Interconnection Between Feed Resources Availability, Livestock Production and Soil Carbon Dynamics Under Smallholder System in Eastern Ethiopia

Ahmed Hassen[a,b], Tessema Zewdu[b] and Adugna Tolera[c]*

[a]*School of Animal and Range Sciences, Haramaya University, PO Box 138, Dire Dawa, Ethiopia*
[b]*Department of Animal Science, Debre Berhan University, PO Box 445, Debre Berhan, Ethiopia*
[c]*School of Animal and Range Sciences, Hawassa University, PO Box 222, Hawassa, Ethiopia*
**Corresponding author: hassenahmed211@gmail.com*

Abstract

Availability of feed resources, herd size and soil fertility status of grazing lands limit livestock production under smallholder condition in Ethiopia. Therefore, we studied the relationship between feed resources availability, livestock production and soil carbon (SC) balance under smallholder conditions in Mieso district of eastern Ethiopia. The JAVA model procedure was used to calculate the maximum number of animals in tropical livestock units (TLU) that can be maintained per unit area. The available feed resources were ranked based on their metabolizable energy contents. Feed balance was calculated based on DM availability and nutrient requirement of livestock in the study area. The SC balance was determined based on carbon inputs from manure, grazing and/or harvesting losses, residues of crop and roots, and soil organic matter decomposition. The JAVA model calculated the optimum level of feed use, livestock performances and soil carbon balance (dynamics), Moreover, monetary values of live weight gain (LWG) and/or loss, manure and draught power were calculated. The analysis of the JAVA model revealed that mean daily LWG and milk production (MP) per TLU increased linearly with decreasing herd size (HS), whereas, annual total LWG and total MP increased with increasing HS at 40% level of best use of feed use and HS of 722 TLU during the study. However, the SC balance at 40% of feed use was negative and decreased with increasing feed use. Moreover, the model estimated that maximum monetary value of LWG, manure and draught power were achieved at 60% feed use. Our study suggested that meat and/or milk production and SC balance could be increased by selective utilization of best feeds available at farmer level under the changing climate and global warming in the study area.

***Keywords**: Body weight gain; Feed quality; Herd size, Java model; Milk and meat yield; Soil carbon balance*

Introduction

In Ethiopia, the livestock sector provides 12 - 16% of the total gross domestic product (GDP) and 47% of the agricultural GDP (IGAD, 2010). The sector also supports about 60 - 70% of the livelihoods of the population in the country (Gebremariam et al., 2010). In addition, livestock makes an immense contribution in the smallholder economy as a source of food, cash income, draft power for cultivation of arable lands, and source of manure for soil fertility and fuel. Moreover, they are used as living assets, and social and cultural values and year round employment. Livestock as well confer a certain degree of security in times of crop failure, as they are a near cash capital stock (Negassa et al., 2011). Despite all these functions, the sector remained under-developed and difficult to perform the above functions satisfactorily (Negassa et al., 2015; Shapiro et al., 2015). Feed problems in both quality and quantity are one of the major factors that hinder the development and expansion of livestock production. To sustain livestock production as a major livelihood to livestock herders, adequate supply of quality feed is a basic requirement; as low quality roughage diets alone do not satisfy both the maintenance and production requirement of farm animals (Murthy et al., 2011; Shenkute et al., 2012).

Natural pasture and crop residues are the main feed resources for livestock under smallholder farming systems, which are low in quality for sustainable livestock production (Murthy et al., 2011; Adugna et al., 2012). Moreover, crop residues alone cannot satisfy the nutritional requirement of livestock under smallholder condition. However, browse trees are becoming major feed resources under smallholder conditions for supplying protein and energy to maintain livestock production (Anele et al., 2009; Shenkute et al., 2012), as browse trees reduce seasonal limitation of feed resources (Njidda, 2010; Belachew et al., 2013), and they are more nutritious than natural pasture and crop residues (Gemedo-Dalle, 2004; Yaynishet et al., 2010; Adugna et al. 2012). In general, availability of feed resources throughout the year is a major problem for sustainable livestock production under smallholder condition in Ethiopia and this is influenced by soil nutrient status (Abule et al., 2005; Tessema et al., 2011), grazing pressure and stage of harvesting (Henkin et al., 2011). According to Tennigkeit et al. (2008), the status of nutrients in the soils of grazing lands affect the quality and quantity of feed resources, and thus reduce the livestock performances as low quality feeds result in low body weight gain, low milk yield, and high mortality of ruminants under smallholder conditions.

The status of soil organic carbon (SOC) is of local importance because it affects on agro-ecosystem functions through mitigation of greenhouse gases at the atmospheric level since climate change and global warming lies on the amount of carbon dioxide (CO_2) in the atmosphere (IPCC, 2007). Accordingly, grazing lands remove CO_2 from the atmosphere through the process of photosynthesis, as it makes a large contribution to reduce atmospheric carbon (C) and increase SOC, which are very important in increasing soil fertility, water holding capacity (Abera and Wolde-Meskel, 2013), biomass production potential and nutritive value of pastures (Yihalem et al., 2005; Tessema et al., 2010). On the other hand, human activities such as rangeland degradation through continuous heavy grazing reduces soil C stocks in grazing lands (Tessema et al., 2011; Bikila et al., 2016) and greatly increase atmospheric CO_2 (IPCC, 2007; Bikila et al., 2016). Hence, the production and productivity of livestock depends on the quality of feed resources and organic matter content of the soil (Assefa et al., 2007). To achieve optimum production of livestock with the available feed resources, smallholder farmers should give priority for quality of feed resources and proper management of grazing lands. Thus, knowledge of on-farm data towards describing the inter-connection between livestock production, feed resources and carbon stocks at community level could offer important insights in developing climate smart livestock production strategies. Therefore, this study assessed the availability and quality of feed resources and their relationship with livestock performance (live weight gain and milk yield) and soil carbon balance under smallholder conditions in eastern Ethiopia.

Materials and Methods

Description of the study area

The study was undertaken in Mieso district of Oromia region, Ethiopia, situated at 40°58' and 40°9' E' and 8°47 and 9°19N' longitude and latitude respectively (Figure 1) within the rift valley of the country at an altitudes range of 823-2475 m above sea level (Aklilu et al., 2014).

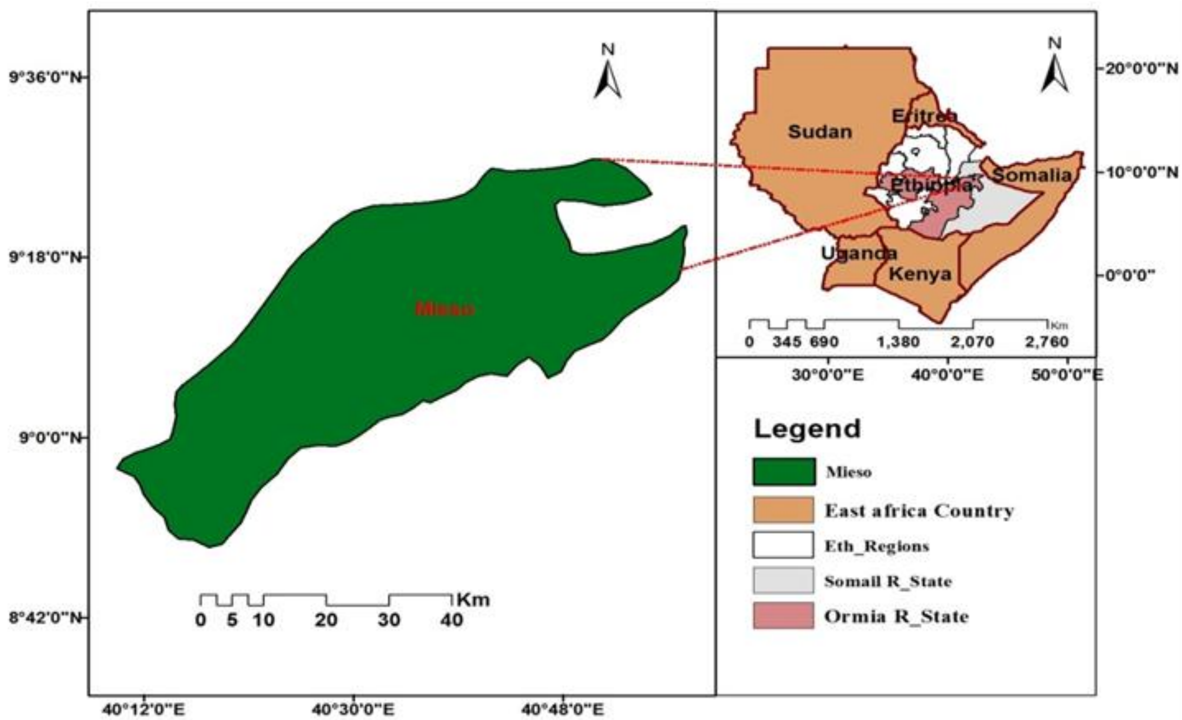

Figure 1: Location of the study area, Mieso district, in Oromia region of Ethiopia

