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Evaluation of livestock feed balance under mixed crop–livestock production system in the central highlands of Ethiopia

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Abstract

Background: Livestock production under smallholder mixed crop–livestock (MCL) production systems is constrained by feed shortage and scarcity of land on which to grow feed. Livestock feeds are obtained from different sources including crop residues (CR), grazing lands (GL), crop aftermath, fallow land and purchased. But the contribution of these feed resources and the extent of feed balance at farm level are not quantitatively examined. The study was conducted to assess the major feed resources available and evaluate feed balance for the prevailing livestock in MCL system.

Methods: Feed types and amount available, livestock holding size and feed demand were estimated for 159 smallholder farmers stratified into wealth status, which were selected following a multistage sampling procedure. The feed balance was evaluated as the difference between requirements of livestock (feed demand) and amount of utilizable feed (supply) per year in terms of dry matter (DM), metabolizable energy (ME) and digestible crude protein (DCP).

Results: Regardless of farmers' wealth status, CR mainly sourced from cereals, particularly barley, contributed more than half of the annual feed supply, followed by GL. The contribution of CR to total feed supply sourced on-farm and purchased combined was 55%. Significant differences in the supply, demand and balance of livestock feed were observed across wealth group of farmers. The wealthier have higher quantities of feed supply and demand, but suffered more in feed insufficiency. Overall, about 51, 19 and 38% annual feed deficit in DM, ME and DCP were observed, respectively. But when the rate is considered based on feed produced on-farm only, the deficit worsened and goes up to 60, 34 and 52% in DM, ME and DCP, respectively.

Conclusions: Expansion of grazing land is not a practical option to increase feed supply. Therefore, increasing food-feed crops production per unit area, conservation of surplus forages, strategic feeding based on productivity and traction services of livestock, purchase of feeds, and increasing livestock off-take during time of scarcity would help to correct the observed feed shortage. Moreover, refinement of the feed balance analysis at specific nutrients level would be compulsory for effective strategic interventions.

Keywords: Debre Berhan, Dry matter, Metabolizable energy, Digestible crude protein, Feed balance, Feed supply and demand, Wealth status

Background

Ethiopia is an agrarian country known for possession of huge livestock numbers. The total livestock population estimated in millions during the 2014/2015 annual livestock sample survey in the sedentary areas of the country was about 56.7 cattle, 29.3 sheep, 29.1 goats, 2.0 horses, 7.4 donkeys, 0.4 mules, 1.2 camels and 56.9 poultry with total tropical livestock unit (TLU) of 52.9, excluding the non-sedentary three zones of Afar and six zones of Somali Region of the country [1]. Livestock perform economic and social functions both at the national and

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household levels. Albeit variations among data sources, livestock contribute 15–17% of national gross domestic product (GDP), 35–40% of agricultural GDP and 37–87% of the household incomes [2]. Moreover, livestock contribute to improve the nutritional status and income gain of the people by providing meat, milk, eggs, cheese, butter, etc. and commodities, such as live animals, hides and skins for home use and export, and avert risks in times of crop failures [1, 2].

Despite the huge numbers of possession, the current contribution of livestock to the producers and to the national economy is dismal to its size. It has increasingly been unable to meet the demands for the rapidly growing population [3–5]. Among the many factors that could explain this disproportionate role of the sector often mentioned are the inadequate quantity and quality of feed supply throughout the year to satisfy the annual demand of livestock [6, 7].

Smallholder farmers in the mixed crop–livestock (MCL) systems keep some form of livestock in conjunction with crop production. However, better soils are allocated for food-feed crops, whereas mountainous, sloppy and less fertile marginal lands, which are naturally vulnerable for soil erosion and land degradation, are left for livestock grazing. Eventually, livestock became more dependent on common feed resources derived from low biomass producing food-feed crops and poorly managed grazing lands (GL). In order livestock to express their productive potentials and increase productivity, the available feed resources should match their demands for dry matter (DM) and nutrients. However, frequently livestock are exposed to seasonal feed shortages both in quantity and quality, especially during the dry season [8]. Moreover, the nutritive quality of native pasture is low especially in dry season and it is much worse for crop residues (CR) owing to the lower content of digestible nutrients [9]. Furthermore, the continuing trends of expansion in cropland cultivation at the expense of GL in the MCL systems have resulted in shrinkage of the area and productivity of GL and reversed the proportional contribution of CR for feed upward.

