on the size and uniformity of plots. The collected samples were submitted to the laboratory of national soil testing center, Addis Ababa, Ethiopia for pH, SOC, N, P and K analysis.

3.5 Model initialization and scenario analysis

Long-term impact of the current crop residues and manure management practices on land productivity and soil carbon stock is simulated using FIELD (Field scale resource Interactions, use Efficiencies and Long term soil fertility Development), the CROPSIM (Crop production SIMulator), in the AfricaNUANCES (Nutrient Use in Animal and Crop systems-Efficiencies and Scales) framework. The model was parameterized for maize and extensively used in Kenya and Zimbabwe. It was adapted to predict sorghum and pearl millet grain yields in Mali (Dagnachew, 2008; Fig.3).

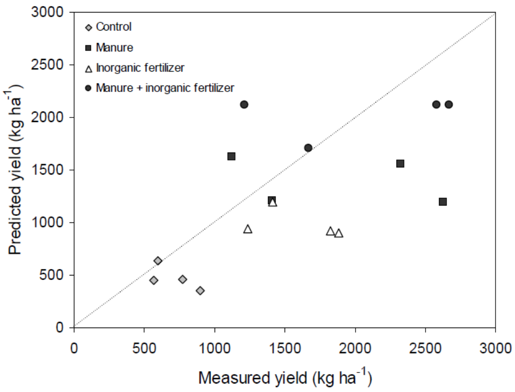


Fig. 3. Fitness of the Model FIELD against measured and predicted yields (*After Dagnachew, 2008*).

Site, soil and crop specific parameters (Annex 2a-d) are used from Dagnachew thesis work to initialize the model. After initializing the model, only rain fall and some soil parameters of Chorie village are used to simulate future biomass production and soil carbon status of the area. Parameters changed to adapt the model are seasonal rain fall (560 mm; Tsegaye, personal communication) and soil parameters given below.

Table 1. Soil parameters changed to adapt the model, FIELD.

No.	Description	Remark
1.	Soil texture (%)	Values for each parameter are not given here; because, they differ as per the plots and farm types.
	Clay	
	Sand	
	Silt	
2.	Soil organic carbon (g kg^{-1})	
3.	Total soil N (g kg^{-1})	
8.	CEC (cation exchange capacity)	
9.	PH	

Three scenarios (Table 2) are simulated to see the impact of different levels of crop residue retention on above ground sorghum biomass and soil carbon stock for 10 years. Farmers' settlement location created considerable distance between main crop plots and homes; because of this reason, manure application is not feasible for the time being; hence, no scenario test is performed considering manure as soil amendment strategy. Besides, data on quantity and quality of manure were not collected as per the model requirement.

Table 2. Different scenarios used to simulate above ground biomass production and soil carbon stock for the next 10 years.

Scenario	FRREM[1]
1	1
2	0.7
3	0.3

[1]. Fraction of residue removal.

3.6 Socio-economic data collection

Socio economic data (age, gender, literacy level, land and herd characteristics, crops and area coverage, food self-sufficiency, resource allocation, decision making processes and limiting factors) were collected by interviewing selected farmers(N=16) using semi-structured questionnaire (Annex 3). Literacy level was determined by the number of study years (formal or informal education system; 1 year =1 grade level). Land is quantified using the local unit "*timd*" meaning one day plowing with a pair of oxen; and converting it in to hectare (4 *timds* =1 ha). Type and number of livestock owned by each farmer is converted to TLU (Tropical Livestock Units). Exploration of crop types and their area coverage was done by constructing a resource flow map for each farmer during the interview. Resource allocations such as grain, crop residue and manure were quantified using the five fingers of a hand to make easy for farmers to estimate the proportion of their allocation; then values were converted to percentages. Stall feeding of crop residues was estimated from the amounts farmers gave to their livestock each day in each month of the year and converting it to kilo grams and finally to percentage (according to farmers' estimation 1 *ekif* crop residue ≈ 5kg).

3.7 Data analysis and presentation of results

Socio-economic data are analyzed using Excel. Straw/stover and grain yields as well as nutrient contents of these plant parts were analyzed using Excel and SPSS version 16 statistical software. Statistical differences between varieties and parts of a crop were determined using Analysis of Variance (one way ANOVA procedure). Mean separations were computed using LSD and Duncans' homogeneity test at α= 0.01 and 0.05. MATLAB (MATrix LaBoratory [a numerical computing environment and fourth-generation programming language]) is used to run the simulation.

Results are presented in figures and tables with supportive explanation. Pictures taken at the field during sampling are also used to illustrate some of the existing practices.

Chapter 4. Results

4.1 Characterization of farming system

4.1.1 Herd characteristics

Total herd sizes in TLU (Tropical Livestock Units) for FS and FL farm types are smaller than MS and ML farm types (Fig. 4A). The higher share of livestock composition in all farm types is local breed (*Raya* breed) cattle (Fig. 4B). Farm type ML has more number of cattle followed by farm type MS. However, there is variability in the type of livestock holding among individual farm types. In addition to cattle, FS owns a few numbers of goats, FL owns donkey, MS owns sheep, goats and camels, and ML owns camel and donkey.

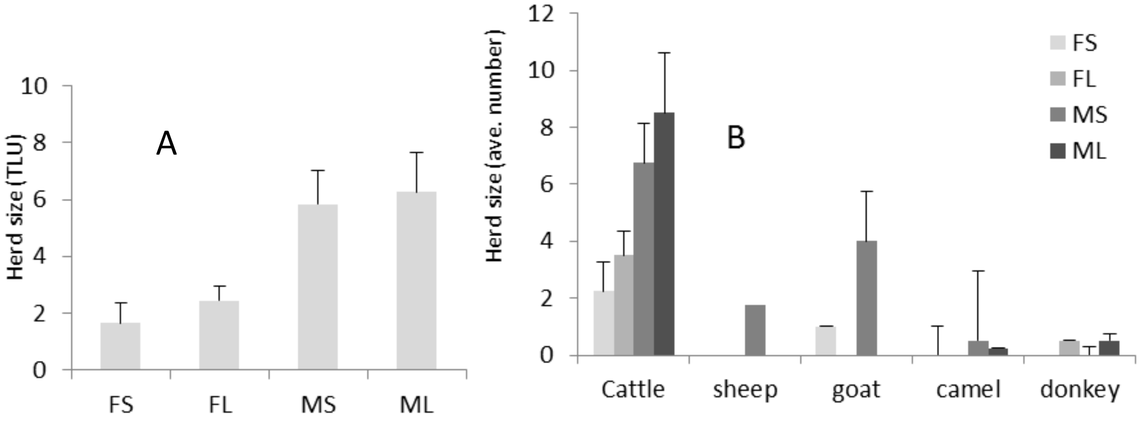


Fig. 4. Total herd size in TLU (A) and livestock type in average number (B) for the different farm types. *FS= few livestock/ small land; FL= few livestock/ large land; MS=more livestock/small land and ML=more livestock/large land.* TLU= Tropical Livestock Unit.

In the village there is no range land for livestock to obtain their feed from grazing or browsing. This could have limited the number of sheep and goats in the system. During the long dry season, livestock are left for free grazing on stubble from crop lands; in the rainy season, arable plots are covered with crops; hence, feeding livestock targets on stored crop residues (straw/stover) which large ruminants can utilize better than the small ruminants. Furthermore, cattle are used for labor during land preparation and threshing, milk and meat production, saving and prestige. These purposes of cattle could have attracted farmers to have them in their farming system rather than other livestock types.

4.1.2 Land holding

The land holding of each farmer is assumed to be equal in size during the land distribution. However, youths who were not given land during the time of land distribution currently possess land in different ways: given from relatives, renting and sharing from other farmers. There is also land splitting to children when a farmer dies. These and similar socio-economic and socio-cultural circumstances create large variability in land holding in the village. Average land holding of the 4 farm types ranges from about 1.5 in FS to about 4 hectares in ML (Fig.5).

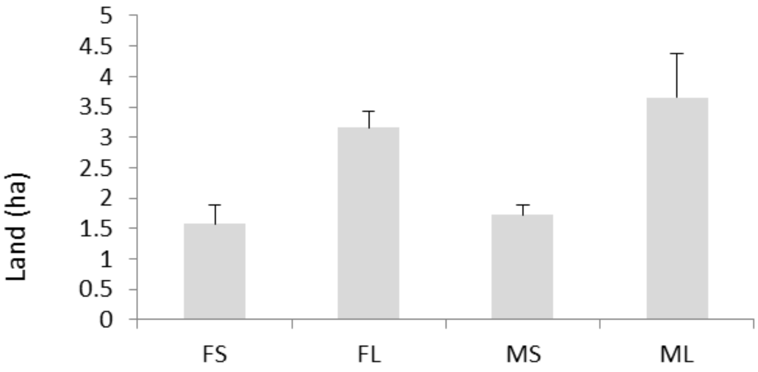


Fig.5. Average land holding of different farm types. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

4.1.3 Gender of the household head

From the sixteen farmers selected for the study, there are five female headed households and eleven male headed households. Three of the five female headed households are in the FS (Fewer livestock/ Smaller land) farm type and two of them are in the FL (Fewer livestock/ Larger land) and MS (More livestock/ Smaller land) farm types. There is no female headed household in the ML (More livestock/ Larger land) farm type (Fig.6).

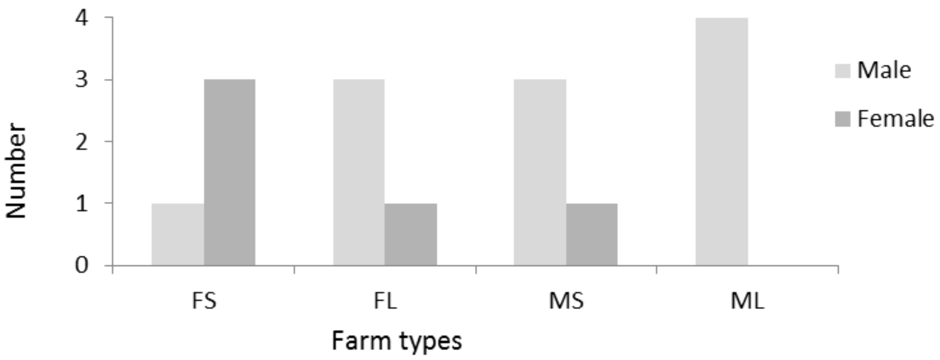


Fig. 6. Gender of a household head (total number in each group) in different farm types. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

In FS farm type two females in the age of 66 each and in FL farm type one female in the age of 45 missed their husband due to death where as one female in FS farm type who is in the age of 25 and one female in MS farm type who is in the age of 28 are divorced. One of the two aged females from FS and the one in the FL farm types have children to manage their farm activities but the other old female in FS farm type has no children or close relative who can support her; so that she totally rent out her land and has no livestock. Both aged females do not have the chance of marrying again due to various social and biological constraints to manage their farm by themselves. Most likely they continue being dependent on the decision of family and land tiller.

The two younger females in FS and MS farm types try to manage their farm partly by themselves; still they rent out part of it. The one in the FS group has no livestock. She gets little support from her ex-husband. He sent little money from Saudi-Arabia to raise their children born before divorce.

4.1.4 Household head literacy level

Literacy level of household heads and leading female for all farm types is very low (Fig.7). There is no family head for FS farm type that can at least read and write. In FL farm type, the household head has better literacy level than the leading female whereas the reverse is true for MS farm type. However, household heads and leading females in MS farm type have better education level than in the other farm types. In ML farm type only the leading female can read and write. These could be due to age effects. Farmers in MS farm type are younger whereas farmers in ML farm type are older than farmers in other farm types (Fig. 8). Currently a new elementary school is established close to the village. Many children from the village have started their education. Hopefully, this will increase literacy level of the future generation living in the village.

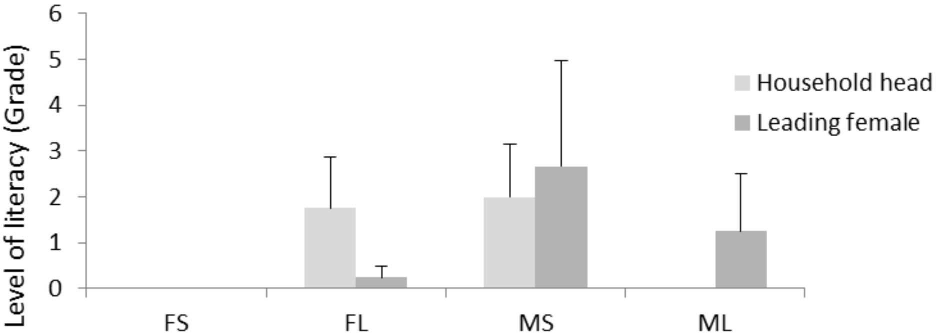


Fig.7. Literacy level of household heads and leading females in different farm types. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

4.1.5 Age characteristics

The age of farmers selected for the study is between25 and 70 years. The mean value of their age distribution is 32 years for MS and 56 years for ML farm types. Others are between the values. Some farmers in the FS and FL farm types are new comers; however, on average, they lived over 30 years in the village. Farmers in MS and ML farm types lived all of their ages in the village (Fig. 8).

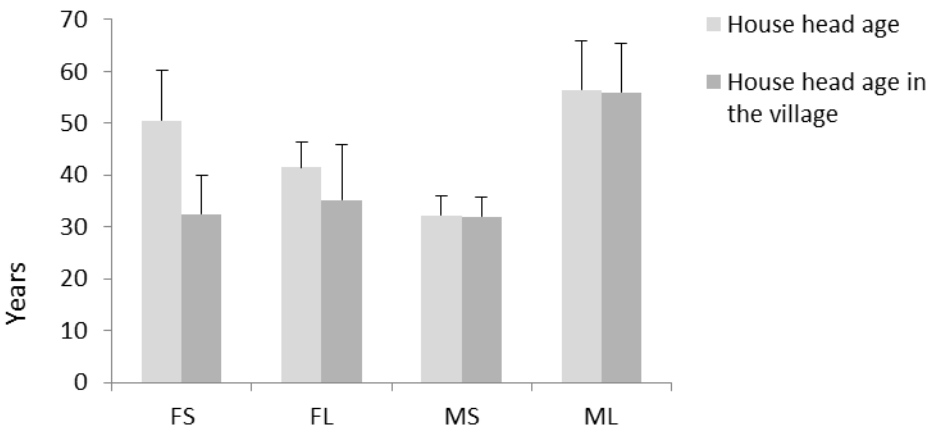


Fig.8. Average age of house hold heads and their years in the village for different farm types. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

Farmers in the FS farm type have less key resources available (livestock and land;Fig.2). This could be due to complementary effects of being newcomers, their age and gender. Farmers in MS farm type are younger and are born in the village; they could have been very young at the time of land distribution which could be the reason for receiving small pieces of land at the time. Farmers who lived in the village for longer times (ML farm type) seem to have good access to key resources. They have relatively more livestock and larger land areas.

4.1.6 Labor availability

The laborious crop production activities such as tillage, harvesting and transporting the harvest to home are done by male family members that are in the age groups between 16 and 60 years. Females in this age group have good participation during hand weeding activities. Family members with ages less than 16 and greater than 60 contribute less labor in to such activities. Farm types FS and ML have more family members in these age groups (Fig. 9), indicating that labor largely influence their farm activities. Different farm types use various strategies to fulfill their labor demand; some rent out their land, some hire temporary labor and some others employ permanent labor (Table 3).

The major strategy followed by all farm types is hiring temporary labor at peak crop activities like tillage, weeding, harvesting, threshing and transporting the produce to home. They employ permanent labor at different level for their permanent support as well. Specific farm type uses strategies depending on gender, age and key resources like land and livestock holdings. For example, FS and MS farm types rent out land. However, the percentage of renting out farm is higher for FS farm type than MS farm type because FS farm type is dominated by female headed households (Fig. 6). FL farm type also has a female headed household but she does not rent out land; her children can manage it. FL and ML farm types own larger land than others (more land activities); so that their temporary labor utilization is higher than other farm types, MS farm type employ permanent labor maybe due more livestock holding of this farm type which demands year round activities (Table 3).