The study site has variable rainfall distribution, having mean rainfall of 976 mm per annum. Under normal condition, there are two rainy and one long dry season. The short and long rainy seasons last from March to May and from June to September, respectively and the long dry season is from October to February. The short rainy season usually fails and not as frequent as the main rainy season with the coefficient variation of 33.4% (1984-2015). As a result, recurrent drought is a major problem in the study area. The mean daily minimum and maximum temperatures from 1984 - 2015 were 12.9°C and 37.1°C, respectively (Figure 2). The district has pastoral, agro-pastoral and mixed crop-livestock production systems. Twenty two out of the 37 *kebeles* (the smallest administrative units under district) belong to mixed crop-livestock farming system. The average land holding per sample household was 1.25 ha. The soils are dominated by Vertic Gambisols, HeplicLuvisol and EutricCambisols. Sorghum, maize, wheat, and teff are the major crops grown in mixed crop-livestock farming system. Cattle, sheep and goats are the dominant livestock. Browse trees, gazing lands and crop residues are the major feed resources in the mixed crop-livestock farming system. In addition, conserving hay, maize and sorghum stalk as a source of feed especially during dry period is a common practice. Oxen are the major sources of draft power for crop production. Milk and milk product consumption are common in the area.

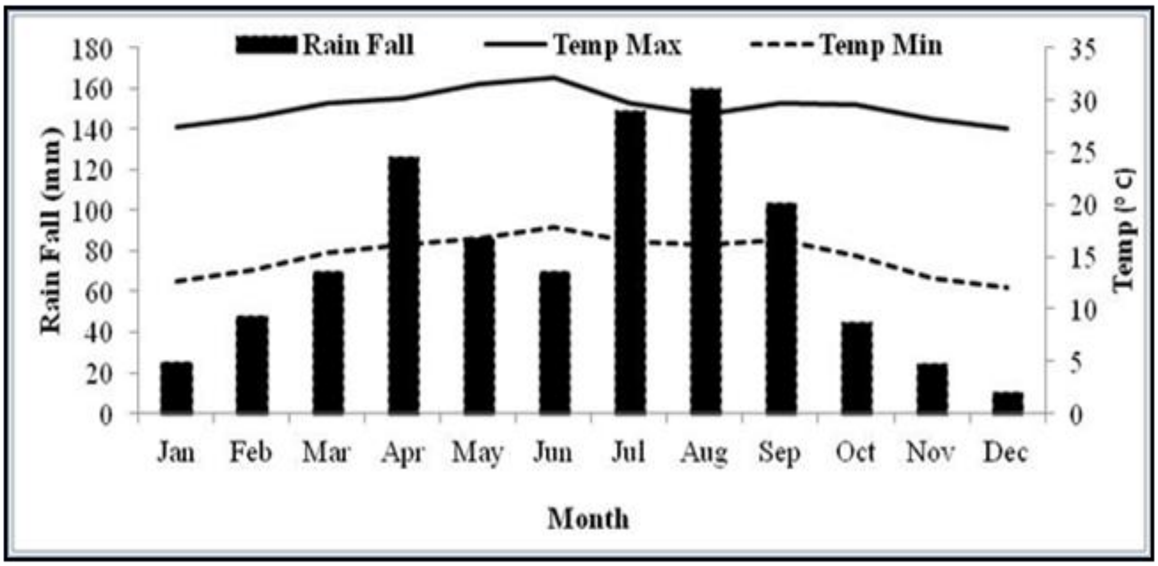

Figure 2. Mean monthly rainfall and minimum and maximum temperatures of Mieso district during the study, from 1984 -2015.

Sampling procedures and method of data collection

Two *kebeles* were randomly selected from smallholder mixed farming system in Meiso district during the study. Thirty farmers were selected from the two study *kebeles*. For each of the selected farms, the area of each field (plot) was measured and classified as either crop land or pasture land and samples were taken from crop residues, stovers, and grazing lands to assess the available feed resource potential. For determination of crop residues/stovers production in mixed farming, 95 sample plots (45, 30, 10, 10 plots respectively for sorghum, maize, wheat and teff) were selected randomly at harvesting time (January and February, 2014) and sampled from an area of 3x3 m in each plot by hand-cutting at ground level using a sickle. Grain was separated from residues manually. The grain and crop residues harvested from each sample plots were transferred into separate plastic bags. The crop residues dry matter (DM) availability for the village was estimated per crop type and per farm by adding the yields of crop residues from each plot for a particular crop.

To determine the DM content of grazing lands four pasture sites representative for the two *Kebeles* were selected randomly (September, 2014). At each pasture site, three sample sites were identified randomly. Furthermore, in each sample site, along each transect line; five regularly spaced quadrates (0.5 x 0.5m) were clipped at ground level using sickle at 50% flowering stage to determine standing herbage. Sixty samples were collected for DM determination from the two study *kebeles*. Pasture availability from grazing lands for the *kebeles* was estimated by multiplying the pasture area by the estimated DM yield of the sample plots in late September when animals were grazing natural pasture. Farmers also harvest part of their grazing lands for hay making. Farmers also used considerable amount of tree leaves. The biomass of trees/shrubs was estimated by using regression equations model developed by Brown et al. (1989): **$Y = 34.4703 – 8.0671 (DBH) + 0.6589 (DBH^2)$,** where Y is aboveground biomass, DBH is diameter at breast height (D≥5cm). Then, the total number of browse trees on-farm was estimated by multiplying the respective mean values by the number of farmers in the two *kebeles.* The detail of browse species collected during the study is found in Ahmed et al. (2017). Finally, after collecting triplicate samples of browse species, herbaceous species and crop residues, the samples were weighed immediately and transferred into plastic bags and fastened at the top and transported to Haramaya University for chemical analyses. Then, the samples were oven dried at 65˚C for 72 hours for DM determination, and ground to pass through 1mm screen of a Wiley mill for chemical analysis (ILCA, 1990). The total DM of each forage types was estimated by subtracting 25% as unavoidable grazing from the total yield (ILCA 1990; Zemmelink, 1995).

Chemical analyses of feed resources

The prepared samples were analyzed for DM, ash and Nitrogen (N) using the standard procedures of AOAC (1990). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined following the methods of Van Soest and Robertson (1985). Metabolisable energy (ME) was estimated using the equation for tropical forages: **ME (MJ/kg DM) = DOM (g/kg DM) x 18.5 x 0.81**, where digestible organic matter (DOM) was calculated as **0.95IVDMD% - 2** (AAC, 1990).

Animal performance data

To assess the actual live weight gain and milk production of the herds of each *kebele* using the available feed resources, 30 farms were randomly selected from the three study *kebeles* and the livestock population, age, milk yield (for a lactation length of 6 months) and live weight gain was measured and monitored based monthly visit for one year during 2013/14 crop season. Live weight gain was estimated from heart girth circumference measurements. Cattle, sheep, goats, and camels were included in the study. Moreover, the total live weight gain (TLWG) of animals of the selected farms was estimated from study herd average LWG per animal multiplied by observed *kebeles* herd size (HS). To determine the feed requirement of each herbivore animal, the estimated total livestock population was converted into tropical livestock unit (TLU) using conversion factors: 0.1, 0.36, 0.5, 0.8, 1.1 and 1.25 for sheep and goat, donkeys, heifers, cows, oxen and camels, respectively (Gryseels 1988; ILCA 1990).

Data on soil carbon dynamics

The soil carbon balance was determined in relation to total carbon inputs in manure, unused crop residues, grazing and harvesting losses, carbon recycled in the field and roots, annual soil carbon losses in the form of carbon dioxide during decomposition of the soil organic carbon (the detailed procedures are indicated in SCB model calculation sections).

Model calculation procedures

JAVA program procedure was used to calculate the relationship between feed availability and quality, and body weight gain, milk production, manure production and carbon balance (Zemmelink et al., 1992; Ifar, 1996; Zemmelink et al., 2003) modified and re-written in Excel (JAVA model). The program estimates the number of animals that can be fed and their production on the basis of availability of a mixture of feeds of different quality. This allows estimating the effect of selective utilization of feeds on animal production and hence to estimate optimum degrees of selection to attain optimum production or optimum number of animals that can be maintained during a given period of time. Calculations have been performed for 12 months, following two approaches: 1) pooling all annually available feeds and assuming carry-over between seasons, and 2) dividing the year into three seasons based on feed availability. Season 1 includes September to January. In the late September, cattle and sheep graze the natural pasture and farmers harvest part of their grazing lands for hay making. Sorghum and maize are also harvested during season I and defined as season 1. Season 2 includes February to May. Crop harvesting usually started late in December and crop residues are stored for feed during this period. June to September is rainy season, when feed availability is relatively good compared to other season during the study, and this is defined as season III (Table 1).