The need to increase both crop and livestock production from the existing resources requires responsive action throughout the production system. Upon examining the livestock feed resources and feed balance at smallholder farm level, Kassa et al. [10] suggested the possible use of livestock feed balance as potential indicator to assess sustainability of the farms. However, the extent and persistency of feed deficit in rainfed MCL systems in the highlands of Ethiopia described in several previous reports [6, 9–12] are a formidable challenge for sustained livestock production. A negative feed balance in the MCL system disrupts the interactions between the system components, impairs livestock performance and compromises the potential roles of livestock in driving the economic development. For instance, Kassa et al. [10] reported that better-off and medium wealth groups of smallholder mixed farmers did not produce enough feed more than the poor group to support their livestock in the *Harar* highlands of eastern Ethiopia. However, it is anticipated that the analysis at farm scale that constitutes the major available feeds and the livestock resources would unveil the prevailing status and hint strategies to address feed shortage problems encountered in the mixed farming systems. In the study area like most other MCL systems areas of Ethiopia, the ongoing land use change from grazing land to other land uses mainly to cropland resulted in shortage of grazing lands. On the other hand, feed obtained as a by-product from crop production on converted land from grazing to cropland is not likely to compensate the feed supply due to the inherently low feed value of crop residues. Moreover, feed from other alternative feed sources is limited. The present study was aimed at assessment of the potential feed resources supply for the prevailing livestock feed demand and evaluate the annual feed balance in the MCL system.

Methods

Description of the study area

The study was conducted in Debre Berhan milkshed in the Amhara National Regional State, central highlands of Ethiopia, 130 km away to the Northeast of Addis Ababa. The area is located between 9°30′ and 9°50′ latitudes and 39°20′ and 39°44′ longitudes (Fig. 1). The elevation ranges from 2840 to 2943 masl [13].

The mean annual minimum and maximum temperatures averaged between 2000 and 2014 years are 6.7 and 19.9 °C, respectively. The mean annual rainfall within the span of the same years is 1026 mm with a potential evapotranspiration of 1396 mm. Rainfall distribution is bimodal, usually the long rains last from June to the beginning of September, and the period of the short rains falls between February and May. About 85.5% of the rain falls between June and September which is the main cropping season (Fig. 2). Most of the area is covered by moderately and poorly drained soils, predominantly black Vertisol [13, 14].

Rainfed MCL farming is the dominant system carried out primarily to meet the subsistence requirements for most of the farmers with their families in the study area. Small-scale irrigated farming is limited to few farmers with small patchy areas along Beressa River mainly for vegetables. The principal rainfed food-feed crops include barley, wheat, faba bean and field pea. The cereals which covered the largest portion of cropped areas are the major sources of CR for livestock feeding. Cultivations