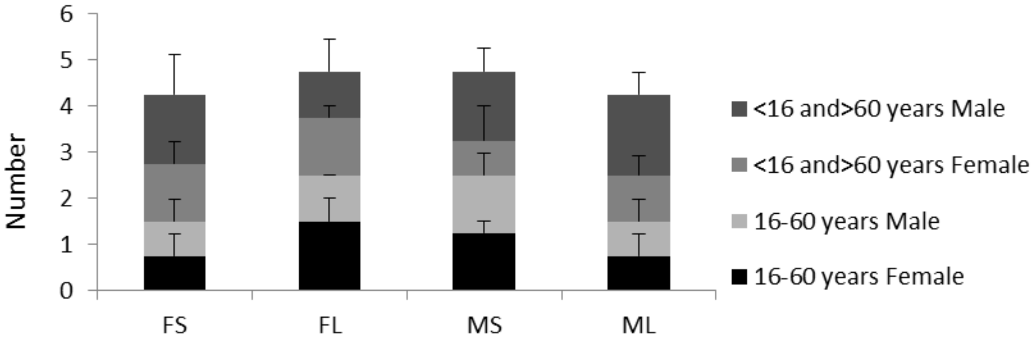


Fig.9. Average number of family members that have lower and higher labor inputs under each farm type. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

Major reasons for shortage of labor for FS farm type are gender, insufficient family labor and age in order of importance (Table 3). For FL and MS farm types the reasons are insufficient family labor and gender. The percentage of gender and family labor shortage pointed out as constraints for FS, FL and MS farm types are in accordance with gender of the household heads (Fig. 6). Labor shortage problem for ML farm type is due to age and to a lesser degree insufficient family labor availability.

Table 3. Reasons for labor shortage and strategies used by farm types to solve the problem of labor shortage (Mean value; N=16).

	Reason for labor shortage (% of respondents)			Strategies used to solve labor problem (% of respondents)		
Farm type	age	gender	insufficient family labor	Rent out/ share land	Hire temporary labor	Employ permanent labor
FS	21.25	46.25	32.50	37.50	50.00	12.50
FL		12.50	87.50		93.75	6.25
MS		12.50	87.50	12.50	62.50	25.00
ML	50.00		50.00		93.75	6.25

FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

4.1.7 Land preparation and fertility management

Seed bed preparation is done by tilling the land repeatedly using an ox driven plow. Generally, farmers do more tillage operations for teff than for other crops; but there is inconsistency in the frequency of tillage (Fig. 10). Variability could be due to availability of oxen, labor, as well as land tenure system (owned/rent/shared). Teff plots are tilled more frequently than sorghum and maize plots in FL, MS and ML farm types; whereas, for sorghum plots, FS and FL farm types use different frequencies (higher frequency in FS, lower frequency in FL). This variation could be due to either of the above mentioned reasons.

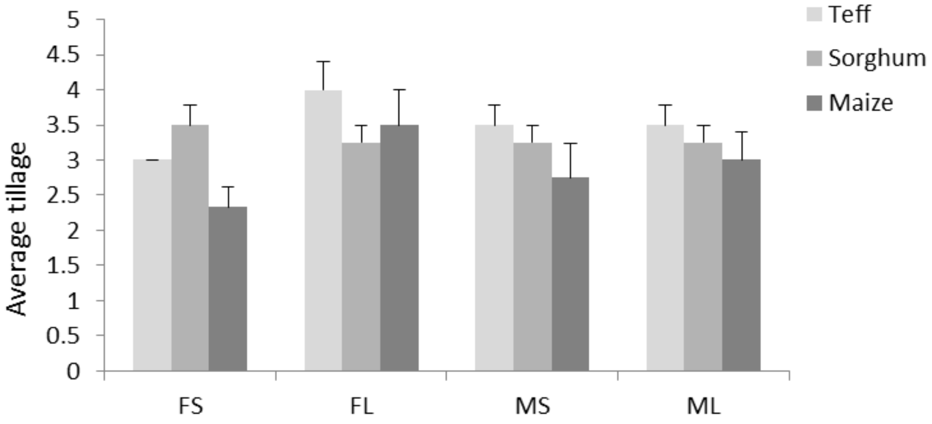


Fig.10. Seed bed preparation for different crops performed by farm types. *FS= few livestock/small land; FL=few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

All respondents (N=16) apply neither chemical nor organic fertilizer to their main crop lands. They apply very small amount (1-5t ha^{-1}) of manure available in the barn (mixture of fresh and dry) and other organic materials like ash only to small homestead plots where they plant maize for early grain consumption (Fig.11A). Nevertheless, the quality of manure and other organic inputs is questionable. Farmers do not have structures where they store manure and protect N volatilization mainly due to insufficient knowledge about manure handling techniques. Dung dropped overnight is picked to spread on stones and dried for fuel. The other part remains in the open barn exposed to sun and continuous destruction by animal hoe (Fig. 11B). Thus, manure quality may not be sufficient enough to restore soil nutrients.

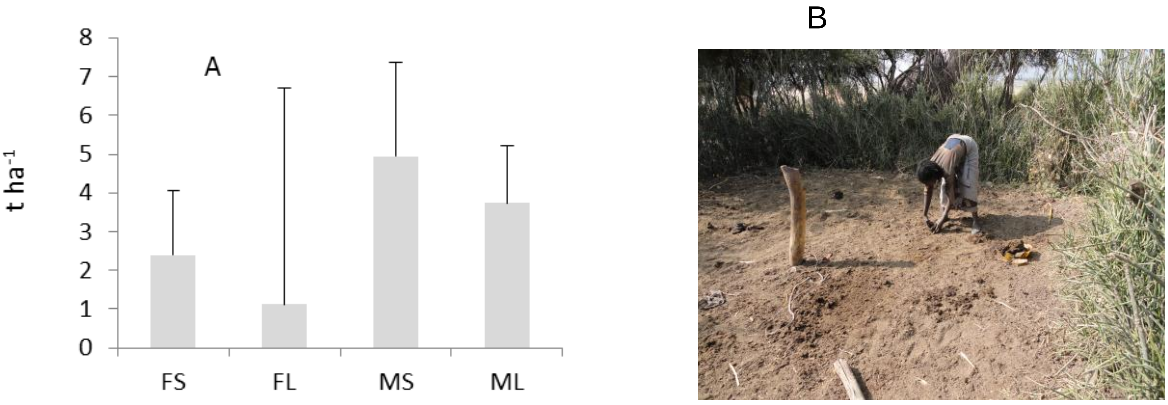


Fig.11. Manure management practices: A) amount used as fertilizer for homestead plots by different farm types; B) manure handling practice. *FS= few livestock/small land; FL=few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

4.1.8 Crop types and land allocation

Major crops grown in the area are teff, sorghum and maize. Average area coverage by teff is larger than by sorghum and by maize in FS, FL and MS farm types. Larger area is allocated to sorghum followed by teff in ML farm type. Average area coverage by sorghum is larger than average area coverage by maize in all farm types (Fig. 12).

Teff is a cash crop in the area. Land allocation for teff is relatively larger for FS and FL farm types than MS and ML farm types. This could be due to the low number of livestock owned by these farm types, which limits their ability to sell and get money for their routine activities. MS and ML farm types may fulfill their cash demand from selling livestock.

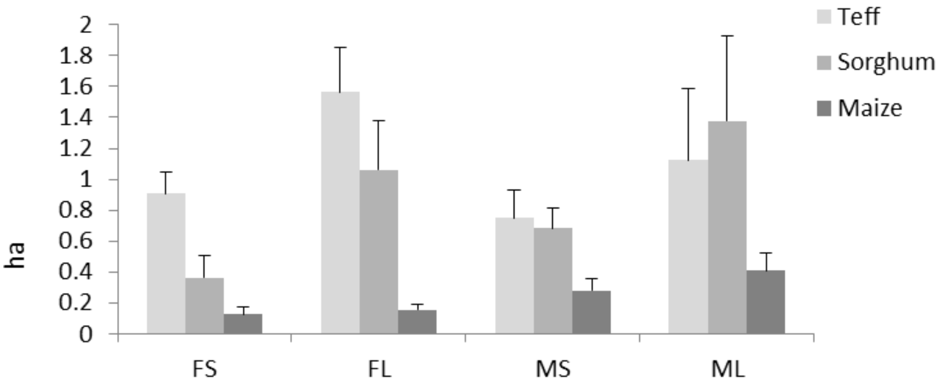


Fig. 12. Average land allocation by farm types for different crops. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

There are different varieties of teff and sorghum used by farmers. Variety selection depends on a number of reasons but availability of sufficient moisture at planting time and demand of the variety for market and home use are the key ones. Characteristics of different varieties of teff and sorghum are presented in Annex 4. Figures 13 and 14 below show teff and sorghum varieties planted in 2010 cropping season with their relative area coverage.

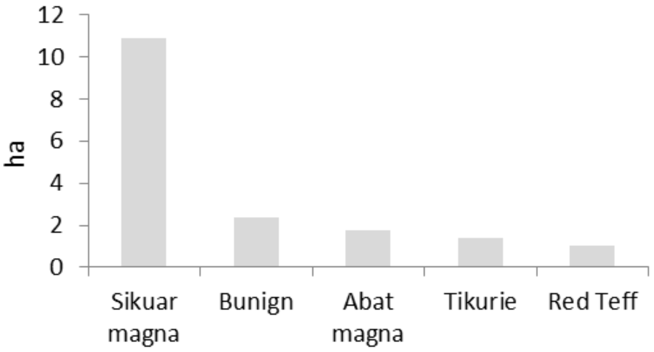


Fig.13. Teff varieties and their area coverage at Chorie, Ethiopia in 2010 cropping season.

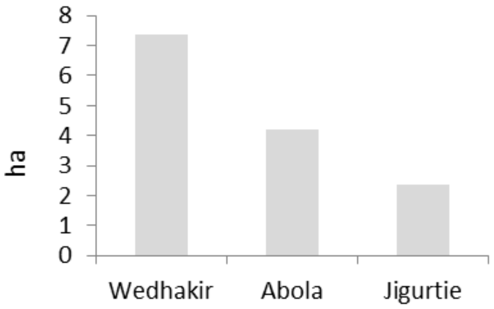


Fig. 14. Sorghum varieties and their area coverage in 2010 cropping season at Chorie, Ethiopia.

4.1.9 Food self sufficiency

Except for the FS farm type, farmers in all categories can feed themselves year round at average rain fall condition (Table 4). However, they are not self-sufficient at lower rain fall times. Various farm types have different level of resilience to drought shocks. FS and MS farm types can feed themselves only for about half year at drought time. Better tolerance to drought impact is observed in ML farm type. FS farm type is not food self-sufficient even at the time of average rain fall. This indicates the impact of land size for food self-sufficiency.

Table 4. Average cereal crop self-sufficiency and number of years food aid received in last 10 years.

	Food self-sufficient months		Food aid received in last 10 years (# of years)
Farm type	At time of average RF	At time of low RF	
FS	10.50	5.50	3.00
FL	12.00	7.50	3.50
MS	12.00	5.75	3.25
ML	12.00	9.00	1.00

#= Number; FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

When farmers face food shortage, their immediate decision is to purchase food from local markets (Table 5). Mainly, the source of money to purchase food is from selling livestock though the price they receive during drought periods goes down. Livestock is a saving strategy for almost all of the respondents who have livestock (Annex 5). Furthermore, livestock can be used as a guarantee to borrow food items from others.

Farm type MS obtains more grain loans from other friends than farm type FS. Farmers who could have grain at hard times seem to show less interest to lend to FS farm type; this may be because of lack of trust on the ability of the borrower to pay back or fear of lower future product price. In any case if borrowing is the last option, FS farm types borrow in agreement to pay back at an expensive rate.

Table 5. Percentage of food remedial sources at scarcity periods.

Farm types	Purchase	Subsidy	Given by others	Borrow *
FS	75.00		12.50	12.50
FL	71.25	8.75	20.00	
MS	50.00		50.00	
ML	100.00			

FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

* ***Borrow at expensive return****: If they borrow 1 quintal of sorghum, the agreement could be to pay back 1 quintal of teff or 1.5- 2 quintals of sorghum at the next harvesting season.*

4.2 Quantity and quality of biomass production

4.2.1 Teff biomass production

Analysis of variance for grain and straw yields of teff varieties shows significant difference (P= 0.001 and 0.000; <α=0.05) among varieties (Table 6). Differences are between lower yielders *Bunign* and *Tikurie*, and higher yielder *Sikuar-magna* for grain yield; and between lower yielders *Bunign* and *Tikurie*, and higher yielders *Abat-magna* and *Sikuar magna* for straw yield.

Table 6. ANOVA Table showing significant differences (α = 0.05) in grain and straw yields of different teff varieties.

		Sum of squares	df	Mean square	F	Sig.
Grain yield	Between Groups	4.944	3	1.648	6.353	0.001
	Within Groups	21.011	81	0.259		
	Total	25.955	84			
Straw yield	Between Groups	64.227	3	21.409	12.172	0.000
	Within Groups	142.463	81	1.759		
	Total	206.690	84			

No statistical difference is observed between *Bunign* and *Tikurie*; and *Abat-magna* and *Sikuar-magna* for both grain and straw yields (Table 7). However, higher grain yield for *Sikuar-magna* and higher straw yield for *Abat-magna* are observed (Fig.15).

Table 7. Mean separation for grain and straw yields of teff varieties.

Local names of teff varieties	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
Dunkcan[1] *Buningn*	0.8344a		2.1160c	
Tikurie	1.0656a		3.2200c	
Abat-magna	1.2158a	1.2158ab		5.5122d
Sikuar-magna		1.600b		5.1753d
Sig.		0.089		0.6010

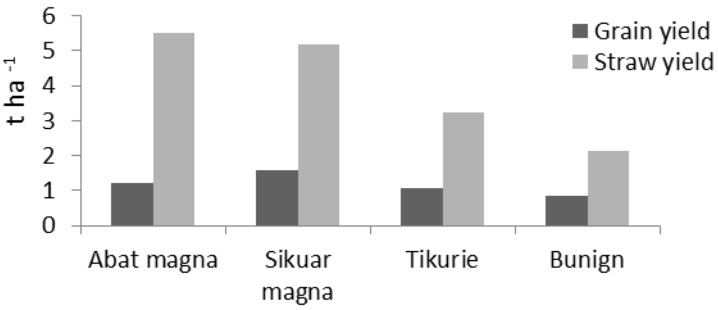


Fig. 15. Yield performance of different teff varieties.

Farmers were asked to estimate grain and straw yields. Analysis indicates very low correlation between measured and farmers' estimation(both grain and straw yield; r^2=0.031; r^2=0.0654 respectively; Fig. 16).

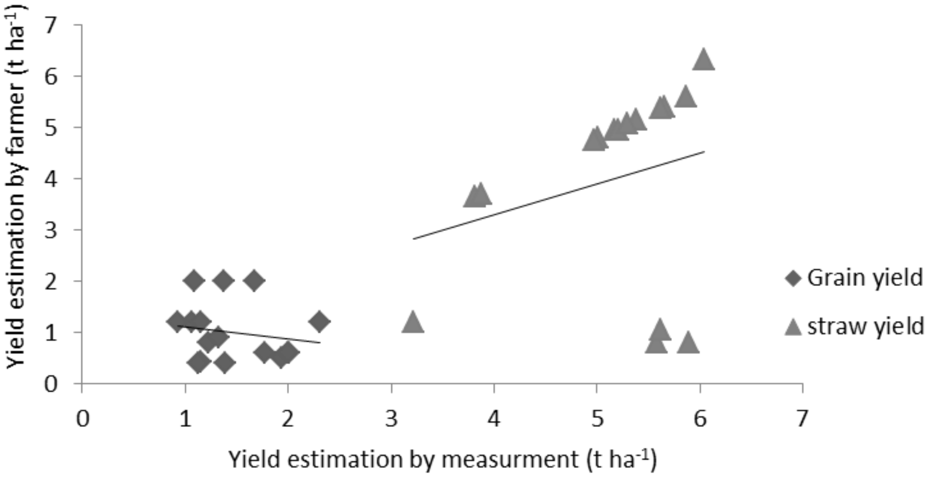


Fig.16. Correlation between measured and farmers' estimation of grain and straw yields of teff.

For straw yield, higher difference is observed between measured and farmers' estimation in FS farm type (Fig.17). This could be due to the influence of gender. In this farm group the ratio of female to male is 3: 1 (Fig.4); female head households either share/rent out their land or give all land management activities to their family (son/daughter if applicable; Annex 6); so that they have less control on land activities which hinders them to adequately estimate land outputs. Especially those who share their land cannot estimate quantity of crop residues, because shareholders take all of it. The agreement with land tiller is to share only grain yield.