Table 1. Intake of metabolizable energy (kJ (kg LW)$^{-75}$) and availability of feed at Mieso district during season I (2014), season II and season III (2015)

Feed type	IME	Available dry matter (in Mega tone)			
		I	II	III	Total
Browse species	958	1014.5	405.6	608.4	2028.5
Natural pasture	760	100.5	16.0	20.0	136.5
Sorghum	398	970.9	-	200.0	1170.9
Maize	376	660.0	-	222.4	882.4
Teff	366	-	65.3	-	65.3
Wheat	348	-	112.6	-	112.6
Total	-	2745.9	599.5	1050.8	4396.2

Season I: September - December; Season II: January - April; Season III: May - August

In the first step of the analysis, the feeds were ranked according to their individual values of metabolizable energy (ME), since the JAVA model consider feed resources in ME as a default value. After this ranking, the JAVA program run a stepwise analyses (procedures), as in step 1, a certain fraction (e.g. 1%) of the total available feed DM was taken, in step 2 the next 1% was added, and it was continued until all feeds are included.

Model calculations

Intake of organic matter

Total available OM was calculated from total annual DM production per forage type by multiplication with its OM content. Intake of OM was estimated from OM digestibility (OMD, g/100 g) and concentration of N in the OM (N, g/100 g OM), using the transfer function developed for sheep by Ketelaars and Tolkamp (1991) multiplied by 1.33 to account for the higher metabolizable energy requirements of cattle (ARC, 1980). Intake of OM was multiplied by OMD to arrive at intake of digestible organic matter (IDOM). Intake of digestible OM was converted to IME by assuming 1 g IDOM to be equivalent to 15.8 kJ ME (Ifar, 1996; Zemmelink et al., 2003). Available feeds are assumed to be consumed in order of decreasing IME.

$\mathbf{IOM = -42.78 + 2.3039 \times OMD - 0.0175 \times OMD^2 - 1.8872 \times N^2 + 0.2242 \times OMD \times N}$ … (eq. 1)

Herd size

Optimum herd size (HS) in tropical livestock units (TLU) was computed on the basis of annually available feed resources as: $\mathbf{HS = TOM_{afu}/TIOMHS}$……………………………………….(eq. 2) where, TOM_{afu} is total available feed OM at a given proportion of feed use (Mega tone yr^{-1}) and TIOM is annual OM intake (Mg TLU^{-1} yr^{-1}).

Mean live weight gain (MLWG)

Animal weight gain was estimated from IDOM, as an indicator of IME. Although ME requirements for weight gain vary with the quality of the ration, under *ad libitum* feeding, live weight gain tends to be proportional to IME minus maintenance requirements (Ketelaars and Tolkamp, 1991; Zemmelink et al., 1992). MLWG is computed as:

$\mathbf{MLWG = [(IME - ME_m) / ME_g] \times (LWTLU^{0.75})}$ ..…………………………………….. (eq. 3)

where ME_m is average maintenance energy requirement (kJ (kg LW) $^{-0.75}$ d^{-1}); ME_g is ME needed per unit of live weight gain (kJ g^{-1}) and LWTLU is live weight of a TLU. ME_m was set 512KJ (kg $LW^{-0.75}d^{-1}$) (Ifar, 1996; Zemmelink et al., 2003). ME_g was also set to 38.1 MJ g^{-1} LWG (Ifar, 1996; Zemmelink et al., 2003).

Mean milk production (MMP)

MMP was estimated; a lactation period of 180 days was assumed with a calving interval of 2 years and IME in excess of maintenance being used for milk production:

MMP = (IME - ME_m) /[(NE_{lac})/CFNEME]…..………………………………………(eq. 4)
Where NE_{lac} is net energy requirement for milk production (MJ kg^{-1}), and CFNEME is conversion factor from NE to ME, and a conversion factor (CFNEME) of 0.6 was used to convert from NE to ME (De visser et al., 2000). Net energy requirement for production of milk (NE_{lac}) with a milk fat content of 40g $kg^{-1}$was set 3.133 MJ kg^{-1} (De Visser et al., 2000).

Mean manure carbon production (MMCP)
MMCP was estimated as: **MMCP = (IOM - IDOM) /CFOMC**..………………………… (eq. 5) where, CFOMC is conversion factor from OM to C, and a factor (CFOMC) of 1.78 was used to convert from OM to C (Sweet, 2004). Calculations of soil C balance have been estimated following the two assumptions: 1) all C from manure is incorporated in the soil 2) manure excretion was homogeneously distributed over day and night (Van den Bosch et al., 2001). For soil organic matter decomposition rate for the top 0.20 m of soil was estimated to 0.06 kg^{-1} yr^{-1} and 0.5 for crop residues, roots and leftovers as humification coefficients (yr^{-1}) and 0.3 for manure was used for calculation (de Ridder and van Keulen, 1990).

Estimation of oxen energy requirement for ploughing
In the study area, land is normally tilled using a pair of indigenous Zebu oxen, pulling the local traditional plough, the 'Maresha'. The land is on the average tilled in 3 rounds (two rounds before seeding and a final round directly following seeding). For the first, second and third round 8, 7 and 6 days, respectively are required with 6 working hours per day, adding to 252 h ha^{-1} during the study time. Hence, energy requirements of draught animals are assumed to comprise energy for maintenance and for work. To estimate the energy requirements of local oxen for ploughing, 1.68 MJ h^{-1} has been used (Van der Lee et al., 1993). Total cultivated land in the *kebeles* was estimated at 677 ha, and the value of an oxen day was estimated to be at 170 Ethiopian birr during the study. The value of weight gain was calculated at a rate of 210 birr kg^{-1} (1 Ethiopian Birr = 0.04 US$ (2016). Manure can be used as a source of fertilizer for both crop and grazing lands. The values of nutrients incorporated in the soil were assumed to be N, P and K at a proportion of 15, 6 and 19 gkg^{-1} of manure DM, respectively. The minerals were valued based on the price of fertilizer during the study (2014). Thus, the price of N, P and K were calculated after deducted costs of labor (30%) for manure management (i.e. transportation and field application).

Estimation of soil carbon balance
The soil carbon balance is computed as **$C_b = (C_{mn} + C_{uf} + C_{rcy} + C_{ram}) – C_{ad}$** …………………(eq. 6a)
Where, C_{mn} is C from manure (Mg ha^{-1}); C_{uf} is C from unused feed ($Mgha^{-1}$); C_{rcy} is C from unavoidable grazing ($Mgha^{-1}$); C_{ram} is C from roots ($Mgha^{-1}$) and C_{ad} is soil C loss via decomposition (Mega t ha^{-1}). **$C_b = (C_{mn} + C_{ur} + C_{rcy} + C_{ram}) – C_{ad} – C_f$**…....……..……..…… (eq. 6b), where C_f is C loss via manure partly used as fuel (Mega t ha^{-1}).

Parameterization of sensitivity of the model

The model estimates the overall mean production of animals and carbon balance. For the model all animals are converted into tropical Livestock Unit (TLU). Then, the model recognizes that feeds differ with respect to ME as well as voluntary intake by the animals. Intake of OM was calculated from OM digestibility and N concentration of the feed (eq. (1) which is a key factor controlling MLWG eq. (3) and MMP eq. (4). Higher estimate of IME lead to higher estimate of MLWG and MMP which is partly compensated by associated lower estimates of the number of HS (Eq.2) and hence, TLWG and TMP of the herd are not affected. For a given IME, calculated MLWG and MMP are affected by the assumed ME_m, because this affects the amount of ME available for production above maintenance. To convert NE to ME the model used 0.6 (CFNEME) (De Visser et al., 2000) and factor of 1.78 to convert from OM to C (Sweet, 2004). ME_m and ME_g were set to 512kJ (kg $LW^{-0.75}d^{-1}$) (Zemmelik et al., 2003) and 38.1 kJ g^{-1} live weight gain (Ifar, 1996; Zemmelink et al., 2003) respectively. The NE requirement for production of milk with butter fat content of 40 g kg^{-1} was set to 3.133 MJ kg^{-1} (De Visser et al., 2000). Differences in the amount of ME_g required per unit of live weight gain and NE_{lac} per unit of milk production affect calculated MLWG and MMP, but not optimum HS and optimum level of feed utilization. For a given IOM, over estimates of IDOM lead to under-estimates of MMCP and vice versa, but optimum HS and optimum level of feed utilizations is not affected. The number of feeds distinguished in the model calculations should be reasonably in relation to farmers' practices (Zemmelink et al., 2003).

Statistical analyses

The JAVA model calculated the optimum level of feed use, livestock performances and soil carbon balance (dynamics), and SAS soft ware (SAS, 2008) was used to analyze the data of quality and availability of feed resources, livestock performances (meat and milk yield) and soil carbon balance during the study after the JAVA model calculations.