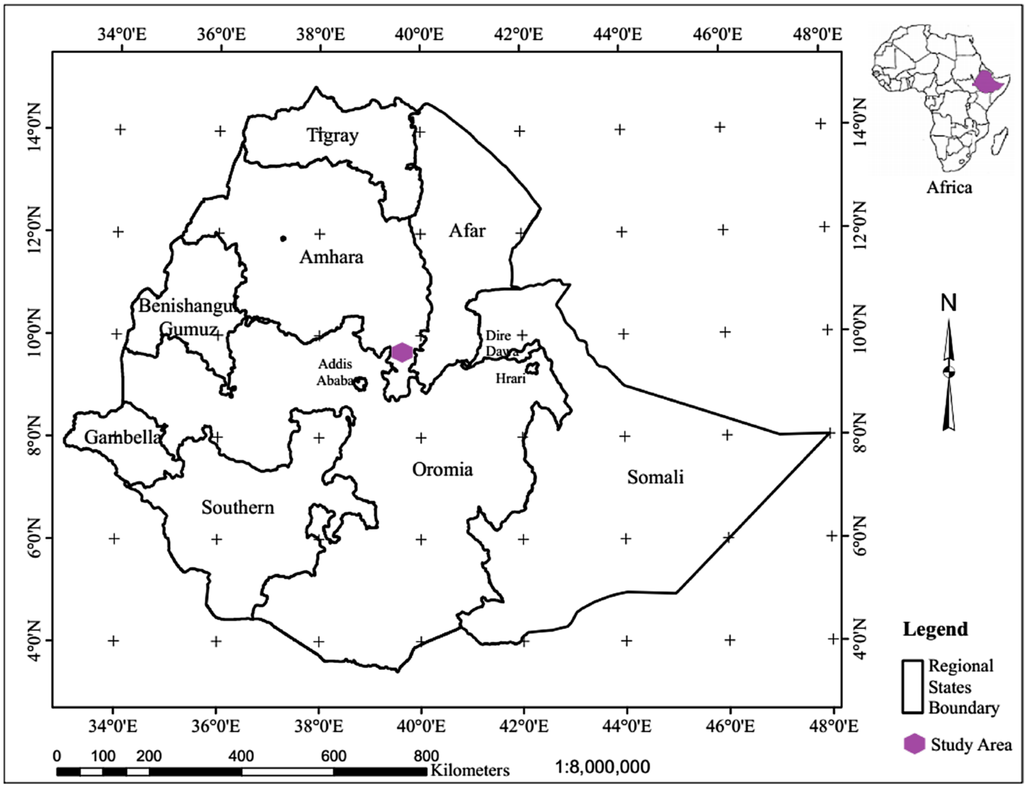

Fig. 1 Map of Ethiopia showing the location of the study area

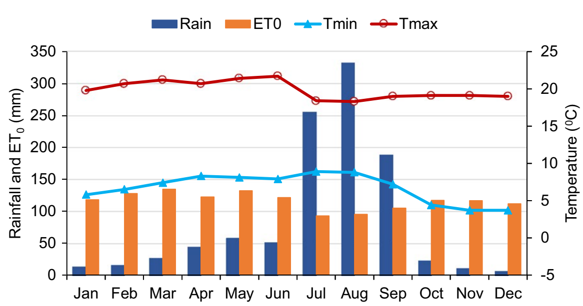

Fig. 2 Average monthly rainfall, potential evapotranspiration (ET_0), maximum (T_{max}) and minimum (T_{min}) temperatures at Debre Berhan weather station (monthly data averaged from 2000 to 2014)

of *teff* (*Eragrostis teff*), lentils, chickpea, oats, linseed and vegetables are intermittent on small plots of cropland. Natural GL and CR are the major livestock feed resources, while fallow land, crop aftermath grazing and concentrates are occasionally used feeds [8, 15]. The livestock species reared include cattle, sheep, goats, donkeys, horses, mules and poultry. Cattle production with indigenous and cross-bred animals predominates the livestock production followed by sheep production [8].

Wealth status classification criteria

The setting of criteria for wealth status was made in consultation with district experts, development agents and confirmed based on the perspectives of local farmers during group discussions. Multiple criteria focused on physical ownership of key assets and their anticipated values at the time of the study were used rather than precarious annual cash income. Ownership of houses with corrugated iron or thatched grass roofs, number and types of livestock, area of land and the capacity of the farmers to satisfy annual household basic needs were the major focuses. Nonetheless, setting an absolute cut-off point to each criterion was not possible, and an overlap in the range of values for the set criterion was evident. Instead of fixing the judgment based on the value of a single criterion, the contribution of the whole was assessed together to group a farmer under one of the three wealth categories (better-off, medium and poor). The descriptions of each criterion are summarized in Table 1.

Survey design and data collection

Sampling procedures and sample size

A multistage sampling procedure was employed to select sample farmers engaged in MCL farming and deliver fluid milk to the nearby milk collection centres (MCC).