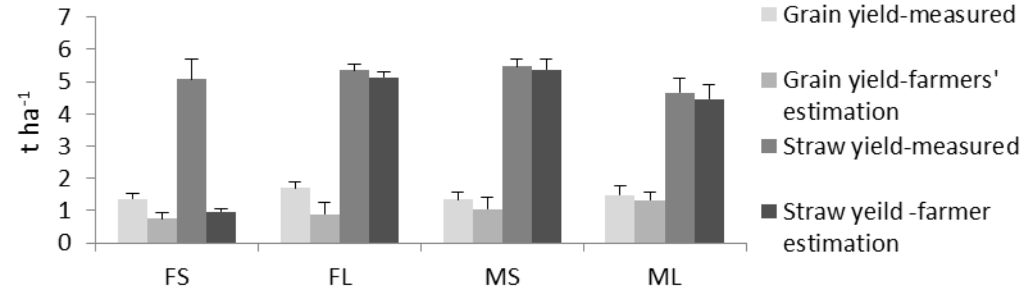


Fig. 17. Teff yields (grain and straw) estimation: measured vs. farmers' estimation. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

4.2.2 Sorghum biomass production

Analysis of variance shows significant difference between sorghum varieties for grain and stover yields (Table 8). Higher grain yield for *Jigurtie*, and higher stover yield for *Abola* are observed (Table 9). However, the proportion of softer parts of the stover (leaf blade, leaf sheath and panicle) to stem is lower for these varieties indicating lower palatability of stover to feed livestock. Low yielding varieties *Wedhakir* and *Berhan+Meko* have thin stem and higher softer parts to stem ration (Fig.18). All parts of the stover from these varieties are palatable by livestock. However the quantity of softer stover parts is still higher for the high yielding varieties (Fig. 19) indicating the benefit of such varieties to increase biomass production to satisfy different (competing) uses of residues such as for soil organic matter input, feed, fuel and construction materials.

Table 8. ANOVA Table showing significant differences (α = 0.05) between grain and stover yields of different sorghum varieties.

		Sum of squares	df	Mean square	F	Sig.
Grain yield	Between Groups	98.298	4	24.574	7.526	.000
	Within Groups	244.902	75	3.265		
	Total	343.200	79			
Stover yield	Between Groups	3849.671	4	962.418	34.828	.000
	Within Groups	2072.484	75	27.633		
	Total	5922.155	79			

Table 9. Mean separation for grain and stover yields of sorghum varieties.

		Grain yield (t ha^{-1})		Stover yield (t ha^{-1})			
Dunkan[1]	*Wedhakir*	2.89a		*Wedhakir*	7.96c		
	White wedhakir	3.52a	3.52ab	*Berhan+Meko*	9.18c		
	Berhan+Meko	4.12a	4.12ab	*White wedhakir*		17.72d	
	Abola	4.36a	4.36ab	*Jigurtie*		21.35d	
	Jigurtie		5.390b	*Abola*			27.07e
Sig.		.156	.070		.653	.184	1.000

[1]. Uses Harmonic Mean Sample Size = 7.519; α=0.05. Means followed by different letters differ significantly.

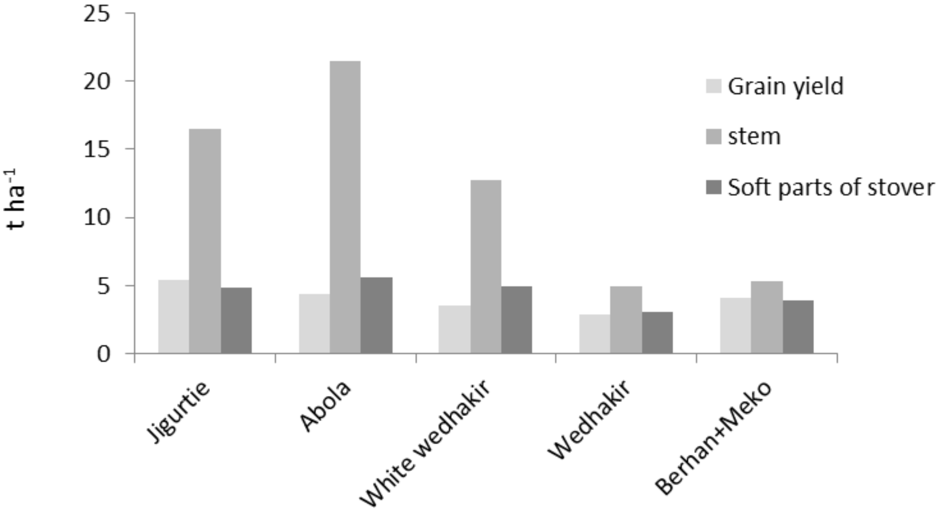


Fig. 18. Yield performance of sorghum varieties. Values for *Jigurtie* are average of 5 plots samples, for *Wedhakir* 8 plots samples and for others only 1 plot samples.

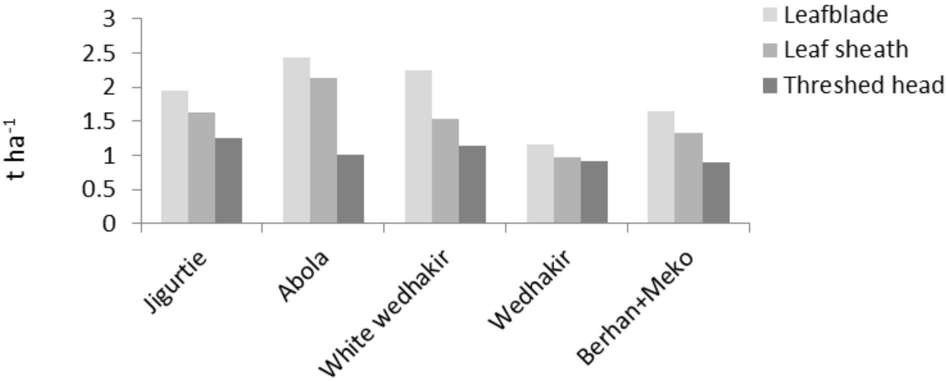


Fig. 19. Quantity and proportion of relatively softer stover parts of sorghum varieties.

Farmers were asked to estimate sorghum yields similar to that of teff. Their estimation for sorghum is also lower than the measured values (Fig.20) resulted in low correlation between yields of measured and farmers' estimation(Fig.21).

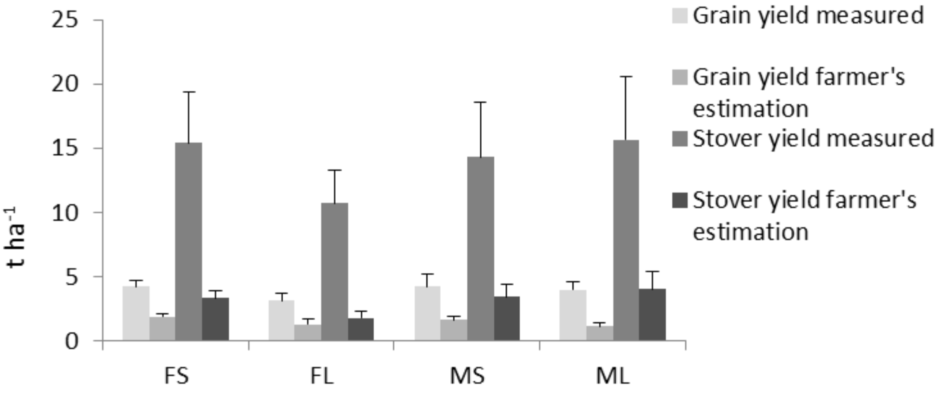


Fig.20. Estimation of sorghum yield: measured vs. farmers' estimation. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

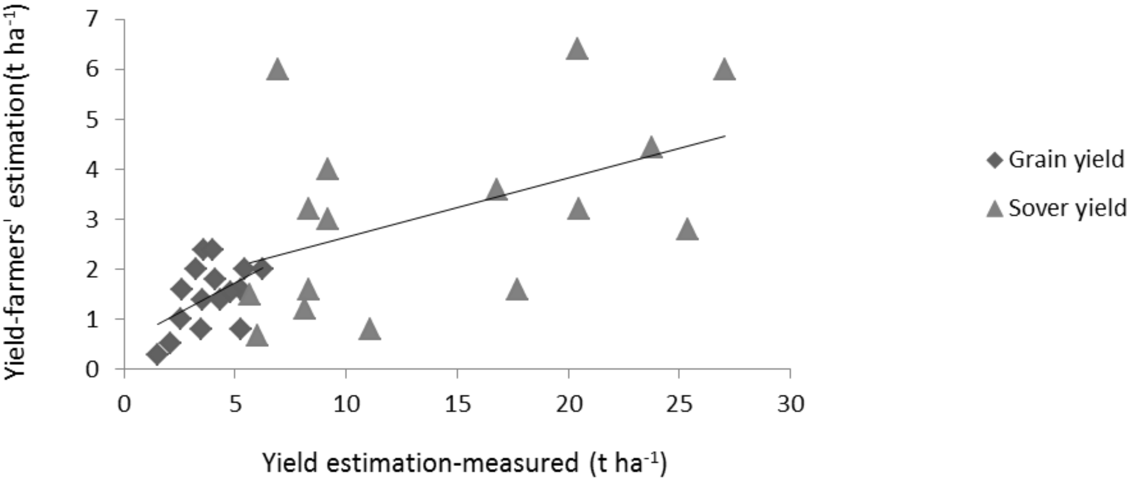


Fig. 21. Correlation between measured and farmers' estimation for grain and stover yields of sorghum.

This higher difference between measured and farmers' estimation could be resulted due to a number of reasons. Few of them may be:

1) Cutting height difference of sampling and farmers' practice: we cut the stover near the surface to measure the whole above ground biomass as totally as possible. However, farmers cut at higher position leaving between 5- 30 cm stover at the field.

2) Inclusion of threshed panicle/head in the sample: Threshed panicle is included in the measured stover yield, to split the total biomass in to grain and stover yields. However, farmers normally leave this part at field after they thresh and take grain yields. The threshed panicle is left at the threshing spot where livestock graze it over there.

3) Unit used for estimation: Farmers' estimation was based on camel pack where further estimation in to quintals and tons is required. Depends on the power of the camel and convenience of packing, one camel pack is estimated to be 0.2 to 0.4 tons.. This creates difficulty to adequately estimate.

4) Attention to the resource: Farmers' attention to crop residues especially for stover is not as high as for the grain yield. They estimated grain yield better than residue yields. Reasons may be quite a lot and complex; whatever the case may be it seems difficult to rely on farmers' estimation if one needs relatively precise values.

4.2.3 Nitrogen content and digestibility of teff straw

ANOVA shows significant difference (Table 10)between varieties in straw digestibility (Ivomd%; Invitro organic matter digestibility percentage). The difference is observed between *Tikurie* and two varieties *(Abat-magna* and *Sikuar magna*); with higher digestibility percentage in *Tikurie* (Table 11). In straw nitrogen content, there is no significant difference between teff varieties.

Table 10. ANOVA Table showing significant difference in straw digestibility but non-significant difference (α = 0.05) in nitrogen content for teff varieties.

		Sum of Squares	df	Mean Square	F	Sig.
Digestibility (Ivomd%)	Between Groups	23.271	3	7.757	2.900	0.040
	Within Groups	216.685	81	2.675		
	Total	239.956	84			
Nitrogen content (%dm)	Between Groups	0.221	3	0.074	1.072	0.366
	Within Groups	5.562	81	0.069		
	Total	5.783	84			

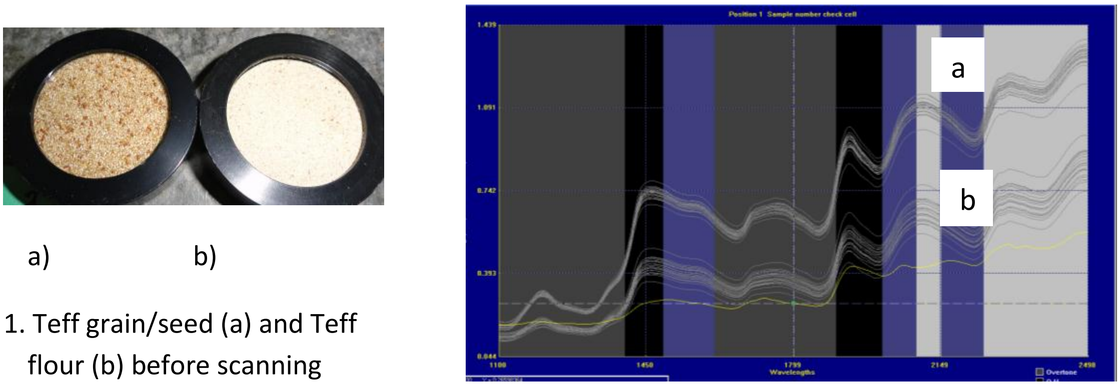
Table 11. Mean separation for straw digestibility of teff varieties.

	Local name of teff varieties	Straw digestibility (Ivomd%)	
Duncan[1]	Abat magna	50.48a	
	Sikuar magna	50.87a	
	Bunign	51.83a	51.83ab
	Tikurie		52.66b
	Sig.	.112	.294

[1]. Uses Harmonic Mean Sample Size = 8.544. Means followed by different letters differ significantly

4.2.4 Teff grain nutrient content

Teff grains are very small in size (Fig. 22:1a). Laboratory analysis was done for both the grain/seed and the flour to see if the size is enough to scan using NIRS and fit models for estimating values. Scanned results of grain (seeds) and flours segregated in to two different patterns (Fig.22:2).



1. Teff grain/seed (a) and Teff flour (b) before scanning

2. Teff grain/ seed (a) and Teff flour (b) after scanning.

Fig. 22. Teff grain/seed and flour before scanning (1) and after scanning (2). Results separated in to two sets showing that teff seed, though very small in size, needs to be ground for nutrient content analysis by NIRS analysis.

Protein content is higher for the flour part than the seed whereas for all other parameters, the grain seed showed higher values (Fig.23). Much higher difference between seeds and flour parts is observed in starch content.

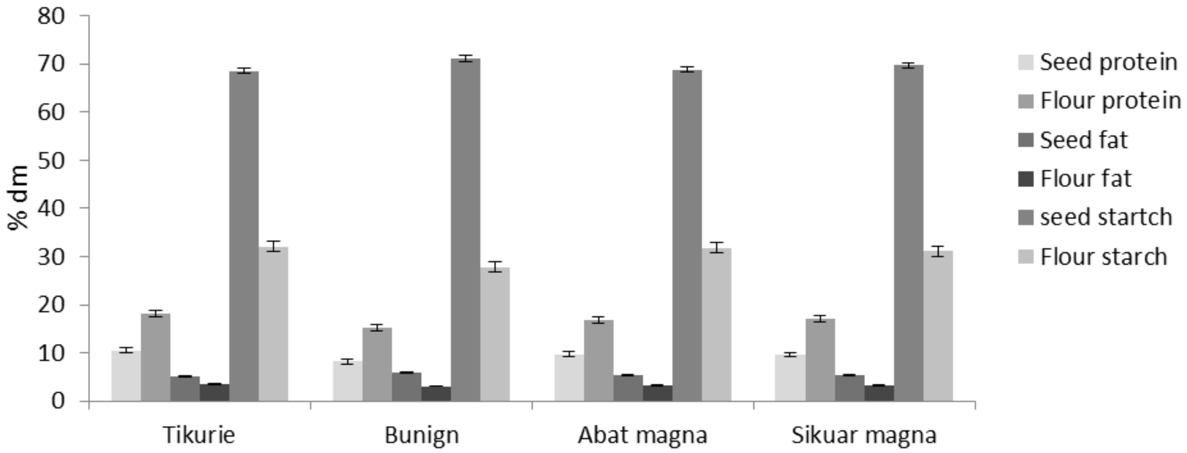


Fig. 23. Protein, fat and starch content of teff varieties before grinding (seed) and after grinding (flour) in %dm (percent of dry matter).

4.2.5 Nitrogen content and digestibility of sorghum stover

Statistical analysis for nitrogen content and digestibility was performed for all stover parts (Threshed panicle, leaf blade, leaf sheath, upper stem, middle stem and lower stem). ANOVA shows significant differences between sorghum varieties in nitrogen content at leaf sheath, middle stem and lower stem (Tables 12 and 13). At lower parts of the stem, sorghum varieties significantly differ both in nitrogen content and digestibility (Table 14). It makes sense to focus on the stem parts than on leaf sheath; because, stem part is higher in proportion of total biomass production (Figs 18 &20).

Table 12. ANOVA Table showing significant difference (α = 0.05) in nitrogen content but non-significant difference in digestibility for leaf sheath of different sorghum varieties.

		Sum of Squares	df	Mean Square	F	Sig.
Nitrogen content (%dm)	Between Groups	.090	4	.022	4.368	.023
	Within Groups	.056	11	.005		
	Total	.146	15			
Digestibility (ivomd%)	Between Groups	5.263	4	1.316	.485	.747
	Within Groups	29.824	11	2.711		
	Total	35.086	15			

Table 13. ANOVA Table showing significant differences (α = 0.05) in nitrogen content but non -significant difference in digestibility of middle stem parts of different sorghum varieties.