Results

Feed availability and chemical composition

In our study areas, the major feed resources for livestock were browse species, grazing lands, hay harvested from natural pastures, stovers and crop residues (Table 1 and 2). The number of ruminant livestock in the study areas was 1418 TLU. There was a specific time in some areas to utilize some enclosed grazing lands in the study area according to their traditional management, which is from late August to November whereas the access to sorghum and maize stovers occurs from October to December. Farmers in the study area store straws and hay for supplementary feeding for lean season. Crop residues feeding mostly begin soon after threshing (December) and extend up to February to supplement the limited supplies from grazing lands. Though hay making is not a common practice, few farmers keep parts of their grazing lands aside during the rainy season to harvest and temporarily store it as hay. The total feed availability during season I was higher than season II and III, and this showed the differences in the amount of individual feed availability between seasons in the study area.

Table 2. Land use patterns and feed production from September 2014 - August 2015.in Mieso district of eastern Ethiopia,

Land use	Land size (ha)	Proportion of crop land	DM feed availability (Mg yr^{-1})
Browse species			2028.5
Cultivated land	677[a]		
Sorghum		386 (0.57)[b]	1170.9
Maize		282 (0.41)[b]	882.4
Teff		3 (0.04)[b]	65.3
Wheat		6 (0.08)[b]	112.6
Natural pasture land and hay	52[c]		136.5
Total	729		4396.2

[a]Grazing losses of 25% were considered, [b]Proportion of total cultivated land, [c]Fraction of total pasture land

Table 3. Feed quality (OM, CP, NDF, OMD, DOM (g kg^{-1} DM) and ME (MJ kg^{-1} DM) of various feed resources at Mieso district during 2014/15 crop season.

Feed type	OM	CP	NDF	OMD	DOM	ME (MJ)
Browse species	866[a]	171[a]	290[g]	812[a]	751[a]	10.91[a]
Native pasture	841[b]	85[b]	557[e]	573[b]	429[b]	7.45[a]
Hay	824[c]	69[c]	437[f]	543[c]	524[c]	7.22[a]
Sorghum stover	813[d]	64[c]	659[d]	505[d]	463[d]	6.94[a]
Maize stover	811[d]	62[c]	678[c]	489[e]	442[d]	6.73[a]
Teff straw	805[d]	51[d]	734[b]	486[e]	445[e]	6.61[a]
Wheat straw	795[e]	39[e]	756[a]	473[f]	434[e]	6.37[a]

Mean with different superscripts within column are different at $P \leq 0.05$; OM = Organic matter, CP = crude protein, NDF = Neutral detergent fibre, OMD = in vitro organic matter digestibility, DOM = Digestible organic matter ME = Metabolizable energy

The CP, OM, OMD, DOM and NDF content of available feed resources significantly ($P<0.05$) varied (Table 3). The CP content of grazing lands was significantly ($P<0.05$) different from crop residues. Browse species had highest CP content than grazing lands, stovers and crop residues. Sorghum and maize stover had higher CP content than teff straw, which in turn contained higher CP than wheat straw. Crop residues had higher NDF than grazing lands and browse trees; the OM content was higher in browse tree than other source of feeds. The OMD content among feed type was significantly different ($P<0.05$) except maize stover and teff straw. Browse trees have the highest OMD of all feed types ($P<0.05$), while grazing lands were the second in OMD which is significantly greater than crop residues ($P<0.05$). Metabolizable energy content of browse trees was the highest ($P>0.05$) and ME content of crop residues was lower than grazing lands.

Table 4. Organic matter content of the soil types in Mieso district during the study.

Soil type	Proportion (%)	Organic carbon content (g kg^{-1})	Bulk density (g cm^{-3})
VerticCambisols	50	21.85	1.302
HaplicLuvisol	16	14.35	1.526
EutricCambisols	11	8.98	1.231

Effect of selective utilization of quality feed on livestock performance

Pooled feeds refer to feeds collected during excess feed availability (hereafter referred as carry-over), stored and carried forward to guarantee animals' continuous supply of quality feed demand for an optimum feeding practices to maintain production lines in good working order. It is assumed that the feeds are temporarily stored and keep its quality throughout the feeding period. In our study, the average nutritive value of the available feed in terms of CP, DOM and IME decreased with increasing the proportion of DM utilization (Figures 3a, b and c). The model showed that the available feed was at higher quality at 5% utilization of feed DM, with 165 g CP kg^{-1} DM and 680 g DOM kg^{-1} OM and 850 IME kJ^{-1} $(kg\ LW)^{-0.75}d^{-1}$. After this point, the quality of feed decreased as the proportion of utilization increased. As a result of high quality feed at 5% feed use, the daily MLWG and annual TLWP increased to 578 g TLU^{-1} and 29.2 Mg respectively (Figure 4a) and 4.5kg of milk yield TLU^{-1} $d^{-1}$and 43 Mg of milk annually can be produced (Figure4b). Moreover, MMCP and TMCP were 947 g TLU^{-1} and 33.6 Mg, respectively (Figure 4c). On the other hand, the model also showed that the daily MLWG and MMP TLU^{-1} decreased when the proportion of feed utilization increased, but TLWP and TMP continuously increased up to 40% feed utilization. This increment is associated with increasing the HS (Figure 4a and b). At 40% feed use, the number of HS supported was 722 TLU at a daily MLWG of 283 g TLU^{-1} and a milk production of 2.3 kg $TLU^{-1}d^{-1}$. Moreover, the daily MMCP also increases from 1% feed use (850 g) to 40% feed utilization (1050 g), but decreases to 910 g TLU^{-1} at 100% feed use (Figure 4c). On the other hand, the TMCP continuously increases with increasing feed use until complete utilization due to compensation by increasing the HS. Furthermore, when a large proportion of feed was used, the quality becomes reduced as a result the corresponding yield in terms of MLWG and MMP reduced. For instance, at 70% feed use the average DOM of the feed was reduced to 570g kg^{-1} OM respectively (Figure 4c). As a result the daily IME $(kg\ LW)^{-0.75}$ was reduced to 590 kJ. At this level of feed use the TLWP become 11.9 Mg yr^{-1} from the HS of 1810 TLU (Figure 4a). At 100% feed utilization the HS can be increased up to 2897 TLU, but the IME is reduced to 515 kJ $(kg\ LW)^{-0.75}$ which was almost equivalent to maintenance requirement. The monetary value of LWG, draught power and manure production was optimum at 60% of feed use, while the optimum level feed use for MMP and MLWG was 40% feed use (Figure 5).