Table 1 Description of wealth status grouping criteria generalized based on farmers' perspectives in the mixed crop–livestock system, central highlands of Ethiopia

No.	Criteria	Wealth categories		
		Better-off	Medium	Poor
1	Cropland holding (ha)	>1.50	1–2.5	0.25–1.5
2	Number of ploughing oxen	>2	≥2	≤1
3	Number of milking cows (local and crossbreds)	>2 most of crossbreds	At least 2, few crossbreds	<2 and usually local breeds
4	Number of sheep (adults)	10–50 or more	5–20	≤10
5	Number of equines (adults)	A mule, a horse and donkeys	At least horse and donkeys	No mule & horse may be donkey
6	Roof of houses			
	Corrugated iron sheet	Yes	Yes (often)	No
	Grass thatched	Yes	Yes	Yes
7	Annual food production and supply to sustain household	Enough with more surplus	Enough but meagre surplus	Not enough, in need of support

Debre Berhan milkshed was purposely selected based on its accessibility and potential representativeness of the MCL system in central highlands of Ethiopia. From 48 villages in the milkshed, six representative MCC (*Wushawushign, Angolela, Kormargefia, Kebele01, Kebele07* and *Kebele09*) were selected using simple random sampling procedure. Farmers sample size was determined using G * power 3.1.7 software considering the farmer wealth group as fixed effect and assuming 0.25 effect size, $\alpha = 0.05$ and 80% power of the statistical test [16]. List of farmers obtained from the selected MCC was categorized into three wealth groups to form the sampling frame. The number of sample farmers in each wealth group was based on the 'probability proportional to size' sampling technique [17]. Finally, a total of 159 farmers (50 in the poor, 58 in the medium and 51 in the better-off wealth groups) were selected using systematic random sampling with whom the questionnaires were administered.

Data collection

A socio-economic survey using pretested semi-structured questionnaires was carried out using a face to face interview in 2014 and 2015. The questionnaires covered data on: household demographic characteristics, land and livestock ownership, livestock species composition and herd structure, feed types, area of private and communal GL, types of food-feed crops produced, area cultivated, input used and crop yield at farm level. Focus group discussions were conducted with farmers at each of the selected MCC. A total of 40 farmers (6–8 per session) representing wealth groups have participated in six sessions. Knowledgeable farmers from all wealth groups were selected anticipating an effective communication between the moderator and within themselves. The secondary data were extracted from previous studies and information documented at agricultural development and research offices. Local climate data were obtained from Debre Berhan agricultural research centre. Data enumerators recruited from agricultural development agents were trained to assist on primary data collection during face to face interview and group discussions.

Estimation of annual feed availability (supply)

Quantity of feed DM available per year was estimated from the major feed resources including CR, crop aftermath (stubble that remain after harvest) and GL. Crop residues DM obtained was derived from grain yield, harvest indices and area of cropland cultivated. Conversion factors derived from harvest indices, 1.5 t/ha for wheat and barley and 1.2 t/ha for faba bean and field pea [18], were used to estimate crop residues from grain yields. The amount of CR DM collected per year by an individual farmer was quantified based on the size of cropland plot allocated for growing a particular crop type during the cropping season. Given the feed shortage and farmers' priority to the use of CR in the highland MCL systems, it is assumed that about 90% of the CR used as feed and 10% for other purposes and wastage [19]. Available DM from crop aftermath grazing on cropland was estimated using conversion factor of 0.5 ton DM/ha per year [20] and the area cultivated. Available feed DM from GL is estimated by taking the private and communal ownership pattern into account. Farmers are eligible to use whole of available feed on their entitled private GL, but can only share certain amount of feed from openly accessible communal GL. It was assumed that the amount of share from communal grazing is a function of livestock density, which is ascribed to the size of livestock ownership that had access to use this communal resource. A livestock density of 14.8 TLU/ha derived based on data on the size of livestock and GL area was used to allocate the communal grazing to each livestock owner relative to livestock possession. The total area of privately owned and part of the communal GL allocated was considered to estimate the available feed DM from GL per household per year. The feed DM productivity on GL was estimated based on multiplier of 2 t/ha established from previous GL condition and productivity studies [20]. Utilization factor of 75% as suggested by [21], for extensive grassland, is used to quantify the DM that would be utilized by livestock. The quantities of metabolizable energy (ME) and digestible crude protein (DCP) of feed resources were calculated based on the in vitro digestibility of organic matter in dry matter (IVDOMD) and crude protein (CP) contents of each feed type reported by [9] in the study area. The following equations were used to estimate the annual energy and protein supply at farm level in relation to the type of feed resource and amount obtained per year [22, 23].

$$\mathrm{ME}\left(\mathrm{MJ/kg\,DM}\right) = 0.015 * \mathrm{IVDOMD}\left(\mathrm{g/kg}\right);$$
$$\mathrm{DCP}\left(\mathrm{g}\right) = 0.929 * \mathrm{CP}\left(\mathrm{g}\right) - 3.48.$$

The seasonal availability of feed resources was assessed based on farmers' judgment and scores given for a particular feed type in each month throughout the year. Availability of feed over the year was scored on a scale of 0–10, where 10 = excess feed available, 5 = adequate feed available and 0 = no feed available [24].