		Sum of Squares	df	Mean Square	F	Sig.
Nitrogen content (%dm)	Between Groups	.576	4	.144	5.116	.014
	Within Groups	.310	11	.028		
	Total	.886	15			
Digestibility (ivomd%)	Between Groups	93.737	4	23.434	1.604	.242
	Within Groups	160.713	11	14.610		
	Total	254.451	15			

Table 14. ANOVA Table showing significant difference (α = 0.05) in nitrogen content and digestibility of lower stem parts of different sorghum varieties.

		Sum of Squares	df	Mean Square	F	Sig.
Nitrogen content (%dm)	Between Groups	.199	4	.050	3.951	.036
	Within Groups	.126	10	.013		
	Total	.325	14			
Digestibility (ivomd%)	Between Groups	257.259	3	85.753	4.550	.029
	Within Groups	188.449	10	18.845		
	Total	445.708	13			

Mean separation was not possible, because of limited number of entries for two varieties (*White wedhakir* and *Berhan+Meko*), to see which varieties differ from the other. However, results of laboratory analysis show higher nitrogen content and higher digestibility for *Berhan+Meko* variety; whereas, lower nitrogen content for *Jigurtie* and lower digestibility for *White Wedhakir* varieties (Table 15).

Table 15. Nitrogen(n-dm%) content and digestibility of lower stem parts of different sorghum varieties.

Variety name	**n-dm%**	**ivomd%**
Jigurtie	0.34	43.18
Abola	0.44	49.58
White wedhakir	0.47	40.25
Wedhakir	0.63	50.74
Berhan+Meko	0.65	52.22

No statistical difference was observed in digestibility at threshed panicle, leaf blade, leaf sheath, upper stem and middle stem for different sorghum varieties. Therefore, varieties that produce higher biomass may be options to balance competing use of crop residues such as for livestock feed, fuel and soil organic input. For *Jigurtie* (high biomass producing variety), leaf sheath and all stem parts (upper, middle and lower) are statistically similar in nitrogen content; only threshed panicle and leaf blade show significant difference from the above mentioned parts (Table 16). However, they are small portions of total plant biomass (Fig. 18).

Table 16. Nitrogen content in %dm (percent of dry mater) of different stover part for *Jigurtie* variety.

	Stover parts	N-content (%dm)	
Duncan[1]	Middle stem	0.33a	
	Leaf sheath	0.33a	
	Lower stem	0.34a	
	Upper stem	0.40a	
	Leaf blade		0.61b
	Threshed panicle		0.62b
	Sig.	0.309	0.859

[1]. Uses Harmonic Mean Sample Size = 5.000.
Means followed by different letters differ significantly

For digestibility analysis, ANOVA shows significant differences between lower stem and other parts (middle stem, upper stem, leaf sheath; and leaf blade, threshed panicle), and between leaf blade, threshed panicle and the other parts with higher percentage of digestibility in leaf bland and threshed panicle. Leaf sheath, upper and middle stems are observed to be statistically the same for digestibility (Table. 17).

Table 17. Digestibility (Invomd% [invitro organic matter digestibility percentage]) of *Jigurtie* stover parts.

	Stover parts of Jigurtie	Digestibility (Invomd%)		
Duncan[1]	Lower stem	43.182a		
	Middle stem		47.050b	
	Upper stem		49.256b	
	Leaf sheath		49.366b	
	Leaf blade			53.418c
	Threshed panicle			55.142c
	Sig.	1.000	.224	.336

[1]. Uses Harmonic Mean Sample Size = 5.000.
Means followed by different letters differ significantly.

4.2.6 Sorghum grain nutrient content

Grains of sorghum varieties show differences in their nutrient contents (Fig. 24). Generally late maturing varieties, *Jigurtie* and *Abola,* have higher starch content than early maturing *Wedhakir* varieties. Conversely, these early maturing varieties show higher protein content than late maturing varieties. However, sample size limited statistical analysis to see whether the differences are significant enough or not. Both varieties show similar percentage of fat content.

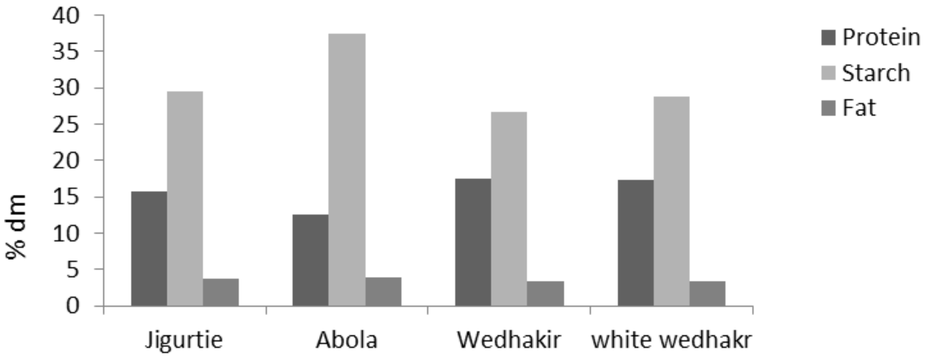


Fig.24. Grain nutrient content (percent of dry matter) of sorghum varieties.

4.3 Resource allocation

4.3.1 Grain allocation

There is higher difference between grains allocated to home consumption and to market for sorghum and maize crops in all farm types. Higher percentage of sorghum and maize grains are used for home consumption while higher percentage of teff is allocated for sale except in FS farm type (small difference between sale and home consumption); however, differences between sold and consumed are not as high as for sorghum and maize (Fig.25).

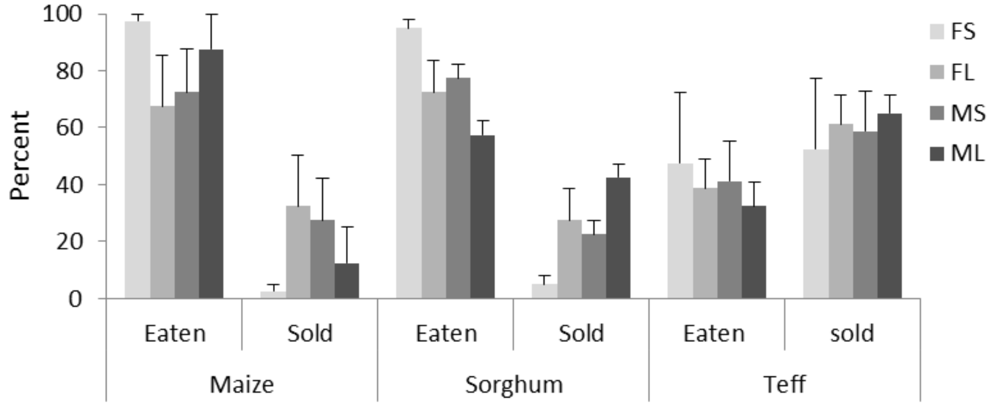


Fig. 25. Grain allocation by farm types for different crops. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

4.3.2 Crop residue allocation

For the major crops (teff, sorghum and maize) high allocation of crop residue is to stall feeding followed by stubble grazing (Figs 26, 27 &28). The amount of crop residue left in the field is subject to grazing during the long dry season; because, after the period of harvesting arable plots are left for open grazing until the next cropping season. Allocations of crop residues for fuel, for construction and for other purposes vary depending on crop type. However, there is higher use of sorghum stover for fuel next to stall feeding and stubble grazing. There is no allocation of teff straw for fuel and maize stover for construction (Fig. 27).

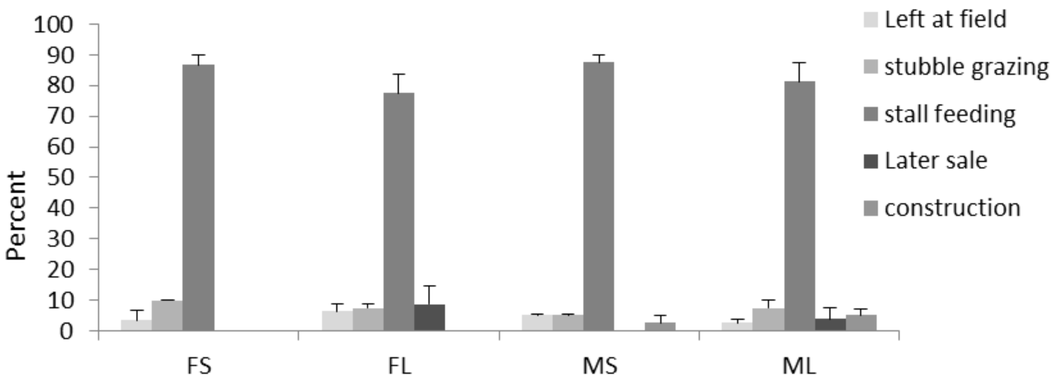


Fig. 26 . Estimation of teff straw allocation by different farm types.
FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

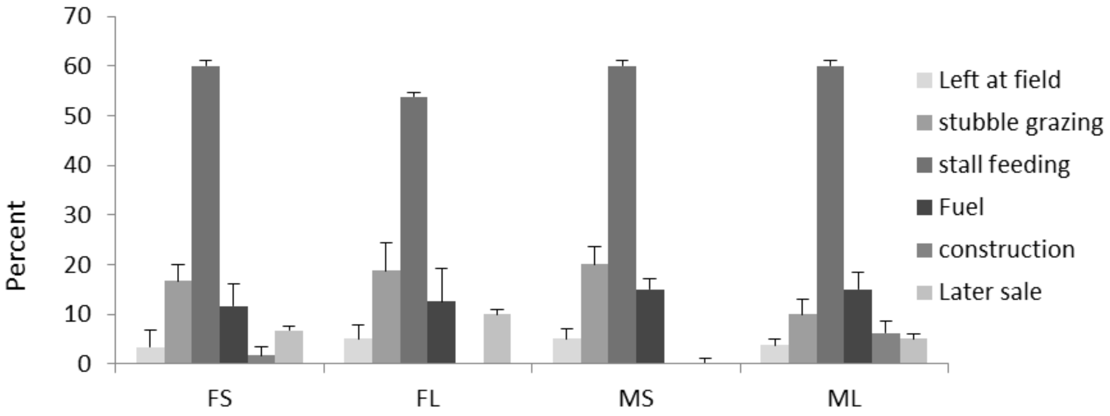


Fig.27. Estimation of sorghum stover allocation by different farm types.
FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

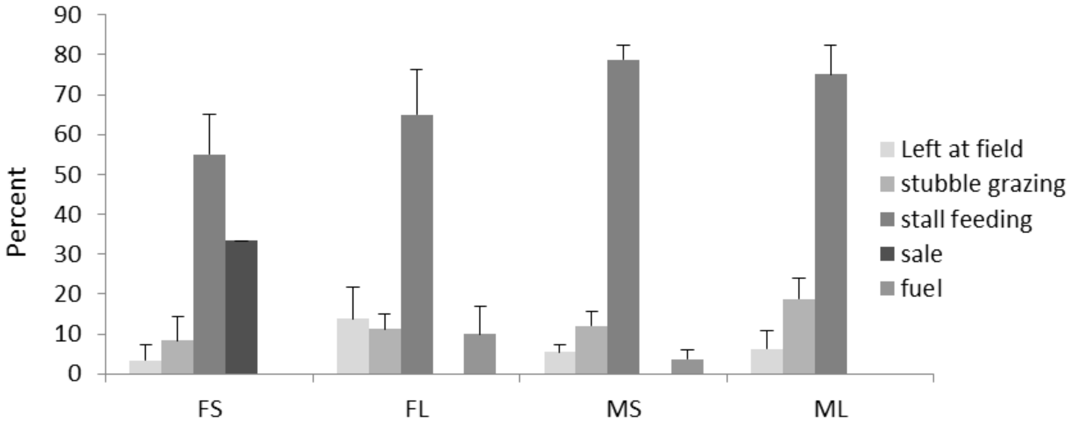


Fig. 28. Estimation of maize stover allocation by different farm types. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

4.3.3 Crop residue feeding strategy

In the months from November to February livestock obtain their feed from stubble grazing; because in this period stubbles are available in the field. From March to November, there is scarcity of dry feed from grazing areas (Fig. 29). Stall feeding strategy from stored crop residues is planned depending on feed availability from grazing areas and cut- carry methods. Even if, farmers provide their cattle additional feed install from stored residues starting from the month of January, higher percentage of stall feeding is observed from April to August (Fig. 30). If there is rain in April, grazing areas, road/river side's and field borders provide supplementary green fodder for livestock. Hence, severity of green feed shortage drops a bit at April (Fig.31). From August to October farmers get fodder for their livestock from road/river side's, weeds, thinning practices (reducing population of maize and/or sorghum to make appropriate plant density) and from communal grass reserves. In these months, major livestock feed is green fodder (Fig. 31).

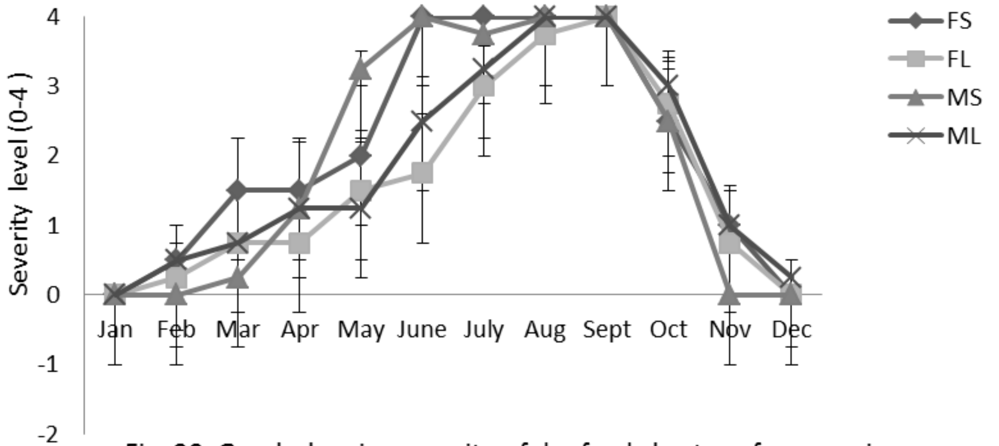


Fig. 29. Graph showing severity of dry feed shortage from grazing areas. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

Farmers' rating for dry feed shortage from grazing.
Severity : 0= no shortage, 1= low shortage, 2= shortage,
3= considerable shortage and 4=Extrem shortage

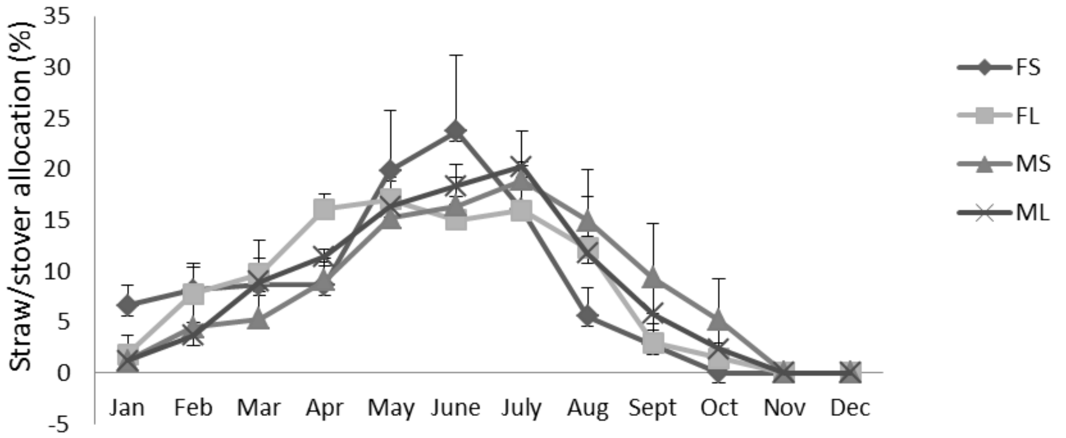


Fig. 30. Stall feeding strategy from stored teff straw and sorghum stover. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

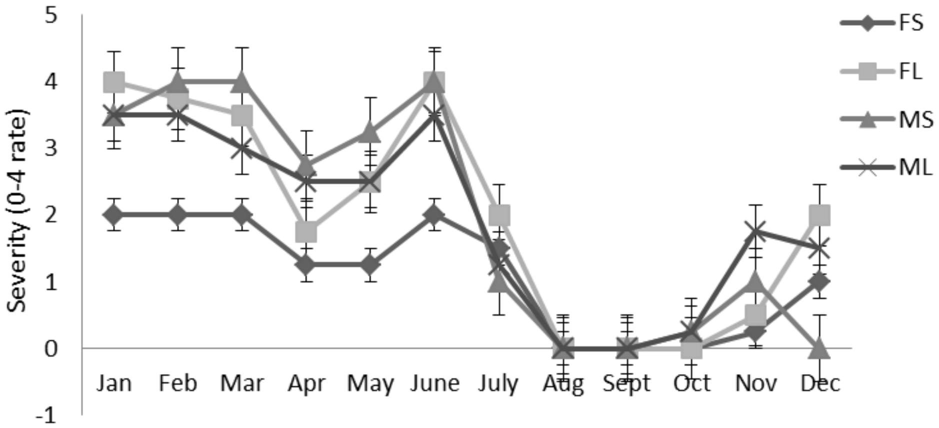


Fig. 31. Graph showing severity of green feed shortage. *FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.*

Farmers' rating for green feed shortage from grazing and cut-carry method. Severity: 0= no shortage, 1= low shortage, 2= shortage, 3= considerable shortage and 4=Extrem shortage.