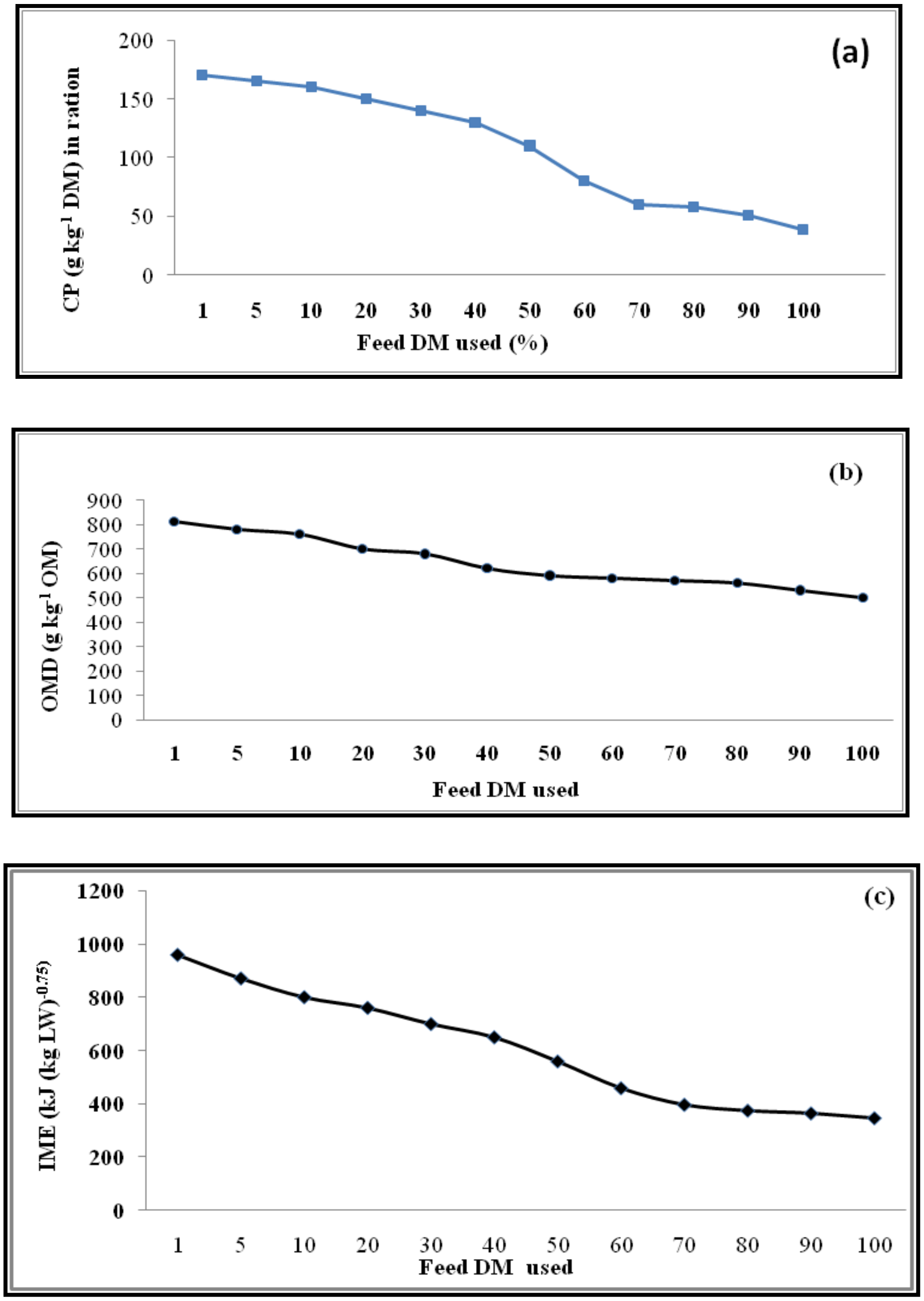

Figure 3. Effect of using various proportions of total dry matter (DM) on concentration of crude protein (g kg^{-1} DM) (a), organic matter digestibility(g kg^{-1} OM) (b) and intake of metabolizable energy (kg $LW)^{-0.75}$)(c).

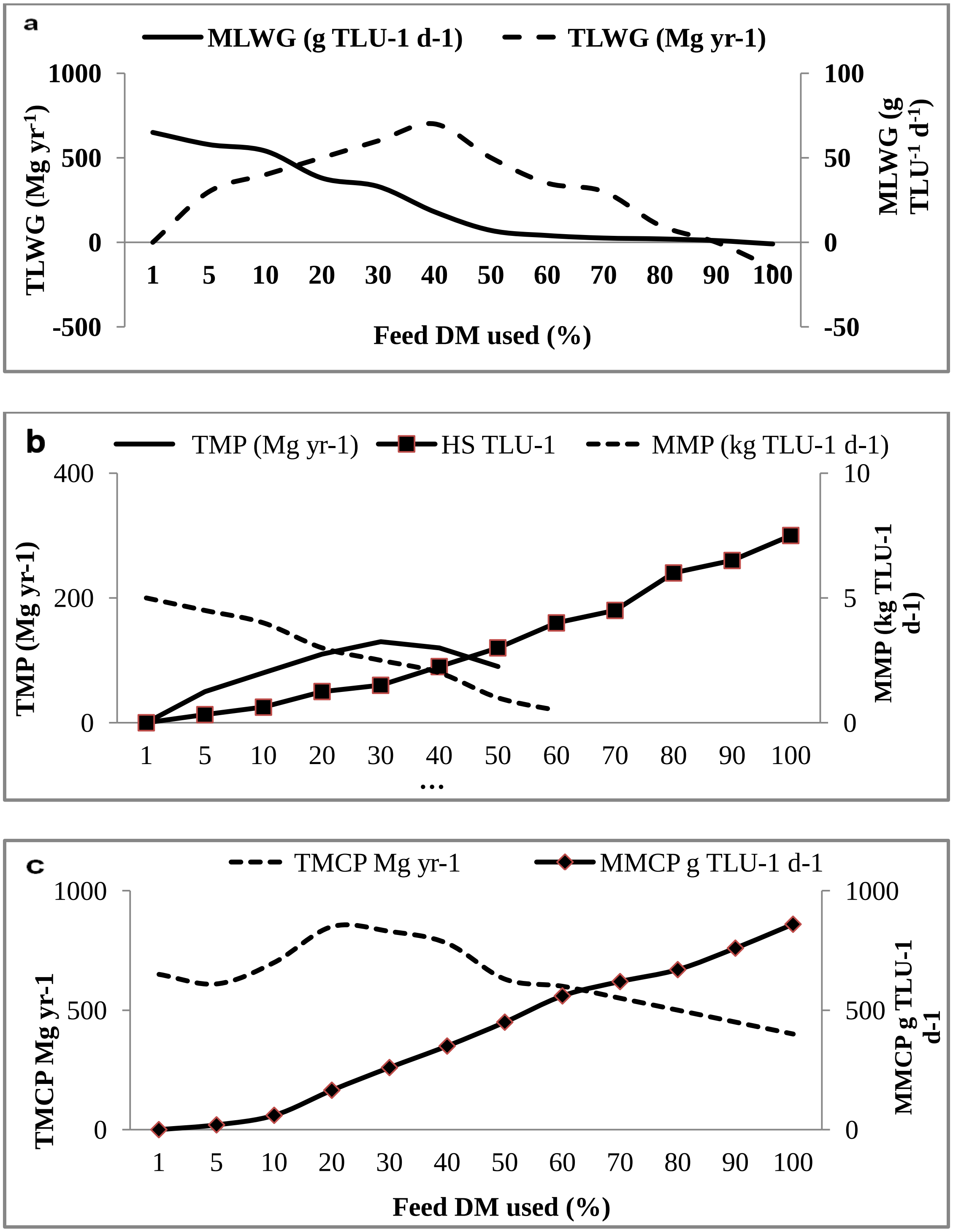

Figure 4. Effect of feed dry matter intake on mean daily live weight gain (MLWG), total live weight gain (TLWG) (a); mean daily and total annual milk production and herd size (b) and daily mean and total annual manure C production (c).

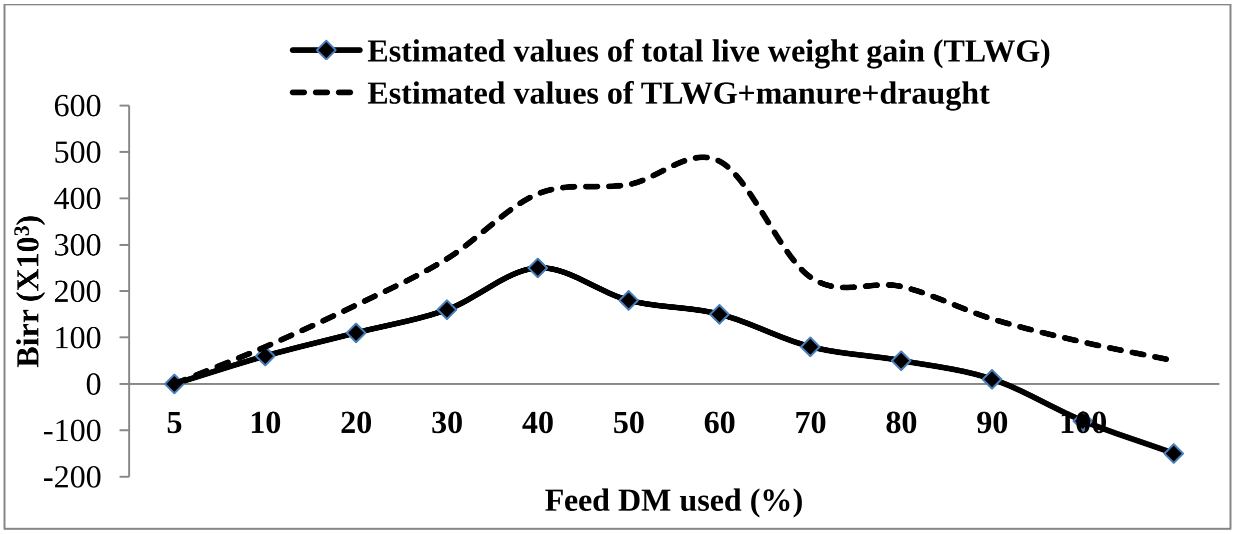

Figure 5. Effect of using total feed dry matter on the monetary value of total live weight gain (TLWG) and the combined monetary value of TLWG, manure and draught power.

Herd size and livestock performance

With increasing HS the MLWG and MMP $TLU^{-1}d^{-1}$ decreased (Figs. 4a-b). The TLWP and TMP increased with increasing HS and vice versa to the level of optimum feed resources use and optimum HS. Optimum HS was 722 TLU for carryover feed use which resulted in the maximum TLWP (57 Mg yr^{-1}), whereas optimum herd size of 596 TLU for maximum TLWP of 35 Mg yr^{-1} for seasonal feed variation (Figure 6). In carry-over feed use, at a herd size of 2300 TLU the production was zero and with further increases in herd size, the animals lose live weight, whereas in the no carry-over system production was zero at 990 TLU (Figure 6).