Estimation of livestock feed requirements (demand)

Livestock holdings per household were aggregated into TLU considering the annual average livestock ownership derived based on the number of animals at the beginning and end of the study year. This was done to take into account the annual inflow and outflow dynamics of livestock at famer level. Species-specific TLU conversion factors of 0.7 for cattle, 0.1 for sheep and goats, 0.5 for donkeys and 0.8 for horses were used [25]. The dry matter demand (DMD) was estimated based on the expected daily dry matter intake (DMI) suggested for the standard TLU of 250 kg at 2.5% of the body weight, which is equivalent to 6.25 kg/day or 2280 kg/year [25]. Comparable rate of DMI was also suggested by [26]. The ME and DCP requirements for maintenance were calculated according to the daily average recommendations given by [26]. Based on metabolic body weight, 118.0, 93.0 and 103.45 kcal of ME/$\mathrm{W}_{\mathrm{kg}}^{0.75}$ and 2.86, 1.72 and 2.51 g of DCP/$\mathrm{W}_{\mathrm{kg}}^{0.75}$ per day for cattle, sheep and goats, respectively, were used for maintenance [26]. Accordingly, the daily nutrient requirement tables for maintenance recommended for ruminants in developing countries by [26] were used to estimate the annual ME and DCP requirements for cattle, sheep and goats. In the case of donkeys and horses, the daily ME and DCP maintenance requirements of 14.9 and 27.6 MJ and 0.18 and 0.37 kg recommended by McCarthy as cited in [9] were used, respectively. Then, farm level DM, ME and DCP requirements for maintenance per year were extrapolated relative to the livestock ownership per household.

Livestock feed balance

Livestock feed balance at individual farmer level over the entire production year was determined as the difference between the annual feed DM, ME and DCP supply estimated from major feed resources and the annual feed DM, ME and DCP demands for the annual average livestock holding of farmers.

Statistical analysis

Means, standard deviations and percentages were used to describe variables observed among farmers stratified into wealth status. To compare the differences across farmer wealth groups in terms of harvested grain yields, net feed supply, net demand and feed balance, a one-way analysis of variance (ANOVA) was used. The one-way ANOVA model is given by:

$$Y_{ij} = \mu_i + F_i + \varepsilon_{ij},$$

where Y_{ij} is the jth observation in the ith wealth group, μ_i is the common effect for the whole wealth group, F_i is the effect of the ith wealth group and ε_{ij} is the random error associated with the jth observation in the ith wealth group assumed to be normally and independently distributed, with mean zero and variance $\sigma^2\varepsilon$, i designates the wealth group, and j denotes a specific observation. The tests were done at 95% level of confidence ($\alpha = 0.05$). Tukeys' HSD mean comparison procedure was used to test mean differences. The analysis was carried out using SPSS version 23.0 statistical software [27].

Results

Farm households and key farm resources characteristics

Descriptions of farm households and key farm resources characteristics with respect to farmer wealth groups are summarized in Table 2. Average family size of the better-off and medium wealth group households was somehow comparable, but for both wealth groups it was higher than the poor farmers. The family labour force followed the same trend of trajectory as that of average family size. In contrast, age dependency ratio was higher in the poor than both the medium and better-off wealth groups. The magnitude of livestock and land holdings matched the wealth status gradient of farmers, exhibiting a decreasing trend from better-off to poor wealth groups. Livestock holding aggregated in terms of TLU for the whole

Table 2 Households demographic and key farm resources characteristics in the mixed crop–livestock system, central highlands of Ethiopia