Crop residues for stall feeding are kept by heaping them firmly to avoid the entrance of rain/moisture and to protect the heap from falling (Fig. 32). The techniques to heap teff residue is different from that of sorghum and maize stovers.

Teff straw is packed in a circular manner and very fine parts such as husk are put on top to seal the end of the heap. Sometimes farmers heap residues of different species separately to feed their ox or cow (for example a plowing ox or a milking cow).

Fig. 32. Teff straw (middle) and sorghum stover heaps (sides) at home stead.

Sorghum and maize stover is heaped by putting them upright. Sorghum stover of shorter varieties like *Wedhakir* is heaped separately for the ease of management. If it is mixed with the longer stalks, it creates an empty space in the middle which obscures firm contact of all stalks that allows moisture entrance. Furthermore, stover from *Wedhakir* is used only for feed but stover form *Abola* and *Jigurtie* are used for feed, construction and fuel. Heaping separately helps them to easily allocate the residue to targeted purposes.

Nevertheless, heaping technique practiced in the area needs improvement to increase shelf life and reduce quantity and quality deterioration of crop residues due to exposure to moisture and sunlight in the open air.

4.3.4 Manure allocation

In the village, higher percentage of manure is allocated for fuel (Fig. 33). Due to reduction of fire wood to satisfy their energy demand, there is an increasing use of dung for fuel from time to time. Farmers apply manure as organic fertilizer only at the homestead plots where they usually plant maize. No one in the village applies manure to the main crop plots; because these plots are far from homes and paths are not convenient to transport with. In addition, transporting manure from homestead to far plots requires labor and capital for camel/donkey rent.

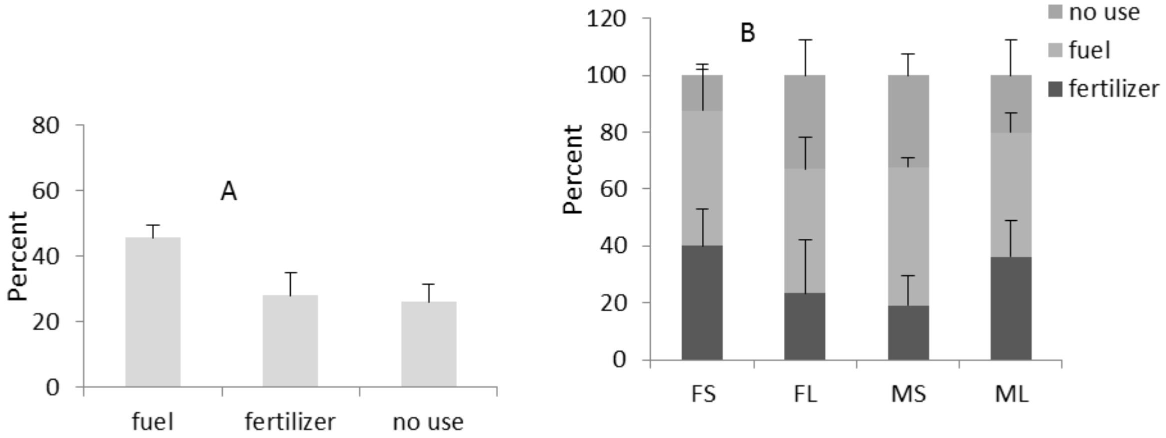


Fig.33. Proportion of dung allocation to different uses (**A**) and allocation by farm types (**B**). FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

Nutrient export from main crop fields that are far from homestead through stubble grazing and removal of residues for stall feeding coupled with manure application limited only to homestead plots creates nutrient concentration around homesteads while degrading distant plots. Still the amount of nutrients lost through burning is considerable. Large proportion of manure and substantial amount of stover is used for fuel. In this way, the continuous nutrient removal from crop plots indicates the need to design strong intervention strategies.

4.4 Farmers' decision-making on resources and limiting factors

4.4.1 Decision maker

From male headed households (N=11) the dominant decision maker is male (Fig. 34). The responses of 5 female headed households are not included in this figure; because some of them rent out their land so that they can't decide on land activities; some of them have son/daughter who take the responsibilities to make necessary decisions; and some of them do not have livestock at all. Females in male headed households have better participation in making decision, at least jointly, on cash crops and livestock than on main crop and crop residues. They do not make decision by themselves on any of these resources. This situation indicates that there is large influence of gender on making decisions on the use of resources.

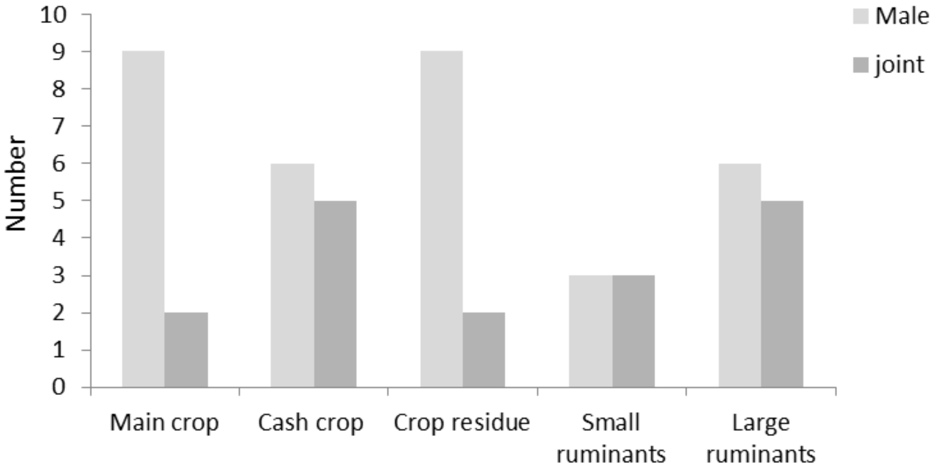


Fig. 34. Decision makers on resources. Females do not make decision from 11 male head households. Joint: husabnd and wife decide together.

4.4.2 Factors influencing decision making processes

Influencing factors in making decision are complex. For example, factors that affect selection of teff varieties for planting differs from factors that influence selection of sorghum varieties.

To select teff variety the factors are: immediate food demand (earliness), grain yield, and market demand and seed availability. Farmers plant *Bunign* if they expect food shortage in September and October otherwise they go for varieties in high demand by the market. *Bunign* is an early maturing variety; it takes about 2 months to mature (Annex 7). The variety *Sikuar magna* gives relatively higher grain yield (Fig. 15) and has higher market demand. That could be the reason for the higher area coverage in the production season (Fig.13) because teff is the main cash crop in the area (Fig. 25).

To select sorghum variety the main factor is moisture availability at planting time. Though there are a number of reasons for making decisions in the production system, the main ones are availability of: water, land and labor. Moreover, gender and open access to crop residues at field influence decision making strategies.

4.4.2.1 Water availability

Sufficient moisture availability at planting time determines the type of crop variety to be planted. Time of rainfall affects especially sorghum variety selection in the area. When farmers get sufficient rain in March and April, they plant late maturing but high yielding varieties, *Abola* and *Jigurtie*. If rain is late (July), they plant early maturing but low yielding variety, *Wedhakir*. There are two *Wedhakir* varieties: relatively higher yielding *White-wedhakir* and low yielding *Wedhakir*. Late maturing varieties, *Abola* and *Jigurtie*, are highly demanded ones for their grain (quantity and quality) and higher stover production (Fig.18);

however water availability limits variety selection at planting time. Respondents rank water as the first limiting factor (Table 18).

Table 18. Influencing factors in making decisions: ranks according to farmers' priority.

	Number of farmers giving rank for major limiting factors		
Limiting factors	1st priority	2nd priority	3rd Priority
Water	15	1	0
Labor	1	4	7
Land size		6	2
Livestock feed		2	0
Soil Fertility		1	1
Fertilizer			1
Information on new technologies			1

Water also limits livestock productivity. In the long dry season, farmers have to buy tape water every day to their livestock (Fig. 35). There are only two watering points serving for human and livestock consumptions of 103 households. One can imagine the stress on livestock and the loses in their body weight due to insufficient water access. spell

Fig.35. Water purchasing for livestock consumption in December (early dry period).

4.4.2.2 Land and herd size

Farmers who have relatively larger land leave more crop residues in the field, where as those who have smaller do not. Farmers who have more livestock collect as many crop residues as possible and transport it to their homesteads for stall feeding. Whereas those who have fewer livestock go for latter sale after they satisfy other needs (feed, fuel and construction).

4.4.2.3 Labor scarcity

Labor scarcity is seasonal for some farmers (at peak planting, weeding and harvesting times) but it is a permanent factor for others especially for aged and female household heads. For seasonal activities they hire labor that comes from the uplands; labor is available but the price increases at peak periods. Labor scarcity affects many land management activities such as harvesting, crop residue transporting and many livestock activities.

4.4.2.4 Feed shortage

A high proportion of livestock feed is crop residues, either from stubble grazing or stall feeding (Fig. 36). Due to erratic rainfall and crop failure, farmers can face feed shortages to the extent that they lose many of their cattle. As a result, they try to gather as many crop residues as possible from crop lands, transport it to homestead and keep for later use; either to sell or to use as fodder or fuel.

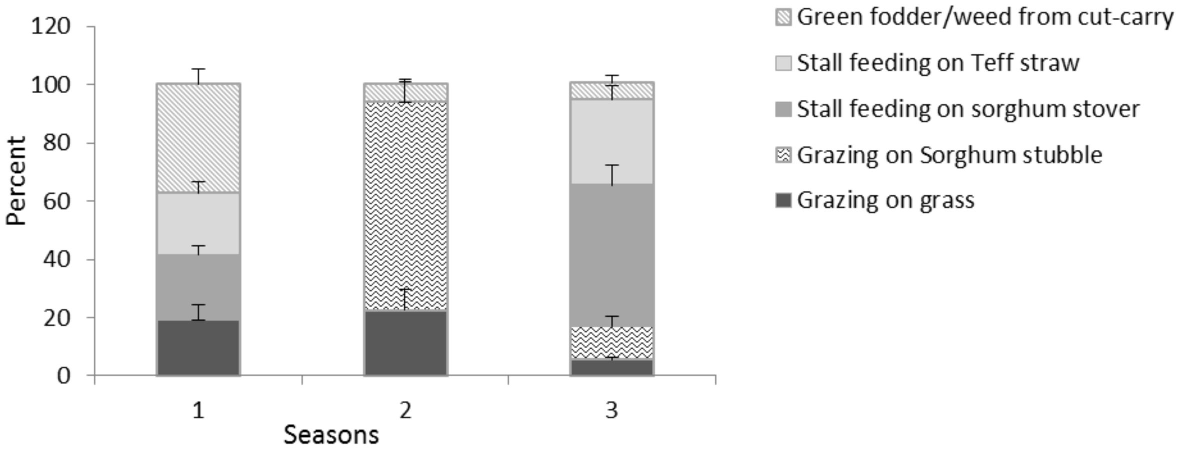


Fig. 36. Seasonal feed sources (cumulative average of all farm types) at Chorie, Ethiopia. Seasons: 1=July -September; 2= October-December; 3= January-June

4.4.2.5 Gender of a household head

There is clear influence of gender on decision making processes (Fig. 34). The influence of gender greatly affects especially land management and utilization of outputs. Female headed households give their land to tillers while sharing grain yields on a pre-set ratio. Grain sharing ratios in the village are: half-half (½: ½), one third to two third (1/3:2/3) and one-fourth to three- fourth (¼:3/4) owner to tiller respectively. This affects productivity of the land in such a way that the renter/shareholder gives higher priority to his own plots to till, weed and performs necessary field management. Figure 37 shows a plot owned by a female headed household whereas rented out. The plot is highly devastated by many weed species such as *Parthenium hysterophorus, Xanthium strumarium, Digitaria spp.,* etc. The reason for less attention to shared or rented plots on the side of the tiller is that extra costs for managing the plot to increase productivity are not included in the agreement set at the beginning. They agree only to share grain yield; then, if the tiller invests extra labor or money to the land he has no legal ground to compensate extra costs from the output.

Fig.37. Poorly managed plot: owned by female headed household but shared.

In the village, very laborious activities such as land preparation, harvesting crops and crop residues, transporting crops and crop residues etc. are the responsibility of males. Timely tillage, weeding, harvesting and threshing activities positively affect quantity and quality of outputs. Thus, lands owned by male headed households have better productivity than female headed holdings. Moreover, males have the possibility to rent/share additional plots leading to better access to resources. When they take plots for share or rent, the agreement is only for grain yields. Decision on the use of crop residues is solely made by the tiller.

4.4.2.6 Open access to crop residue

Fig.38. Livestock freely grazing on previous cropped lands.

Arable plots, after crop harvest, are converted to communal grazing lands for longer time in the dry season (Berhanu et al, 2002). They are accessed by everyone for free grazing and free collection to home use fuel (Figs 38, 39 and 40). This leads to crop residue competition in such a way that farmers transport it from field to homestead as much as they can, to maximize their share and allocate it later for various uses. This practice worsens the removal of crop residues. As a result the physical and chemical characteristics of soils deteriorate.

4.4.2.7 Energy demand

Fig.39. Crop residue collection for fuel.

Woodlots are very limited in the vicinity of the village. Farmers in the village can’t fulfill their energy demand from these wood lots. For this reason, people in the village, even some people in the nearby town, kobo, are using crop residues and dung as main energy supply (Figs 39 and 40).

Fig. 40. Backing *Injera* using sorghum stover.

According to the information obtained through discussion with farmers, during tillage people from the nearby town (Kobo) come with carts to collect sorghum stover together with the roots for fuel. This indicates the severity of crop residue removal from the arable plots. In addition, dung dropped overnight at the homestead is picked, spread over stone fences to facilitate drying and then used for fuel. Only the part that is not possible to use for fuel due to repeated animal trampling is applied as fertilizer at homestead plots.

Fig.41. Dry dung collected from crop plots: for house use fuel.

Similar to crop residue collection, in-situ dung is also removed freely for fuel after it dries in the field (Fig. 41). Even though dung dropped at crop fields while livestock graze on stubbles can be one source of soil organic input, people from the surrounding come with sacs or other containers, collect and take it to home for their cooking energy source. This is done throughout the dry period until fields are covered by crops. One can see the negative effect of this practice on soil organic matter status.

4.4.2.8 Others

- **Increased market demand**: - at the time of rain failure, the demand for crop residue to livestock feed increases. Some farmers in the village gather as much crop residue as possible and store it for later sale expecting a possible market demand.
- **Transportation from field to home**: - Camel is the main pack animal for transporting crop residues from field to homestead. Having camel or ability to pay for camel rent (current rent is between 35-60 birr ≈ $2.1-3.6/camel/trip) determines the transport of crop residues from field to homestead. Farmers who cannot afford this are forced to leave residues at field.
- **Plot distance (from home):**- Farmers collect crop residue first from nearby to home plots and then move to far plots. If the plot distance is far enough that they cannot manage due to shortage of labor & capital, then crop residues are left at field which latter are taken by anybody for free. Many farmers in *Chorie* village have plots at *Denbi* which is about 1 and ½ hour walk from their village. None of them bring crop residue from *Denbi* to home. In addition to plot distances, farmers who have relatively large plots satisfy their demand from nearby plots and leave crop residues that are relatively on far plots.

4.5 Soil fertility

4.5.1 Current fertility status

There are highly significant differences (α=0.01) among plots where different crops were planted in N, P and K contents (Table 19). Mean separation using LSD shows that differences are between the homestead maize plots and the main crops (teff and sorghum) plots which are found at distant location from farmers' houses (Table 20). Difference in C content between maize plots and sorghum plots at α= 0.01 is not significant. This could be due to the fact that sorghum has deep root system and higher root biomass to build up soil carbon than teff crop; Yet, there is significant difference between them at α=0.05 level of significance. ANOVA shows non-significant differences (α=0.05; Annex 10) among farm types in soil C, N, P, and K contents with in plots that are planted similar crops.