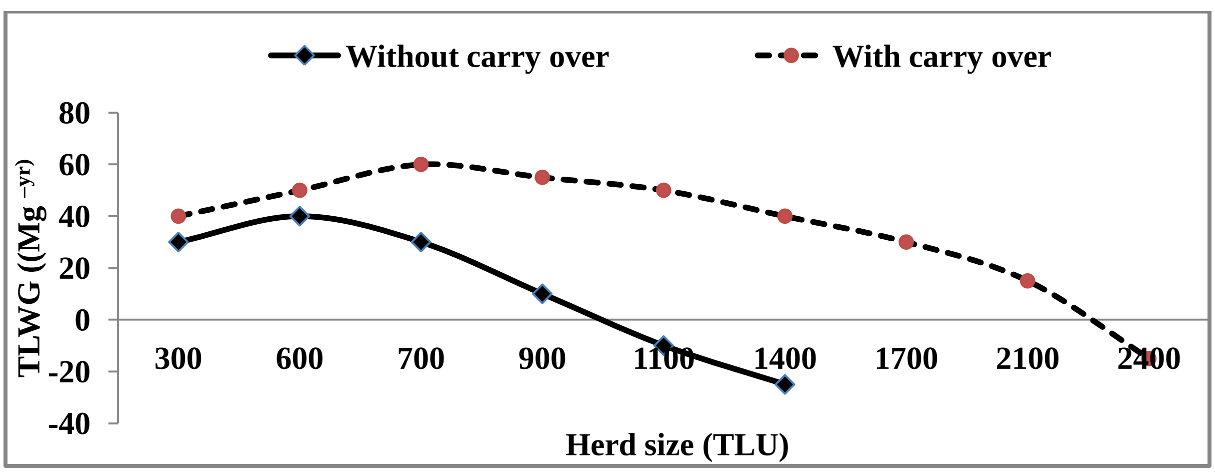

Figure 6. Herd size and total live weight gain with and without carry-over of feed resources.

The feed quality and availability varied from season to season. For instance, during season I (September – December) feed quality was better than season II (January – April). As a result in season II MLW losses of 164 g $TLU^{-1}d^{-1}$ and TLW loss of 142.1 Mg was observed. Similarly, in season III, 75g $TLU^{-1}d^{-1}$ and 6.3 TLW losses were also reported. Moreover, IME varied between 792 in season I and 441kJ $(kg\ LW)^{-0.75}d^{-1}$ in season II (Table 5). The availability of feed and the number of animals supported per season also varied from season to season. Herd size varied between 1312 in season I and 631 in season III. When feed availability, selection and maximum LWP per season were aimed, optimum HS varied between1312 TLU and 277 in seasons I and III respectively. When the HS increased, the productivity of animals decreased. In season II and III, productivity decreased with increasing HS, beyond 451 and 277 TLU respectively. In this situation the MMCP is 0.95, 0.76 and 0.80 kg $TLU^{-1}d^{-1}$ in season I, II and III respectively. The TMCP was the highest in season I as the contribution of season I in terms of availability and quality is higher than season II and season III. Use of 100% of the pooled feeds resulted in less loss of total annual live weight than adjusting herd size each season to complete use of seasonally available feed as there is relatively continuous supply of feed throughout the feeding period. At 40% feed use, maximum total milk production was 120.5 Mg when all feed are pooled. On the other hand, when HS was adjusted seasonally to realize optimum feed utilization (no carry over situation) the maximum total milk was 112.1 Mg yr^{-1}. The MMP was 2.5, 0.5 and 0.65 in season I, II and III respectively in pooled feed situation. In the seasonal feed situation, it was 2.0, 0.25 and 0.35 in season I, II and III respectively.

Soil carbon balance (dynamics)

Figure 7 showed selective feed utilization practices on the soil carbon balance through carbon inputs in manure, unused crop residues, 25% grazing and harvesting losses, recycled in the field and roots and annual soil carbon losses in the form of CO_2 during decomposition of soil organic matter during our study. Accordingly, the model showed that the annual carbon loss via decomposition at depth of 0.20 m soil was estimated at 2.76 Mg ha^{-1}, whereas total carbon input was 0.97 Mg at 100% feed utilization, which resulted in the reduction of soil carbon balance (1.79 Mg C ha^{-1} yr^{-1}).Total carbon input at 40% feed utilization (optimum LWP and MMP) was higher than at 100% feed use. To maintain the current soil carbon balance, application of 18 Mg of manure OM yr^{-1} is required, however, the total soil carbon balance was negative at all levels of feed use in the present study (Figure 7).

Table 5. Feed use and some production parameters if all available feeds in each season are used and if the use of available feed is optimized.

Feed use	Season	Production parameters							
		IME (kJ (kg LW)$^{-0.75}$ d^{-1})	HS (TLU)	MLWG (gTLU^{-1}d^{-1})	TLWG (Mg season^{-1})	MMP (kg TLU^{-1}d^{-1})	TMP (Mg season^{-1})	MMCP (kg TLU^{-1}d^{-1})	TMCP (Mg season^{-1})
All feeds used	Season I	792	1312	378	55.5	2.00	101.2	0.90	160.9
	Season II	441	568	-164	-142.1	0.25	16.5	0.65	40.2
	Season III	507	631	-75	-6.3	0.35	14.2	0.70	64.2
Optimum feed use	%DM used								
	Season I (100)	792	1312	378	55.5	2.50	101.2	0.95	160.9
	Season II (12.4)	638	451	95	6.0	0.50	6.8	0.76	30.4
	Season III (25.1)	661	277	16	3.0	0.65	11.2	0.80	18.4

Season I: September to December (2013); Season II: January to April (2014); Season III: May to August (2014); IME= intake of metabolizable energy; HS =herd size; MLWG= mean live weight gain; TLWG= total live weight gain; MMP= mean milk production; TMP= total milk production; MMCP= mean manure carbon production; TMCP = total manure carbon production.

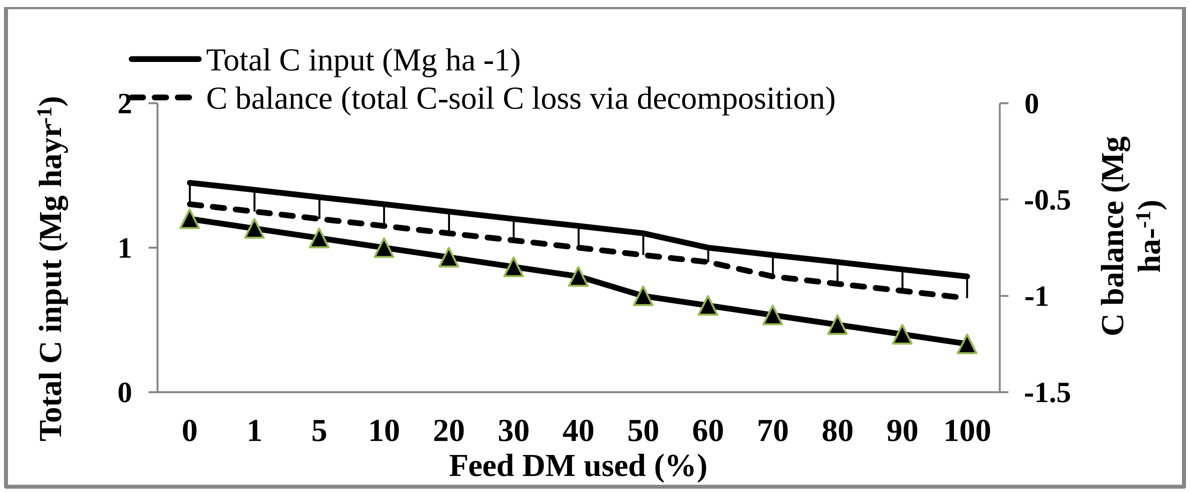

Figure 7. Effect of using proportion of total feed dry matter on soil C balance.

Discussion

Feed resources availability and quality

Our study indicated that animal production in the form of milk and meat would be increased by reducing the HS at the level of optimum feed use in addition to increasing production of quality feed. According to Assefa et al. (2007) and Basha et al. (2015) livestock performance indicators such as LWG and milk production are a function of feed availability and nutrient concentration. In this study, the CP, DOM and ME values of browse trees were significantly higher than other feed resources, indicating that browse species are the outstanding feeds which could provide high CP and energy above maintenance. Similarly, Abebe et al. (2012) reported that .browse species are one of the major feed resources, which are characterized by higher nutrient content than grazing lands and crop residues. However, crop residues had a lower CP (nearly ≤7%) that could limit intake and microbial function in the rumen (Van Soest 1994)). The results of this study revealed that cereal straws have low CP content and are composed of more insoluble components than browse trees. The decrease in CP, DOM and ME and an increase in NDF contents in crop residues could be due to their increased lignifications as a result of differences in stage of maturity at harvest as well as differences in soil fertility of the farm (Yayneshet et al., 2009; Belachew et al., 2013). Wheat and teff straws are low in quality, with 39 and 51 g CP kg^{-1} DM respectively and high NDF contents that is only less digestible. This is associated with the availability of less nitrogen, and higher proportion of fibre fraction (Belachew et al., 2013).