Households and farm resources characteristics	Wealth groups			Total ($n = 159$)
	Poor ($n = 50$)	Medium ($n = 58$)	Better-off ($n = 51$)	
Family size	4.9 (2.0)	6.2 (1.5)	6.4 (1.6)	5.9 (1.8)
Labour force (in adult equivalent)	2.5 (1.2)	3.5 (1.1)	3.8 (1.1)	3.3 (1.3)
Age dependency ratio (ADR)	1.0 (0.6)	0.7 (0.5)	0.6 (0.5)	0.8 (0.6)
Livestock holding (TLU)	5.1 (1.2)	8.2 (2.0)	12.0 (2.4)	8.5 (3.4)
Cattle	3.0 (0.9)	4.6 (1.2)	6.4 (1.4)	4.7 (1.2)
Sheep and goats	0.9 (0.5)	1.7 (0.8)	2.7 (1.2)	1.8 (1.1)
Equines	1.2 (0.7)	1.9 (1.0)	2.9 (1.0)	2.0 (1.1)
Cropland entitled (ha)	1.1 (0.5)	1.3 (0.6)	1.8 (0.6)	1.4 (0.6)
Fallow land (ha)	0.1 (0.1)	0.1 (0.2)	0.3 (0.3)	0.2 (0.3)
Cultivated and grazing land (ha)	2.3 (0.4)	3.2 (0.7)	4.1 (0.7)	3.2 (1.0)
Cropland cultivated (ha)	1.6 (0.4)	2.2 (0.6)	2.5 (0.6)	2.1 (0.6)
Grazing land (ha)	0.7 (0.2)	1.0 (0.4)	1.6 (0.5)	1.1 (0.5)

N number of respondents; numbers in parenthesis are standard deviations (SD); *ADR* age dependency ratio; *TLU* tropical livestock unit; *1 TLU* 250 kg live weight; *ADR* the dependency ratio relates the number of children (0–14 years old) and older persons (65 years or over) to the working-age population (15–64 years old)

and grouped/disaggregated into species was higher in the better-off followed by medium and poor farmers, respectively. The size of cultivated cropland that includes cropland righteously entitled and cropland temporarily acquired based on local lease agreements between farmers, GL and the total land holdings similarly reflected the image of farmers' wealth status consistently being higher for the wealthier.

Food-feed crops production

Descriptions of cultivated crops which are the staple human food and major sources of CR for feeding livestock are presented in Table 3. The same table also presents the comparisons of mean grain yields (ton) of the major crops cultivated per household between farmer wealth groups. The trends in the size of plot of cropland allocation to a particular crop type and proportion of farmers who have grown the crop during the cropping season were similar irrespective of their wealth status. Barely was the most extensively grown food-feed crop followed by faba bean, wheat and field pea, respectively, which is manifested by the larger size of cropland plot allocated for barley growing than for the other crop types and it was cropped by every wealth group of farmers. The quantity of both barley and wheat grain yield harvested per household was significantly higher for better-off than both medium and poor farmer wealth groups ($P < 0.001$). The grain yield of faba bean harvested per household by the better-off and medium wealth groups was significantly higher than the poor group ($P < 0.001$). However, no significant difference in field pea grain harvested was observed among the wealth groups.

Types and availability of feed resources

Estimated farm level annual feed supply from different sources in terms of DM, ME and DCP is presented in Table 4. On-farm produced feed resources were derived from food-feed crops grown, GL, crop aftermath and fallow land. In addition, livestock feeds were sourced off-farm, though the quantities procured were dependent on the capability of farmers to afford. The wealthier were relatively more capable to afford considerable amount of additional purchased feed sources (hay and some concentrates) off-farm. Corresponding to the amount of grain yield harvested, the quantity of CR obtained from individual crop types and aggregated were higher for the wealthier group of farmers. Moreover, the quantities of DM, ME and DCP obtained from on-farm feed sources including GL, fallow land and aftermath grazing were lower compared to the amount attained from total CR; however, the trend and extent of disparities between farmer groups have mirrored their wealth status.