Table 19. ANOVA Table showing highly significant differences in soil nutrient contents among fields where different crops were planted.

Description	Sum of squares	df	Mean square	F	Sig.
N-content(%)					
Between Groups	.033	2	.016	9.744	.000
Within Groups	.076	45	.002		
Total	.108	47			
C content (%)					
Between Groups	1.624	2	.812	6.278	.004
Within Groups	5.821	45	.129		
Total	7.445	47			
P content (ppm)					
Between Groups	56965.560	2	28482.780	11.652	.000
Within Groups	110000.272	45	2444.450		
Total	166965.832	47			
K content (ppm)					
Between Groups	1429735.500	2	714867.750	6.636	.003
Within Groups	4847349.703	45	107718.882		
Total	6277085.203	47			

Table 20. Mean separation using LSD showing differences between soils of different crop fields in nutrient content at α= 0.01 and 0.05 levels of significances.

Interaction between fields		N (g kg^{-1})	C (g kg^{-1})	P (ppm)	K (ppm)
Teff field	sorghum field	1.42^{ns}	11.92^{ns}	11.30^{ns}	226.30^{ns}
	maize field	1.89**	15.26**	81.47**	560.80**
Sorghum field	teff field	1.28^{ns}	10.97^{ns}	5.79^{ns}	169.70^{ns}
	maize field	1.89**	15.26*	81.47**	560.80**
Maize field	teff field	1.28**	10.97**	5.79**	169.70**
	sorghum field	1.42**	11.92*	11.30**	226.30**

**. The mean difference is significant at the 0.01 level.

*. The mean difference is significant at the 0.05 level.

^{ns}. The mean difference is non-significant at the 0.05 level.

There is higher nutrient concentration at homestead maize plots than the teff and sorghum plots. This could be resulted due to higher nutrient importation from distant teff and sorghum plots, better application of manure and other organic materials, better protection from free access to crop residues and/ or better agronomic practices to these homestead plots than the far plots.

Crop residues are exported every year from teff and sorghum plots resulting in nutrient deterioration at those fields. In addition to nutrient exhaustion of arable plots, their physical stability is also declining (Fig. 41) due to insufficient structural build up contributed by low organic materials. The more fragile the soil in its physical structure, the more it will be prone to erosion, gully formations and landslides. Crop residues are important not only to replenish soil nutrients but also to stabilize soil aggregates.

a. One season gully; formed after crop establishment. Sorghum at both sides of the gully were planted by the same plough pass in this season.

b. Older gully; increasing its dimension every rainy season. In this cropping season, soils are lost together with teff crop!

c. Sacs filed with sand and put on young gullies to protect erosion (effort made by one farmer around the study area).

Fig. 42. Soil erosion and gully formation (a)on sorghum, (b) on teff plots; and (c) farmer's effort to protect erosion, at Chorie, Ethiopia. Pictures **a** and **b** show the fate of soils that has poor aggregate stability and that lack soil and water conservation practices. Picture **c** shows the possibility of protecting soil erosion. Crop residues can increase aggregate stability and protect soils from erosion.

Organic carbon content of most plots (83%), irrespective of the farm type (Table 21), is below 15 g kg^{-1} of soil (Fig. 43). Low level of organic matter in soils is a key factor to decreased structural stability of soils (Franzluebbers, 2002).

Table 21. Soil organic carbon of arable plots owned by each farmer at Chorie village, north Wollo, Ethiopia.

SOC (g kg^{-1})	Available P (ppm[parts per million])	Farmer ID	Number	Total land size (ha)
6-10	3.16-10.46 *1 field 17.94	FS	2	0.825
		FL	3	2.500
		MS	3	1.00
		ML	5	5.500
10-15	2.06-32.3 * 2 fields: 46.7 & 51.3	FS	11	4.625
		FL	8	7.625
		MS	7	3.125
		ML	11	6.500
15-20	9.38-81.5 * 1 field 252.6 (homestead maize plot)	FS	0	0.00
		FL	4	1.875
		MS	5	2.487
		ML	2	1.125
20-25	124.6-266.2 * homestead maize plots	FS	2	0.375
		FL	0	0.000
		MS	1	0.250
		ML	0	0.000
Total land size (ha)				**36.062**

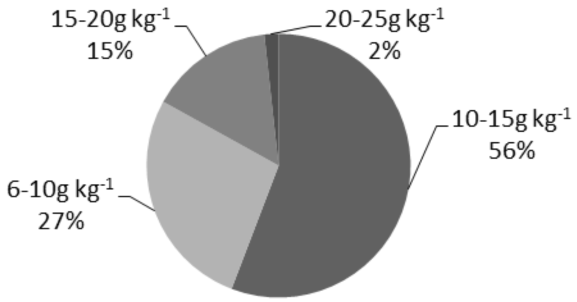
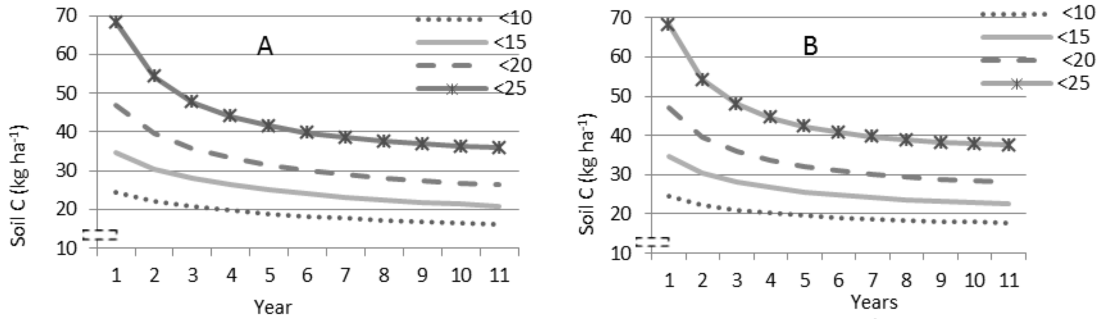


Fig. 43. Proportion of arable plots on the basis of SOC content (nearly all plots of the sixteen selected farmers [g kg^{-1} soil]).

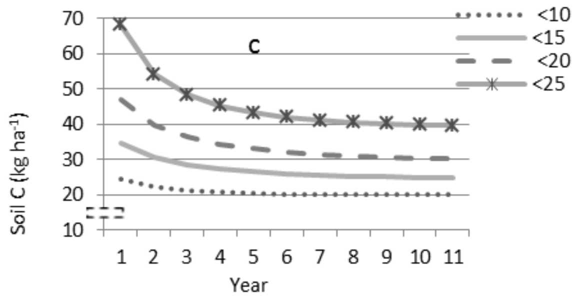
4.5.2 Future trends in soil organic carbon and land productivity

Simulated results show different levels of soil organic carbon maintenance and biomass production in the coming ten years (Figs 44 to 47). As crop residue retention increases from 30% to 70%, a more stable condition in soil carbon and biomass production is created in a relatively shorter periods (Figs 44C, 45F, 46I and 47L). If 70% of crop residue is retained, fields that have low soil organic carbon (<10g kg^{-1}) attains its equilibrium faster (in about 4-5 years; Fig.44C) than other soil types. Biomass production positively correlates with soil carbon status (Fig. 45). However, the model under estimates biomass production.



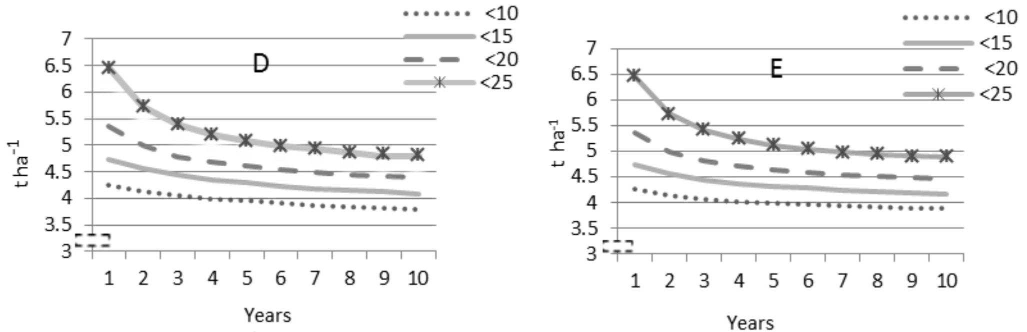
Scenario 1: Crop residue retention =0%.

Scenario 2: Crop residue retention =30%.



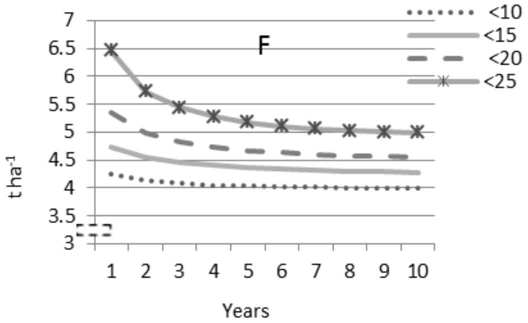
Scenario 3: Crop residue retention =70%.

Fig. 44. Simulation result of SOC for 3 scenarios based on soil types (SOC). Legend explanation: soils that have <10g Kg^{-1} SOC- dotted lines; <15g Kg^{-1} SOC- solid lines; <20g Kg^{-1} SOC- broken lines and <25g Kg^{-1} SOC- solid lines with asterisk.



Scenario1: Crop residue retention =0%.

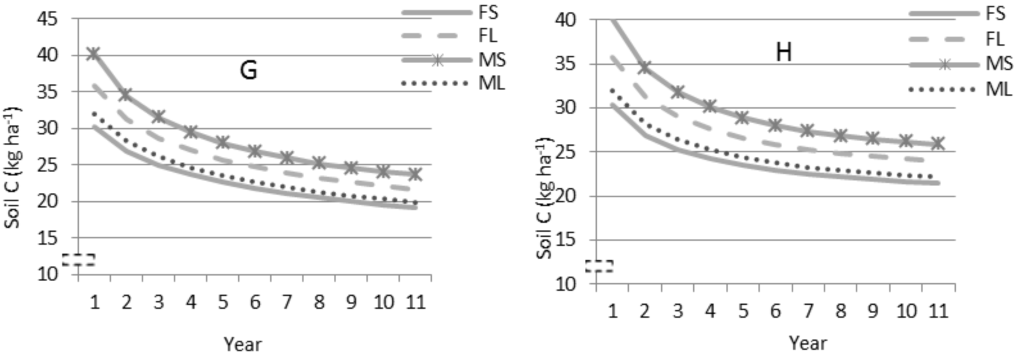
Scenario 2: Crop residue retention =30%.



scenario 3: Crop residue retention= 70%.

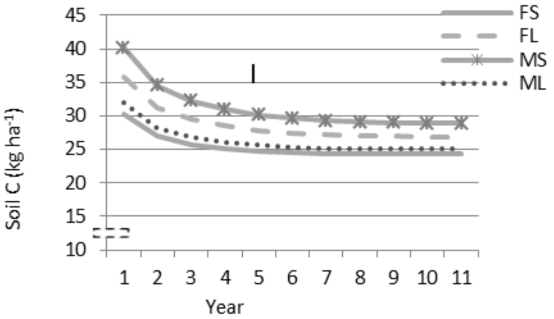
Fig. 45. Simulation result for above ground sorghum biomass for 3 scenarios based on SOC (g kg^{-1} soil) content.

Simulation run based on different farm types(Figs 46 and 47) also show similar trends, in all scenarios, with simulation results that are run based on soil carbon contents (Figs 44 and 45). The results show that soil fertility status is not correlated with farmers' wealth. Fertility of soils managed by the two opposite (on the basis of wealth typology) farm types (FS and ML) is similar.



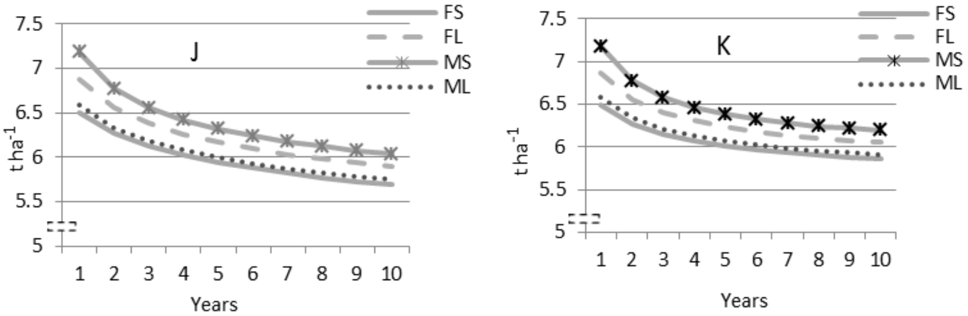
Scenario 1: Crop residue retention =0%

Scenario 2: Crop residue retention = 30%



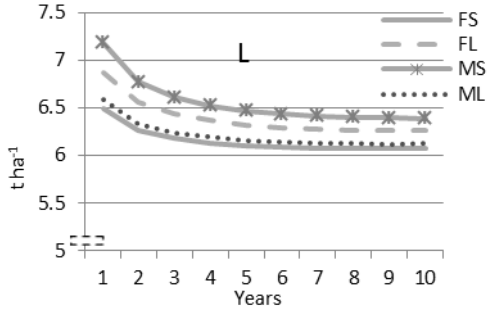
Scenario 3: Crop residue retention =70%.

Fig. 46. Simulation results of SOC for 3 scenarios based on farm types. *FS= few livestock/ small land; FL= few livestock/ large land; MS=more livestock/small land and ML=more livestock/large land.*



Scenario 1: Crop residue retention =0%

Scenario 2: Crop residue retention = 30%



Scenario 3: Crop residue retention = 70%

Fig. 47. Simulation result for above ground sorghum biomass based on farm types. *FS= few livestock/ small land; FL= few livestock/ large land; MS=more livestock/small land and ML=more livestock/large land.*

The model under estimated above ground biomass production; because may be it is parameterized for grain yield prediction. However, these simulation results can be indicative to understand the impact of different level of crop residue retention on productivity of the farming system.

Chapter 5. Discussion

5.1 Crop residues utilization

At Chorie, more than 90% of teff straw, 74% of sorghum stover and 81% of maize stover are used for livestock feed through stubble grazing and stall feeding (Figs 26,27 and 28). The result is in line with the finding of de Leeuw (1997). Crop residues use for home energy is almost similar for all farm types (11-15%; Fig. 27). The result indicates that extremely low amounts of crop residues are left for soil organic matter enhancement; probably not more than the root biomass (Tables 19 and 20). Simulation results (Figs 42, 43, 44A, B and 46G, H) and previous works already explained in Chapter 2 reveal that severe crop residues removal results in degradation of soil physical and chemical characteristics. One strategy to retain sufficient crop residues and produce satisfactory feed could be increasing biomass production through high yielding varieties.

For teff crop, the improved variety, *Sikuar magna*, has many superior qualities to be selected to the system. It produces higher biomass, has good home and market demand, and matures early next to *Bunign* (Annexes 4 and 7). However, for sorghum crop, the local varieties *Jigurtie* and *Abola* produce higher biomass than the improved *Wedhakir* varieties. Therefore, from local sorghum varieties, farmers can get higher biomass production, good feed, food and market values; these varieties have low nitrogen content and digestibility percentages but it can be compensated by higher biomass yield. For Chorie farmers, biomass production is the priority criteria for a variety to be selected to satisfy feed, food, as well as organic inputs to their soils. Due to rain uncertainty, farmers greatly shifted to early maturing but low yielding sorghum varieties. This means that the probability of losing higher yields at good production seasons is high. Extension workers should be careful in advising farmers which variety they should use in order to maximize advantages from these varieties.

Quantity of crop residues can be adequately increased through high yielding varieties provided that there are no limiting factors. Yet, scientists (e.g. Williams et al., 1997) argue for digestibility of thicker and stronger stovers from high yielding sorghum varieties. Digestibility analysis for stem parts of different sorghum varieties show none-significant difference at upper and middle stem parts; differences are significant only at lower stem parts(Tables 13 and 14). Based on this result, farmers can allocate upper parts for livestock feed and lower parts for soil amendment activities.

Strong feed shortages from pasture/rangelands and firewood shortages from woodlots in the area forced farmers to depend on crop residues for their livestock feed; and to use it as energy supply. This situation leads to strong tradeoffs between short term benefits and long term farm sustainability. These negative trade-offs can be improved by retaining more crop residues (up to 70% or even higher when possible; Figs 44C and 46I; Tittonell et al., 2008) in the field. However due consideration should be given to ensure higher percentage of incorporating it to the soil.