Seasonal (pooled/carry-over) feed availability on livestock performance

Seasonal variation in the availability and quality of feed is a serious constraint in our study area. Thus, during September to December (season I) livestock use browse species, stovers, natural pastures and hay as a source of feed. These feeds have high CP contents and relatively low content of NDF than teff and wheat residues. In addition, the amount of feed availability was higher than other seasons, which might be due to the time of harvesting for stovers, and hay from natural grazing lands. In season II, crop residues and browse species were the dominant available feed resources. Cereal straws provide CP and energy below maintenance requirements, whereas browse species result in above-maintenance energy levels. Based on our chemical composition result, wheat straw was the lowest quality feed that provides below the maintenance requirements of animals. The reduced quality of feed in terms of CP during the dry season is associated with moisture stress, advanced age and slow rate of photosynthesis. The findings conform to the reports of previous studies (Hassen et al., 2007; Yayneshet et al., 2009; Abebe et al., 2012). In season III (May to August), less amount of feed resources were available, which contribute for reduction of meat and milk production. Thus, the inability of farmers to feed animals uniformly throughout the year remained the main constraint for increasing meat and milk production. In this study areas, where most feeds are of low quality, maximum LWG and MMP can be obtained if livestock herders selectively use better feeds and all feeds are pooled and made available throughout the year. In our study, MMP and MLWG increased up to the optimum level of feed use (40% of DM), whereas, beyond the optimum feed use, both MMP and MLWG decreased.

Herd size and livestock performance

The decrease in LWG and MMP with increasing HS could be due to inclusion of low quality feed that could not satisfy the requirement of animals in the ration. On the contrary, the TLWP and TMP were small at a smaller HS and increase with increasing HS up to the optimum level of feed resource use (40% of DM) due to compensation by increasing the HS. Beyond this level, both individual LWG and TLWP decreased. The result of this model study is in agreement with the farm scale study on live weight dynamics in the northern highlands of Ethiopia (Assefa et al., 2007). The Ethiopian livestock master plan projections for the year 2028 show a deficit of 53% and 24% for meat and cow milk, respectively, due to rapid population growth and rising *per capita* income (Shapiro et al., 2015). This could be achieved by adjusting the number of animals with the available feed resources. Increasing HS beyond the optimum level would also create overgrazing and leads to reduction of rangeland resources and soil carbon stocks (Tessema et al., 2011). Moreover, in most cases, increasing HS may be associated with high risks of large losses of animals, reduction of soil carbon balance and livestock productivity.

In our study, livestock herders in the study area do not want to adjust their herd size based on feed availability. One of the aims of keeping livestock in the semiarid area is to promote savings and capital asset. So reducing herd size may conflict with these objectives. However, optimum feed resource use can be maintained for possible maximum meat and milk production and reduced land degradation. In this study, livestock herders used to practice seasonal mobility as an adaptation strategy during shortage of rainfall to reduce the negative effect of feed shortage, but these days, it was not possible to practice this option due to shortage of pastures and water resources in most of their neighboring areas. The actual HS in the study area was 1418 TLU, however, the estimated optimum HS for maximum TLWP, TMP and soil carbon inputs were obtained at optimum feed use suggesting that in areas where most feeds are of low quality, optimum benefits from livestock can be obtained by selective utilization of quality feeds, through proper storage and carry-over systems. These results agreed with the findings of Assefa et al. (2007). Environmentally friendly development of livestock production can be maintained by increasing production per animal for optimum HS and not through increasing numbers. Individual animal productivity decreased with increasing HS as low quality feeds were included in the feed ration. On the contrary, at a smaller HS, TLWG and TMP were lower and increased with increasing HS up to the optimum level of feed use. Beyond optimum level DM feed use both individual animal and herd productivity decreased.

Soil carbon balance (dynamics)

In our study, the soil carbon balance was negative at all levels of feed use, as the balance at optimum feed use for TLWP and TMP is 40% smaller than at 100% feed use. This is due to inclusion of low quality feed at 100% feed use. Moreover, the lower SOC might be due to lower rainfall distribution that affects rate of decomposition of litter falls and biomass (Chibsa and Ta'a, 2009) as moisture is vital to incorporate residues or litter to soils. In addition, the lower SOC might be associated with soil disturbance (Abera and Wolde-Meskel, 2013). According to Bikila et al. (2016), greater soil C stock was exhibited under enclosure pastures than communal grazing lands, indicating more new microbial biomass formation and low C loss through respiration than unprotected/degraded soils (Saggar et al., 2004). On the other hand, optimum feed resource use can maintain the SOC balance and reduce land degradation. Thus, environmentally harmony production could be attained increasing production per animal at optimum HS not at increasing number.

Conclusions

Our study revealed that optimum benefit from livestock could be obtained through adjusting the herd size with increasing the quality of available feed resources vis-à-vis proper storage and carry-over system. However, intensity of grazing was responsible for reducing the soil carbon balance but it could be managed by adjusting herd size close to optimum level of feed use, since at optimum level of feed use (40% DM use), the number of HS supported was 722 TLU at a daily MLWG of 283 g TLU^{-1} and a milk production of 2.3 kg TLU^{-1} d^{-1}. In our study, browse species and grazing lands were found as major feed sources as well as carbon sinks. However, erratic rainfall distribution a result of climate variability reduced the vegetation cover, herbaceous biomass and crop residues, leading to low carbon stocks in the soils of the study areas. Hence, proper land management would be important for increasing the performances of livestock and soil carbon dynamics as well as for better economic gains and ecological stability of the farming systems. Therefore, capacity building of communities engaged in livestock production how to properly utilize the available feed resources to satisfy either the maintenance and/or production requirement of their livestock without affecting the soil carbon stock balance is crucial to safeguard the livelihoods of livestock dependent people in semi-arid environments the changing climate and global warming.

Acknowledgements

The authors would like to acknowledge Haramaya University (HU) of Ethiopia Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) Ethiopia, Pastoral, and Agro-pastoral Research and Capacity Building Directorate (PARCBD) and Somali Region Pastoral and Agro-pastoral Research Institute (SORPARI) of Ethiopia or the financial and material support during the field and laboratory studies. We also acknowledge the Holeta Agricultural Research Center and HU Animal Nutrition Laboratory for providing the analytical services.

References

AAC. 1990. Feeding standard: Australian Livestock, Ruminants Sub-committee. Australian Agricultural Council, CSIRO (Australia).

Abera G, and Wolde-Meskel E. 2013. Soil properties and soil organic carbon stocks of tropical Andosol under different land uses. Journal of Soil Science 3: 153-162.

Adugna Tolera, AlemuYami and Dawit Alemu 2012. Livestock Feed resources in Ethiopia: Challenges, Opportunities and the Need for Transformation. Ethiopian Animal Feed Industry Association, Addis Ababa, Ethiopia.

Ahmed Hassen, Tessema Zewdu and Tolera Adugna 2017. Seasonal variations in chemical composition, *in vitro* digestibility and ruminal degradation of browse species in the Rift Valley of Ethiopia. Livestock Research for Rural Development. Volume 29, Article #112. http://www.lrrd.org/lrrd29/6/tess29112.html

Aklilu Mekasha, Bruno G., Kindie Tesfaye, Lisanework Nigatu, and Alan, D. 2014. Interconnection between land use/land cover change and herders'/farmers' livestock feed resources management strategies: a case study from three Ethiopian eco-environments. Agriculture Ecosystem Environment 188: 150-162.

Anele, U., Arigbedea, O., Südekumb, K., Onic, A., Jolaoshoa, J., Olanitea, A., Adeosuna, P., Delea, K., and Ike, K.A. and Akinolad, O.B. 2009. Seasonal chemical composition, in vitro fermentation and in sacco dry matter degradation of four indigenous multipurpose tree species in Nigeria. Animal Feed Science Technology 154: 47–57.

AOAC (Association of Official Analytical Chemists).1990. Feeding Standard: Australian Livestock, Ruminants Subcommittee. CSIRO, Australia.

ARC (Agricultural Research Council). 1980. The nutrient requirement of ruminant Livestock. Common Wealth Agricultural Bureoux, Slough.

Assefa Abegaz, van Keulen, H.and Oosting, S.J. 2007. Feed resources, livestock production and soil carbon dynamics in Teghane, Northern Highlands of Ethiopia. Agriculture Systems 94:391- 404.

Aster Abebe,Adugna Tolera, Holand, O., Tormod, Å. and Lars, O.E. 2012. Seasonal variation in nutritive value of some browse and grass species in Borana rangeland, southern Ethiopia. Tropicaland Subtropical Agro-ecosystem 15: 261-271.

Basha, N., Scogings, F., Fon, F., Ahmed, M. and Nsahlai, I. 2015. Effect of season and species on in sacco degradability of forages in the sub-humid subtropical savannah. Africa Journal of Agricultural Research 10:1312-1319.