Livestock feed supply, demand and feed balance

Comparisons of the annual feed demand, supply and balance quantified on DM, ME and DCP basis per farm household across wealth groups of farmers are presented in Table 5. The demand of livestock estimated for expected annual intake of DM, ME and DCP was significantly different ($P < 0.001$) across wealth group of farmers, consistently increasing along with the wealth gradient of farmers. The aggregated annual supply obtained on-farm from different sources, as well as the total annual supply (on-farm obtained combined with purchased feeds), differs significantly ($P < 0.001$) across

Table 3 Area of plots of cropland allocated, proportion of farmers who grow the specific food-feed crop types and grain yields per household in the mixed crop–livestock system, central highlands of Ethiopia

Area cultivated, grain yield and proportion of farmers who grow	Wealth groups			Total ($n = 159$)
	Poor ($n = 50$)	Medium ($n = 58$)	Better-off ($n = 51$)	
Land allocated (ha)				
Barley	0.9 (0.3)	1.1 (0.6)	1.2 (0.4)	1.1 (0.5)
Wheat	0.3 (0.2)	0.3 (0.2)	0.5 (0.3)	0.4 (0.2)
Faba bean	0.4 (0.2)	0.6 (0.3)	0.7 (0.4)	0.6 (0.3)
Field pea	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
Farmers who grow (%)				
Barley	100.0	100.0	100.0	100.0
Wheat	78.0	93.1	100.0	90.6
Faba bean	100.0	100.0	92.2	97.5
Field pea	20.0	43.1	49.0	37.7
Grain yield (t/hh)				
Barley	1.7 (0.7)^{a}	2.1 (1.0)^{ab}	2.5 (0.9)^{c}	2.1 (0.9)***
Wheat	0.5 (0.4)^{a}	0.7 (0.4)^{ab}	1.2 (0.7)^{c}	0.8 (0.6)***
Faba bean	0.6 (0.3)^{a}	0.9 (0.5)^{bc}	1.0 (0.5)^{c}	0.8 (0.5)***
Field pea	0.1 (0.2)	0.2 (0.2)	0.2 (0.2)	0.1 (0.2)^{NS}

Values in parentheses indicate standard deviations (SD)

n number of respondents, *ha* hectare, *t* ton, *hh* household

^{a,b,c} Means in a row with different superscripts differ significantly ($P < 0.05$), *NS* not significant at the 0.05 probability level

***Significant at 0.001 probability level

wealth group of farmers. Similar to the demands, the wealthier obtained more quantities of DM, ME and DCP from feeds sourced on-farm and from the total feed supply including the additional purchased feeds. The annual balance of DM, ME and DCP at farm household level assessed based on the on-farm feed supply and total feed supply that included purchased feeds was significantly different ($P < 0.001$) across wealth groups of farmers, except that the balance in ME was not significantly different between the poor and medium wealth groups. However, in all cases the wealthier encountered more deficit than the poor group of farmers in the quantities of DM, ME and DCP balance attained.

The degree at which the demands for DM, ME and DCP were fulfilled or not with respect to the estimated quantities for maintenance requirement of livestock at farm household level is illustrated in Fig. 3. The magnitude of insufficiency in feed DM, ME and DCP supply for livestock was unlike between the stratified wealth groups of farmers. The better-off group had more inadequate supply followed by the medium and poor in order of importance. When the supply of DM, ME and DCP was observed at farmer level in a particular wealth status group, the DM supply shortage was more pronounced followed by DCP and ME shortages in order of the magnitude of insufficiency. It was also observed that acquiring additional purchased feeds helped to relief part of the deficiencies in the DM, ME and DCP supply differently between the poor and wealthier group of farmers. The poor farmer group was able to reduce the shortage in the DM, ME and DCP supply by 6, 9 and 9%, respectively, whereas the medium and better-off wealth groups have reduced the DM and ME shortage equally by 10 and 15%, respectively. The deficiency in DCP was reduced by 15% among the medium and by 16% among the better-off wealth groups. The overall supply shortage in DM, ME and DCP in the farming system was mitigated by 9, 14 and 14%, respectively, due to additional purchased feeds acquired.

The proportion of farmers under wealth status groups who were in a positive balance are presented in Table 6. Overall, very few farmers were able to source sufficient feed to satisfy the maintenance requirements of livestock throughout the year. Relatively more number of farmers from the poor wealth group were in positive state of feed balance in the DM, ME and DCP supply. The situation was better for ME irrespective of farmers' wealth status, especially when farmers acquire additional purchased feeds. Based on the feed obtained from on-farm only, none in any wealth group were in a positive DM balance, but less than 2%, all of them from the poor farmers group when purchased feeds were considered. Generally, the proportion of farmers in a positive feed balance for DM, ME and DCP were contrary to their wealth status, the wealthier suffered more than the poor in feed insufficiency.