The competing use of crop residues for livestock feed, fuel and soil fertility management activities may be improved through various efforts, such as encouraging farmers to plant leguminous fodder trees, multipurpose trees (Oluyede et al., 2007) around homesteads, riversides and field boarders to reduce use of crop residues for fuel and construction materials. Multipurpose trees can be used for livestock feed, they can fix atmospheric nitrogen and are also fuel sources (Unger et al.,1997). Encouraging farmers' indigenous tree and shrub management practices like shade trees in their fields, contour hedges, live fences, wood lots etc. are likely to contribute a lot in any intervention strategy (Kindu et al., 2009). Trees increase water infiltration, protect erosion, provide feed to livestock, nutrients to soils, fire wood for energy, logs for construction materials and many more environmental benefits.

5.2 Manure utilization

In the study area farmers need technical support to improve their manure allocation for fertilizer. They allocate only about 28% to fertilize their small size homestead maize plot; teff and sorghum plots receive no manure. More than 46% of manure is used for fuel and about 26% is left un-used (Fig. 33A). There is small difference among farm types in manure allocation (Fig. 33B). FL and MS farm types apply lower than FS and ML farm types. This variation could be due to labor availability, land tenure or field distance from home. In any case farmers use relatively low proportion of manure as fertilizer; yet, they complain that it resulted weed infestation and crop burning effects. This could be due to low quality of manure in its nutrient content as findings (e.g. Tittonell et al., 2008; Giller et al., 2011) already confirmed this case, and /or it could be due to inappropriate time and method of application (Thomsen,2005). Therefore, it is very important to provide technical support to farmers to properly utilize manure at least in their homestead plots. Interventions for soil fertility management measures can be started with low cost resources like manure and other organic materials that are available at the hands of farmers.

Many scientists (e.g. Zingore, 2006; Zingore et al., 2007a;b; Bationo et al., 2007; Okumu et al., 2011) reported that soil fertility gradient have developed due to farmers' preferential application of organic and chemical fertilizers to homestead plots. In the study area, the settlement location is the most important factor due to difficulties to transport the bulky manure to the far main crop lands. Villagers live at higher elevation following a mountain contour belt. This could be good strategy to avoid flood and mud challenges during heavy rainy season but it creates considerable distance between crop lands and homesteads. The distance negatively affects the timeliness of agronomic management practices. There is hardly any nutrient transport from home to these far arable plots except seeds. Extreme removal of crop residues for feed, fuel and other purposes coupled with no manure or chemical fertilizer application to replenish nutrients exported through crop production is the characteristic of the current farming system at Chorie. Resettlement of farmers close to their main crop plots may help to improve their soil fertility management activities.

Nutrient contents of plots managed by different farm types are statistically similar; there are no significant differences in C, N, P and K contents (Annex 8) among plots of farm types, even at the homestead plots. Though there are differences among farm types in the number of livestock (that affect amount of crop residues collection and manure), land holding, gender, labor availability and so on, nutrient status of their soils are not statistically different. Farmers who have livestock may apply more manure than those who do not have livestock, yet the effect is not explained in the soil fertility status. This could be due to poor manure application practice and/or poor quality of manure to enhance soil fertility at least at homestead plots where farmers usually apply manure. Low quality of manure is resulted because of poor handling and storage practices (Fig. 11; Powell and Williams, 1993; Nzuma et al., 1997; Rufino, 2008; Tittonell et al., 2008; Giller et al., 2011).

5.3 Crop residues and manure management practices of farm types

Generally, there are no differences among farm types in soil fertility management practices. Crop residues and in-situ dung collection from arable plots as well as crop residues and manure allocation strategies are similar. However, quantity of allocating these resources to various uses differ among farm types depending on the number of livestock owned, land tenure condition and labor availability. In addition to these, the following are other multiple factors that create differences.

1) **Social:** farmers settle far from their main crop lands. They need to transport crop residues from field to homestead. In this case, in addition to labor, gender and age variability create differences in the amount of transported crop residues, management and decisions on the allocation.
2) **Environmental:** Amount and distribution of rainfall affects variety selection and hence total biomass production, as well as livestock productivity (Fig. 35). High yielding sorghum varieties are late maturing ones and require sufficient moisture in April with subsequent topping. Early maturing varieties are low in their biomass yield (Fig. 18). The less biomass production in the cropping season, the sever crop residue removal for stall feeding will be. Farmers are forced to shift their energy source from woods to crop residues because of declining woodlots to supply firewood (Figs 38 and 40).
3) **Economic:** farmers hire labor for peak land activities like harvesting, and rent camel for transporting crop residues. Moreover, selling crop residues also depends on economic performance of farmers in such a way that poor farmers collect as many residues as possible for sale whereas richer farmers collect residues mostly for their own demands.
4) **Lack of legal protection**: Anybody has free access to arable plots after crop harvest, people living in the surrounding collect crop residues for fuel and other purposes, and

allow livestock for free grazing. Everybody tries to maximize its share; this competition results in severe depletion of soil organic matter.

5) **Lack of alternative technologies**: Feed technologies (different annual and perennials feed plants), alternative energy sources like biofuel, wood lots etc. are not tried yet. Soil and water conservation practices are very limited to highly degraded areas. The situation alerts quick and strong intervention to ensure sustainable farm productivity and improve farmers' livelihood in the area.

5.4 Limitation of the study

Data on socio-economic aspects and resource allocations are collected based on farmers' estimation through interviews. Even though thorough discussions were made with farmers and care was taken during farmers' estimation, precision on values are still lacking. Yield samples are taken from crops that are planted at farmers' fields of different soils, that received different agronomic practices. Hence, comparison for different traits may not represent potential differences of varieties. Furthermore, the number of replica for varieties is not equal due to random selection of farmers. Results for some varieties are averages of 8, for others are averages of 4 or 3 and for others average of only one plot samples. So results in this report could be indicative but may not be precise.

Chapter 6. Conclusion and recommendation

- It is important to maintain crop diversity to increase the chance of farmers' flexibility according to climatic and economic influences. All local varieties should not be substituted by improved ones; because, not all improved varieties are suitable to production objectives of a given area. Farmers' priority should be considered when providing seeds to them. Accordingly, the improved teff variety, *Sikuar magna*, and the local sorghum varieties, *Jigurtie* and *Abola*, are better varieties for Chorie farming system.
- The current method of crop residue storage, especially sorghum and maize residues need processing activities (at least chopping down) to facilitate intake by livestock. Furthermore, attention should be given to storage places /conditions to protect crop residues from extended solar radiation and moisture entrance that deteriorate its quality and quantity.
- There is no difference among farm types in soil fertility management strategy and the use of crop residues. Variations are rather on decision makings due to climatic, social, gender, economic and institutional influences.
- Gender of the head of a household is key element to resource management in the study area; legal document concerning land renting or sharing agreements to protect female and aged farmers from personal (tiller) exploitation, and to safeguard land productivity is very important to female headed and aged households.
- Current crop residue and manure management practices are negatively affecting soil carbon stock and land productivity. To restore the declining soil carbon and ensure sustainable land productivity, sufficiently higher percentage of crop residues need to be retained in the soil.
- The study area needs strong interventions about alternative livestock feeds, alternative energy sources, rain water harvesting (at least for homestead gardening), efficient use of manure, legal support to crop residues property right and so on.
- Although models developed elsewhere can be adapted to predict crops having similar characteristics, site variations could create differences in crop performances and biophysical processes; which may limit the prediction power of models parameterized at other localities. Primary data for specific condition is important to generate reliable prediction from models.

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Annexes

Annex 1. Population and land availability at Chorie village

Description	Quantity	Description	Quantity
Total population	515	Total house hold	103
Cultivated land (ha)	618	Female head house hold	25
Rain fed	618	House hold without dairy	50
Irrigated	0		

Annex 2. Parameters used to calibrate the model FIELD

a. Site specific parameters

No.	Description	Value used
1	Maximum relative decomposition rate of residue C	0.8
2	" " " " " root C	0.8
3	" " " " " active C	0.69
4	" " " " " soil C	0.2
5	Growth efficiency of microbes (immobilization of N b y active organic matter)	0.6
6	C-N ratio active C pool (kg C ha^{-1})/(Kg N ha^{-1})	8
7	C-P " " " " "	40
8	Humification factor	0.25
9	Relative amount of decomposed soil organic matter that re-enters the soil organic matter pool	0.2
10	Fraction of C originally in the soil C pool	0.9
11	Fraction of inert C in the soil C pool	0.55
12	Seasonal relative turnover of inert C pool	0.001
13	Rain fall (mm $season^{-1}$)	550
14	Water capture efficiency	0.20
15	Water conversion efficiency	88.7
16	Correction factor for relative decomposition rate of active organic matter	1
17	" " " " " soil organic matter	1
18	" " " " " residues	1
19	" " " " " residues	1
20	Maximum soil organic matter level (kg C ha^{-1})	30,000

b. Soil specific parameters

No.	Description	Value used
1	Soil texture (%) Clay Sand Silt	 6 52 42
2	Soil organic carbon (g kg^{-1})	4.7
3	Total soil N	0.4
4	Exchangeable P	9
5	" K	170
6	" Ca	1.5
7	" Mg	2.1
8	ECEC	4.5
9	PH	6.6

10	C/N ratio of soil organic matter	15.5
11	C/P ratio of soil organic matter	180.0
12	Bulk density	1450

c. Crop specific parameters

No.	Description	Value used
1	Harvest index	0.27
2	Above ground biomass (kg ha^{-1})	50,000
3	Water capture efficiency (fraction) ?0.4	0.26
4	Water conversion efficiency (Kg DM mm^{-1}	88.7
5	Minimum nutrient concentration (kg ha^{-1}) Nitrogen Grain Residue	 0.0100 0.0035
	Phosphorus Grain Residue	 0.0013 0.0005
	Potassium Grain Residue	 0.0025 0.0080
7	Maximum nutrient concentration (kg ha^{-1}) Nitrogen Grain Residue	 0.0320 0.0120
	Phosphorus Grain Residue	 0.0065 0.0030
	Potassium Grain Residue	 0.0007 0.0280
8	Root nutrient content Nitrogen Phosphorus Potassium	 0.0025 0.0005 0.0030
9	FRINT (??)	0.6

d. Management aspects

No.	Description	Value used
1	Initial amount of crop residues (kg ha^{-1})	500
2	C/N ratio of residue	50
3	Fraction incorporated	0.8
4	Initial amount of roots (kg ha^{-1})	800
5	C/N ratio of roots	35
6	fraction of available N loss	0.2
7	Fraction of P reached by roots	0.5
8	FACP ??	0.1
9	Fraction of crop residues that is labile	0.7

Annex 3. Questionnaire used for socio-economic data collection

Household level survey: Crop residue and manure use in smallholder crop-livestock systems

The objective of this survey is to obtain a better understanding on farmers' decisions related to crop residue and manure management, and feeding strategies. Data collected here will be confidentially kept and reports will not make reference to individual cases explicitly.

1. HOUSEHOLD GENERAL DATA

1.1. Identification: if possible, please add the coordinates of the homestead.

Village______________

a. Place of interview ____________________ (1) Homestead; (2) other, name: ______________________________

Coordinates homestead **b**. N/S ___________ **c**. E __________ **d**. Altitude __________masl

1.2. Household head: main information of the household head

a. hh head name ___________________ **b**. hh head father's name _________________

c. hh head gender _____ (1) De jure female; De facto female; (3) Male

d. hh head age ____ years old. **e**. hh head years in the village __ years **f**. Phone no. _____________

Number of years of education of the:* **g**. Head household _____ **h**. Leading female/wife _____

* It includes both formal/informal.

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

	1. Female	2. Male		1. Female	2. Male
< 6 years old			6 – 9 years old		
10 – 15 years old			15 - 60 years old		
> 60 years old					

1.4. Decisions: who take the decisions in the household (1) female, (2) male; (3) joint; (4) other

Decision on:	Responsible
Main crops selection and management	
Cash crops selection and management	
Use of crop residues	
Selection and management of small ruminants	
Selection and management of large ruminants	

1.5. Labor availability: is here a problem? Why?

____

2. ASSETS, ACCESSIBILITY & FOOD

2.1. Assets and services - (0) No; (1) Yes

Mobile phone _______ Radio ________ *Region specific (transport)* _____

2.2. Saving strategies: Is the household engaged in savings? ___ (0) No; (1) Yes. If yes, how? ____

(1) banks; (2) livestock; (3) property, Land (4) other way_______

2.3. Net food: How many months can you consume the main staple food (cereals) you produce in:

A year of average rainfall? ____ months A year of low rainfall? ____ months

2.4. Food source: if yours is finished, how do you normally obtain extra staple food (cereals)? ___

0) no need; (1) purchase food; (2) subsidised/food aid; (3) given by others; (4) other _________

2.5. Food-aid: In how many years did you need food-aid during the last 10 years? ____ years

3. LAND & CROPS

Agricultural seasons: don't ask this to the farmer, please use the ones identified in the village survey

Duration of season	1st Season	2nd Season	3rd Season
First – last month	July – Sept.	Oct. – Dec.	Janu.- June

3.1. Plots/management units *managed* by hh: general information (use with the resources flow map)

	Code	1. Size	2. Ownership	3. If owned, who owned it?	4. Current use	5. Productivity	6. Distance from home	7. Level slope
1								
2								
3								
4								
5								
		Unit: ___ (a) acre (h) hectare (o) other _______	(1) Owned; (2) Shared; (3) Rented; (4) Other _________	(0) No owned (1) Female (2) Male (3) Joint (4) Other relative (5) Other	(1) Idle/fallow; (2) Crops; (3) Fodder; (4) Pasture; (5) Other _____	(1) Good; (2) Average; (3) Low.	Unit: ______________ Unit in km:	(1) Flat; (2) Mild; (3) Steep.

3.2.Plots/management units *managed* by hh: use/inputs per season (use with resources flow map)

Characteristics	Crops (use codes above)							
Type/variety								
Plot IDs								
Season								
Tillage passes								
Residue visible at sowing?								
Seed rate [kg/LU]								
Date of sowing [dd/mm]								
FYM use [qtl/LU]								
other manures [qtl/LU]								
Fertilizers (specify)								
(a) urea [qtl/LU]								
(b) DAP [qtl/LU]								
Herbicides								
Fungicides & insect.								
Date of harvest [dd/mm]								
Grain yield [qt*/LU]								
Crop residue [qt*/LU] * qt= quintal=100Kg = 0.1ton								

CROP LIST
1. maize
2. sorghum
3. Beans
4. teff
5. Mixed
6. Tomato
7. Onion
8. Cabbage
9. Chickpea
10.Fodder grass
11.Others: ___

3.3. Use of main crop products: data to be collected in % or absolutes ___ (1) %; (2) absolutes

Crop (list)	Season	Product name	Use product					
			Eaten	Sold/ bartered	Seed	Livestock	Others	Total*
								100%
								100%
								100%

* If % percentages are used

3.4. Variety preference: Which varieties of a crop under which condition do you prefer?

Varieties of a crop	Reason for preference
sorghum	
Tef	
	Consider moisture stress, low soil fertility, water logging, CR, grain yield,

3.5. Access to information (0) No; (1) Yes

Type of information	1. Family, friends or farmers	2.Government/ extensionist	3. Private sector/NGOs	4. Other ________
For information on new crop varieties				
For information on crop inputs/outputs price				
For information on other crop technologies				

3.6. Extension: how many times do you meet crop extensionist?

4. CROP RESIDUE MANAGEMENT

4.1. Height of CR remaining in the field at harvest (cm): at what height do you harvest the CR?

Crop type	Owned land	Rented land	Reason
sorghum			
Tef			
other			

4.2. CR Allocation: for the year 2010

	Crop 1	Crop 2	Crop 3	Trend last 5 years
Where CR is allocated:	Name:			
	Season:			
	Technology:	Manual	Manul	
In field	**Reason**			
Left in the field (mulch)	%	%	%	↑ = ↓
Stubble grazing own animals	%	%	%	↑ = ↓
Stubble grazing by others	%	%	%	↑ = ↓
Taken home for:				
Stall feeding	%	%	%	↑ = ↓
Household fuel	%	%	%	↑ = ↓
Roofing/construction	%	%	%	↑ = ↓
Selling later	%	%	%	↑ = ↓
Other:	%	%	%	
	100%	**100%**	**100%**	

4.3. Do you think leaving ample CR in the field can benefit the soil? 1) yes 2) no

Reason:____

4.4. CR exchange: unit ______; unit in kg _______

	Name	to/ from whom?	1st Season	2nd season	3rd season	Trend 5 yrs
Amount sold CR1						↑ = ↓
Amount bought CR1						↑ = ↓
Amount sold CR2						↑ = ↓
Amount bought CR2						↑ = ↓

(1)farmer,(2)market
(3)trader(4)other___

4.5. Access to information: Have you heard about: (0) No; (1) Yes

Type of information	Knowledge and use	If yes, from whom?
Chemical treatment of CR?		
Use of CR for mulching?		
Composting of CR?		
Improved storage methods of CR?		
Chopping/cutting CR?		
Varieties with improved straw quality?		