Belachew Shenkute, Hassen A, Assafa A, Amen N, and Abule Ebro 2012. Identification and nutritive value of potential of fodder trees and shrubs in the mid rift valley of Ethiopia. Journal of Animal and Plant Science 22:1126-1132.

Belachew Z, Yisehak Kechero, Taye T. and Janssens, G. 2013. Chemical composition in- sacco ruminal degradation of tropical trees rich in condensed tannin. Czech Journal of Animal Science 58:176-192.

Bikila Negasa, Tessema Zewdu and Abule Ebro. 2016. Carbon sequestration potentials of semi-arid rangelands under traditional management practices in Borana, Southern Ethiopia. Agriculture Ecosystem and Environment 223: 108-114.

Brown, S., Gillespie, A.R. and Lugo, A.E. 1989. Biomass estimation Methods for Tropical Forests with Application to Forest Inventory Data. Forest Science 35: 881-902.

Chibsa, T. and Taa, A. 2009.Assessment of soil organic matter under four land use systems in the major soils of Bale highlands, Southeast Ethiopia. World Journal of Agricultural Science 6:1506-1512.

De Ridder, N. and Van Keulen, H. 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid tropics (SAT). Fertilizer Research 26:299-310.

De Visser, P., Van Ittersum, M., De Ridder, N. and Van Keulen, H. 2000.Plant and Animal Production Module of Quantitative analysis of Agro-ecosystems. Plant Production Systems group, Wageningen University, Wageningen.

Gebremariam, S., Amare, S., Baker, D., and Solomon, A. 2010. Diagnostic study of live cattle and beef production and marketing: Constraints and opportunities for enhancing the system. Constraint to International Food Policy Research Institute. Addis Ababa, Ethiopia.

Gemedo Dale. 2004. Vegetation Ecology, Rangeland Condition and Forage Resources Evaluation in the Borana Lowlands, Southern Oromia, Ethiopia. A PhD Thesis Presented to the University of Gottingen, Germany.

Gryseels, G. 1988. Role of livestock on a mixed smallholder farms in the *Woredas* near Debre Birhan. PhD Thesis. Agricultural University, Wageningen, The Netherlands.

Hassen, A., Rethman, N., van Niekerk, W. and Tjelele, T. 2007. Influence of season/year and species on chemical composition and in vitro digestibility of five Indigofera accessions. Animal Feed Science Technology 136: 312–322.

Henkin, N., Ungar, L., Dvash, A., Perevolotsky, Y., Yehuda, M., Sternbergs, H., Voet, H. and Landau, S.Y. 2011. Effects of cattle grazing on herbage quality in a herbaceous Mediterranean rangeland. Grass and Forage Science 66: 516-525.

Ifar, S. 1996. Relevance of ruminants in Upland Mixed farming systems in East Java, Indonesia. PhD Thesis,Wagningen Agricultural University, Wageningen, The Netherlands.

IGAD (Intergovernmental Authority on Development).2009. The Contribution of Livestock to The Ethiopian Economy. IGAD Center for Pastoral Areas & Livestock Development (ICPALD) Policy brief series. IGAD LPI Working Paper No. 02-10.

IPCC (Intergovernmental Panel on Climate Change).2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z.

Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller. United Kingdom and New York, NY, USA. Cambridge University Press, Cambridge.

Ketelaars, J. andTolkamp, B.J. 1991. Towards a new Theory of Feed Intake regulation in Ruminants. PhD. Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Murthy, K.S.R. 2011.Nutritional potential and biochemical compounds in *Cajanus albicans* (Wight & Arn) van der maesan for food and agriculture. Journal of Agriculture Technology 7:161-171.

Negassa, A., Berhanu Gebremedhin, Getachew Gebru, Desta, S., Nigussie, K., Negassa, B.I., Dutilly-Diane, C. and Tegegne, A. 2015. Integrated bio-economic simulation model for traditional cattle production systems in Ethiopia: Ex-ante evaluation of policies and investments. LIVES Working Paper 6. Nairobi, Kenya: ILRI.

Negassa, A., Rashid, S. and Gebremedhin, B. 2011. Livestock Production and Marketing. Development Strategy and Governance Division, International Food Policy Research Institute - Ethiopia Strategy Support Program II, Ethiopia. 40p.

Njidda.2010. Chemical Composition, Fibre Fraction and Anti-Nutritional Substances of Semi-arid Browse Forages of North-Eastern Nigeria. Journal of Basic Applied Science 18: 181-188

Saggar, S., Andrew, R.M., Tate, K.R., Hedley, C.B., Rodda, N.J. and Townsend, A. 2004. Modeling Nitrous Oxide Emission From New Zealand Dairy Grazed Pastures. Nutrient Cycling in Agro-ecosystem 68: 243-255.

SAS (statistical Analysis System)., 2008. Statistical Alalysis system. Users Guide: statistics version 9.1, SAS institute INc, Cary, NC, USA.

Seyoum Bedye, Zenash Sileshi, and Dereje F. 2007.Chemical Composition and Nutritive Value of Ethiopian Feeds.Research Report 73.Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.

Shapiro, B.I., Getachew Gebru, Solomon Desta, Asfaw Negassa, Kidus Negussie, Gezahegn Aboset and Henok Mechal. 2015. Ethiopia Livestock Master Plan. ILRI Project Report. Nairobi, Kenya: International Livestock Research Institute (ILRI). 127p.

Shenkute, B., Hassen, A., Assafa, A., Amen, N.and Ebro, A., 2012. Identification and nutritive value of potential of fodder trees and shrubs in the mid rift valley of Ethiopia.The J. Anim. Plant Sci., 22, 1126-1132

Sweet, C. 2004. Soil organic matter. http://www/agric.gov.ab.ca/ department/

Tennigkeit, T. and Wilkes, A. 2008.An Assessment of the Potential for Carbon Finance in Rangelands. Working Paper no. 68.

Tessema Zewdu, Ashagre Abate and Solomon Mengistu. 2010. Botanical composition, yield and nutritional quality of grassland in relation to stages of harvesting and fertilizer application in the highlands of Ethiopia. Africa Journal of Range and Forage Science 27: 117-124.

Tessema Zewdu, de Boer, W.F., Baars, R.M.T. and Prins, H.H.T. 2011.Changes in soil nutrients, vegetation structure and herbaceous biomass in response to grazing in semiarid savanna in Ethiopia.Journal Arid Environment 75: 662 - 670.

Van den Bosch, H., Vlaming, J., Van Wijk, M.S., De Jager, A., Bannink, A. and Van Keulen, H. 2001. Manual to the NUTMON methodology.Alterra/LEI, Wageningen University and Research centre, Wageningen/ The Hague.

Van de Ven,GWJ., De Ridder, N., Van Keulen, H., and Van lttersum, MK.2003. Concepts in production ecology for analysis and design of animal and plant-animal production systems. Agricultural Systems 76: 507-525.

Van der Lee, J., UDo, H.M.J. and Oosting, B. 1993. Design and validation of an animal traction model for a smallholder livestock system simulation model. Agricultural system 43: 199-227.

Van Soest, P.J. and Robertson, J.B. 1985. Analysis of forage and fibrous foods. A laboratory manual for Animal Science 613. Cornell University, USA.

Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant, 2nd ed. Comstock Publishing Associates/Cornell University Press, Ithaca, NY (USA).

Yayneshet Tesfay. 2010. Feed Resources Availability in Tigray Region, North Ethiopia, for Producing Export Quality Meat and Livestock. Ethiopia Sanitary and Phytosanitary Standards and Livestock and meat Marketing Program (SPS-LMM). USAID, Ethiopia.

Yayneshet, T., Eik, LO., and Moe, SR.2009. Seasonal variations in the chemical composition and dry matter degradability of enclosure forages in the semi-arid region of Northern Ethiopia. Animal Feed Science. Technology 148: 12-33.

Yihalem Denekew, Berhan Tamir and Solomon Mengistu. .2005. Effect of harvesting date on composition and yield of natural pasture in northwestern Ethiopia. Tropical Science 45: 19–22.

Zemmelink, G. 1995. Allocation and utilization of Resources at the farm level, Symposium' A research Approach to livestock production Systems from a System perspective, a farewell to professor Dick Zwart' Animal Production System Group, Wageningen University and research centre, Wageningen, The Netherlands.

Zemmelink, G., Brouwer, B.O. and Ifar, S. 1992. Feed utilization and the role of ruminants in farming system. In: Ibrahim, M.N.M., De Jong, R., Van Bruchem, J., Pumomo, H. (Eds), Livestock and feed development in the tropics. Proceedings of an international Seminar held at Brawijava University, Malong, 21-25 October, 1991. Wageningen Agricultural University, Wageningen, The Netherlands, PP. 444-451.

Zemmelink, G., Ifar, S. and Oosting, S.J. 2003. Optimum utilization of feed resources: model studies and farmers practices in two villages in East java, Indonesia. Agricultural systems 76: 77-94.