(0) I haven't heard about it	(1) Family/friends/farmers
(1) I've heard but I never practiced it	(2) Government/extensionist;
(2) I'm practicing it;	(3) Private sector/NGO
(3) I practiced it before, but I stop it	(4) Other _________

4.6. Perceptions on crop residues

Statements	Strongly disagre	Disagree	Neither agree or disagree	Agree	Strongly agree	Not applicable
Tillage considers CR incorporation in to the soil	-2	-1	0	1	2	-8
The incorporation of CR improves soil quality	-2	-1	0	1	2	-8
The use of CR as mulch is a waste of feed	-2	-1	0	1	2	-8
CR are a vital feed source for my livestock	-2	-1	0	1	2	-8
Feeding CR to livestock improves the profit of my farm	-2	-1	0	1	2	-8
No CR should be left on field before next tillage	-2	-1	0	1	2	-8
If I leave CR in the soil, I don't need to use fertilisers	-2	-1	0	1	2	-8
Quantity of produced stover is essential to select my crop varieties	-2	-1	0	1	2	-8
CR must be a property of each household	-2	-1	0	1	2	-8
Better to feed my livestock with crop residues than to leave them in the soil	-2	-1	0	1	2	-8
With the current storage technique, quality of CR doesn't change in time	-2	-1	0	1	2	-8

4.7. CR storage: how do you store the CR of your 2 main crops?

	Crop ID (use list)	Part plant	How is it stored?
Main crop 1	2		
Main crop 2	4		

(1) heap in the field (2) heap next to home (3) room (4) Other _________

5. LIVESTOCK

5.1. Information access (0) No; (1) Yes

	1. Family, friends or farmers	2.Government/ extensionist	3. Private sector/NGOs	4. Other _______
On new breeds				
On feed requirements of animals				
On animal health				
On other livestock technologies				
On marketing livestock products				

5.2. Extension: how many times do meet livestock extensionist?

1st Season	2nd season	3rd season

5.3. Perceptions on livestock

Statements	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree	Not applicable
Manure is essential to grow my crops	-2	-1	0	1	2	-8
To keep livestock is not economically profitable	-2	-1	0	1	2	-8
I don't have enough land to grow green fodder	-2	-1	0	1	2	-8
The more livestock, the higher status in my village	-2	-1	0	1	2	-8
Livestock is vital as cash income	-2	-1	0	1	2	-8
Livestock is a vital saving strategy	-2	-1	0	1	2	-8
Feed shortage is a major constraint for my farm	-2	-1	0	1	2	-8
The higher livestock, the better competition to communal resources for private benefit	-2	-1	0	1	2	-8

Is keeping more livestock culture of the society? ___________________________

5.4. Livestock structure and dynamics: species fed and taken care of the household. Initially, just list all livestock/breeds kept by household to help with filling the table

	Species/breeds (use codes listed below)										
Structure											
Adult males – castrated											
Adult males – intact											
Adult females – in milk											
Adult females – dry											
Young males											
Young females											
Calve/lamb/kid											
Total kept in household											
Total owned by female											
Total owned by male											
Total owned household											
Trend 10 years	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓	↑ = ↓
Trend 1st reason-code											
Born last year											
Bought last year											
Sold/bartered last year											
Eaten last year											
Given away last year											

Death last year											
Manure animal/day											
Milk female/day (average)											

Species and breeds
1 = Indigenous cattle (Zebu, N'dama etc)
2 = Cross-bred cattle (Ind. x Exotic)
3 = Indigenous goat breed
4 = Cross-bred goat breed
5 = Indigenous sheep breed
6 = Cross-bred sheep
7= Camel
8 = Donkeys
9 = Horse
10 = Poultry
11 = Other

Trend main reason
1=More/less grassland
2=More/less feed
3=More/less labour available
4=More/less disease
5=More/less market
6=More/less drought
7=Other

5.5. Feeding strategies: select the main livestock species/breeds (max 3). Please try first with absolute, if it fails switch to %.

	1st season	2nd season	3rd season
1st livestock specie/breed (use codes of the previous page) ____			
Grazing grass			
Grazing stubbles of _______			
Dry fodder 1 ____________			
Dry fodder 2 ____________			
Green fodder			
Supplements 1 __________			
Supplements 2 __________			
Total feed intake	100 %	100 %	100 %
Overnight keeping (code below)			
2nd livestock specie/breed: (use codes of the previous page) ____			
Grazing grass			
Grazing stubbles of _______			
Dry fodder 1 __________			
Dry fodder 2 __________			
Green fodder			
Supplements 1 __________			
Supplements 2 __________			
Total feed intake	100 %	100 %	100 %
Overnight keeping (code below)			
3rd livestock specie/breed: (use codes of the previous page) ____			
Grazing grass			
Grazing stubbles of _______			
Dry fodder 1 __________			
Dry fodder 2 __________			
Green fodder			
Supplements 1 __________			
Supplements 2 __________			
Total feed intake	100 %	100 %	100 %
Overnight keeping (code below)			

Overnight keeping codes (1) stall; (2) homestead; (3) other on-farm; (4) off-farm; (5) other

5.6. Grassland access: percentage of grass and browse intake

	1st season	2nd season	3rd season	Trend 5 yrs	If change, main reason
Open communal land	%	%	%	↑ = ↓	
Communal grass. reserves	%	%	%	↑ = ↓	
Private land	%	%	%	↑ = ↓	
Along road/rivers	%	%	%	↑ = ↓	
Other ________	%	%	%	↑ = ↓	
Total access	**100 %**	**100 %**	**100 %**	↑ = ↓	

5.7. Shortage periods

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry fodder												
Green fodder												
Grazing												

no shortage,(1) low shortage, (2) shortage, (3) considerable shortage, (4) extreme shortage

When do you start feeding CR?

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amount per day (a)												
Total (a*30)												

5.8. Livestock product allocation of the two main livestock species/breeds

	1. Species code	**2. Production**	**3. Self-consumption**	**4. Sold**	**5. Other ________**
Milk		**l/day**	**%**	**%**	**%**
Meat			**%**	**%**	**%**
Milk		**l/day**	**%**	**%**	**%**
Meat			**%**	**%**	**%**

5.9. Dung allocation

	1st season	2nd season	3rd season	Trend 5 yrs	If change, main reason
Fuel	%	%	%	↑ = ↓	
Manure/organic fertiliser	%	%	%	↑ = ↓	
Sold	%	%	%	↑ = ↓	
Other ________	%	%	%	↑ = ↓	
Not used	%	%	%	↑ = ↓	
Total dung	**100 %**	**100 %**	**100 %**	↑ = ↓	

5.10. If you apply manure, do you apply it to the main crop fields or just around the homestead? Why?

Reason:____

6. ADDITIONAL INFORMATION

6.1. Labor use per agricultural activity (unit: days a year)

		Household		employed	hired	Is this activity also shared with other farmers?
		female	male			
Cropping	Preparing land					(0) No; (1) Yes
	Planting					(0) No; (1) Yes
	Weeding					(0) No; (1) Yes
	Harvesting					(0) No; (1) Yes
	Collecting crop residues					(0) No; (1) Yes
	Other					(0) No; (1) Yes
Livestock	Milking					(0) No; (1) Yes
	Grazing					(0) No; (1) Yes
	Watering					(0) No; (1) Yes
	Collecting dung					(0) No; (1) Yes
	Other					(0) No; (1) Yes

6.2. Limitations: please order from 1 to 5 the most restricting resource (1) to less restricting resource(5) for your crop & livestock production

	1. Order	2. Main reason	3. Coping strategy*
Water quantity (incl. droughts & spells)			
Land access (amount of land)			
Soil quality (related to fertility)			
Access to fertilizers/herbicides/improved seeds			
Options to sell crop/livestock products			
Information on how to improve crop/livestock production			
Livestock feed availability			
Labour availability (family/market)			
Other main limitation ______________________			

* Only when is a limitation ‘high’

6.3. Planned changes: please order from 1 to 6 the highest priority to change your farming systems: (1) lowest priority (6) highest priority (based on the real situation)

Statements	1. Order	2. Main reason	3. How
To start or intensify dairy production			
To increase my herd			
To test new feed technologies			
To irrigate (more) my farm			
To test new crop varieties			
To obtain more land to farm			

6.4. Household income for the year 2010.

Activity	1. Revenue	2. Trend 5 yrs	3. If change, main reason
On-farm			
Crops	%	↑ = ↓	
Crop residue	%	↑ = ↓	
Other feed or forage	%	↑ = ↓	
Livestock	%	↑ = ↓	
Milk	%	↑ = ↓	
Others	%	↑ = ↓	
Off-farm			
Agricultural labour	%	↑ = ↓	
Other non-agric. labour	%	↑ = ↓	
Regular employment	%	↑ = ↓	
Business/self-employed	%	↑ = ↓	
Remittances	%	↑ = ↓	
Others	%	↑ = ↓	
Total revenue 2010	100 %	↑ = ↓	

Expenditure household 2010, data to be collected in % or absolutes ___ (1) %; (2) absolutes

Item	2. Trend 5 yrs	3. If change, main reason
Food	↑ = ↓	
Education	↑ = ↓	
Health	↑ = ↓	
Social events/leisure	↑ = ↓	
Personal transport	↑ = ↓	
Housing	↑ = ↓	
Hired labour	↑ = ↓	
Crop inputs	↑ = ↓	
Livestock inputs	↑ = ↓	
Others	↑ = ↓	
Total expenditure 2010		

Annex 4. Characteristics of teff and sorghum varieties

teff and sorghum varieties grown at Chorie, north Wello, Ethiopia as characterized by farmers of the village.

teff varieties	**sorghum varieties**
Sikuar Magna	*Abola*
High market demand	High market demand
Good backing quality	Good backing quality
Good yield at low fertile soils	Higher grain production
Higher residue production	Higher stover production
Tolerate high/low moisture	Tolerance to water loging
Tolerate disease	Early planting (April rain)
Early maturing	Good grain storage (in holes)
Abat magna	*Jigurtie*
High market demand	Moderate market demand
Good backing quality	Good backing quality
Tolerate high moisture	Moderate yield
Gives better yield at low fertile soil	Higher stover production
Tikurie	Tolerance to high/low moisture
High market demand	Early mature than Abola
Good backing quality	Early planting (April rain)
Higher grain production	Good stover for fuel
Tolerate to high moisture	Possible for late rain planting
Tolerate disease	Tolerate early rain stop (cesation)
high market demand	Good grain storage (in holes)
Good backing quality	
Late maturing	*Wedhakir*
Bunign	Tolerate low moisture
Early maturing	Gives better yieldat low/good fertile soil
Give better yield at low fertile soil	Option for late RF(July) and late planting
Palatable straw	Palatable stover
Early maturing	Acceptable grain yield
Red teff	Early maturing
Good backing quality	Possibility for dry planting
Higher grain production	

Annex 5. Farmers' saving strategy

Saving strategy	Frequency *	Remark
Livestock	13	2 farmers do not have livestock, 1 farmer has no herd keeper
Property/land	2	Young farmers rent land from others
Cash at relative	1	Keeping cash in the hand of closely related family
Bank	0	No one out of 16 farmers save money in bank. The nearby town has bank service.

* Number of respondents out of 16 interviewed farmers

Annex 6. Decision makers on resources

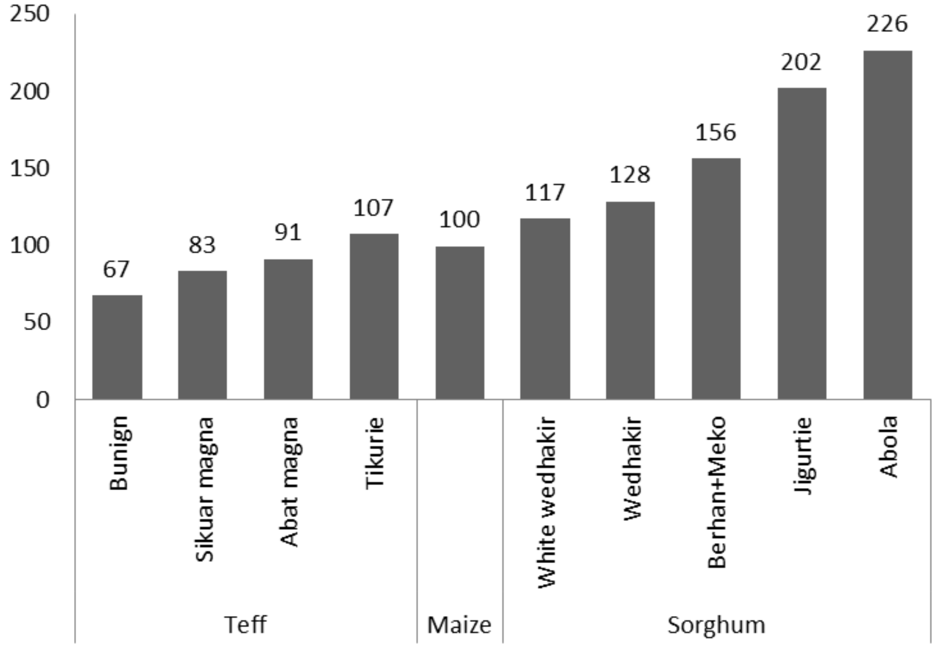
Farm types	Female	Male	Joint *	Son/daughter	Joint**	Tiller	Remark
	1. Main crop selection and management						
FS		1		1	1	1	
FL		2	1			1	
MS		2	1			1	
ML		4					
	2. Cash crop selection and management						
FS	1	1		1	1		
FL		1	2	1			
MS		2	2			1	
ML		3	1				
	3. Crop residue allocation and management						
FS	1	1		1		2	
FL		2	1	1			
MS		3				1	
ML		3	1				
	4. Small ruminant selection and management						
FS		1			1		2F =n/a
FL		1		1			2M=n/a
MS	1	1	2				
ML		1		1			2M=n/a
	5. Large ruminant selection and management						
FS		1			1		2F=n/a
FL			3	1			
MS	1	1	2				
ML		3	1				

FS= few livestock/small land; FL= few livestock/large land; MS=more livestock/small land and ML=more livestock/large land.

Gender composition in each farm: FS (M=1, F=3), FL (M=3, F=1, MS (M=3,F=1), ML (M=4,F=0); Numbers indicate frequency of decision maker at each farm type

* Husband and wife; ** Female head and son/daughter

Annex 7. Number of days to mature for different crop types



Annex 8: ANOVA for soil nutrient analysis of different farm types

ANOVA showing non-significant difference (α = 0.05) in nutrient content for teff, sorghum and maize fields of different farm types (FS, FL, MS and ML).

	Sum of Squares	df	Mean Square	F	Sig.
	teff fields				
N-content(%)					
Between Groups	.000	3	.000	.107	.954
Within Groups	.003	12	.000		
Total	.003	15			
C content (%)					
Between Groups	.109	3	.036	1.776	.205
Within Groups	.246	12	.021		
Total	.356	15			
P content (ppm)					
Between Groups	24.045	3	8.015	.699	.570
Within Groups	137.514	12	11.459		
Total	161.559	15			
K content (ppm)					
Between Groups	104111.922	3	34703.974	2.390	.120
Within Groups	174242.062	12	14520.172		
Total	278353.984	15			

	Sum of Squares	df	Mean Square	F	Sig.
sorghum fields					
N-content(%)					
Between Groups	.000	3	.000	.107	.954
Within Groups	.003	12	.000		
Total	.003	15			
C content (%)					
Between Groups	.109	3	.036	1.776	.205
Within Groups	.246	12	.021		
Total	.356	15			
P content (ppm)					
Between Groups	24.045	3	8.015	.699	.570
Within Groups	137.514	12	11.459		
Total	161.559	15			
K content (ppm)					
Between Groups	104111.922	3	34703.974	2.390	.120
Within Groups	174242.062	12	14520.172		
Total	278353.984	15			
maize fields					
N-content(%)					
Between Groups	.005	3	.002	.432	.734
Within Groups	.050	12	.004		
Total	.055	15			
C content (%)					
Between Groups	.803	3	.268	.878	.480
Within Groups	3.657	12	.305		
Total	4.460	15			
P content (ppm)					
Between Groups	18225.553	3	6075.184	.810	.513
Within Groups	90024.503	12	7502.042		
Total	108250.057	15			
K content (ppm)					
Between Groups	179565.797	3	59855.266	.173	.913
Within Groups	4153061.562	12	346088.464		
Total	4332627.359	15			