Table 4 Feed resource types and estimated quantities of DM, ME and DCP obtained per year per farm household in the mixed crop–livestock system, central highlands of Ethiopia

Feed resource types	Wealth groups			Total ($n = 159$)
	Poor ($n = 50$)	Medium ($n = 58$)	Better-off ($n = 51$)	
DM (t/hh)				
Crop residues	3.8 (1.2)	5.1 (1.4)	6.6 (1.9)	5.2 (1.9)
Barley straw	2.3 (0.9)	2.8 (1.3)	3.4 (1.2)	2.8 (1.2)
Wheat straw	0.7 (0.6)	0.9 (0.5)	1.6 (1.0)	1.1 (0.8)
Faba bean straw	0.7 (0.4)	1.2 (0.7)	1.5 (1.0)	1.1 (0.8)
Field pea straw	0.1 (0.2)	0.2 (0.2)	0.2 (0.2)	0.2 (0.2)
Grazing land	1.1 (0.3)	1.6 (0.5)	2.1 (0.5)	1.6 (0.6)
Fallow land	0.1 (0.2)	0.1 (0.3)	0.4 (0.4)	0.2 (0.4)
Crop aftermath	0.6 (0.2)	0.8 (0.2)	0.9 (0.2)	0.8 (0.2)
Purchased	0.7 (0.5)	1.9 (1.7)	2.5 (2.0)	1.7 (1.7)
ME ('000 MJ/hh)				
Crop residues	28.4 (9.3)	38.1 (10.8)	48.8 (14)	38.5 (14)
Barley straw	18.3 (7.4)	22.2 (10.4)	26.7 (9.5)	22.4 (9.8)
Wheat straw	4.6 (3.8)	5.9 (3.2)	10.3 (6.5)	6.9 (5.2)
Faba bean straw	4.7 (2.5)	8.7 (4.9)	10.4 (7.1)	8.0 (5.7)
Field pea straw	0.8 (1.7)	1.2 (1.6)	1.3 (1.5)	1.1 (1.6)
Grazing land	9.0 (2.6)	12.6 (3.7)	17.2 (4.4)	12.9 (4.9)
Fallow land	0.7 (1.5)	1.1 (2.6)	3.4 (3.4)	1.7 (2.9)
Crop aftermath	4.4 (1.2)	5.7 (1.8)	6.5 (1.6)	5.6 (1.7)
Purchased	5.0 (3.9)	13.6 (12.3)	18.6 (14.8)	12.5 (12.6)
DCP (kg/hh)				
Crop residues	128.8 (42.0)	182.7 (51.2)	230 (70.8)	180.9 (68.7)
Barley straw	68.3 (27.7)	83.0 (38.8)	100 (35.4)	83.8 (36.6)
Wheat straw	18.4 (15.1)	23.6 (12.5)	41.0 (25.7)	27.5 (20.7)
Faba bean straw	35.8 (18.6)	66.1 (37.1)	78.5 (53.7)	60.5 (42.7)
Field pea straw	6.4 (13.7)	10.1 (12.8)	10.5 (11.9)	9.1 (12.9)
Grazing land	70.1 (20.4)	98.0 (28.7)	134 (34.2)	100.8 (38.1)
Fallow land	5.4 (11.5)	8.2 (20.4)	26.5 (26.3)	13.2 (22.2)
Crop aftermath	11.4 (3.1)	15.0 (4.2)	16.9 (4.0)	14.5 (4.4)
Purchased	36.4 (28.6)	99.3 (90.2)	136.0 (108.5)	91.3 (92.4)

Values in parentheses indicate standard deviations (SD)

n number of respondents, *DM* dry matter, *ME* metabolizable energy, *MJ* mega joules, *DCP* digestible crude protein, *kg* kilogram, *t* ton, *hh* household

Relative contribution of feed resources

Proportional contributions of livestock feed resources produced on-farm only (Fig. 4a) and combined with purchased off-farm sources (Fig. 4b) to the total feed DM obtained per year at farmer level are illustrated among different wealth groups of farmers. Regardless of farmers' wealth status, the foremost on-farm feed source that covered more than half of the annual feed DM supply was CR derived from major food-feed crops (Fig. 4a). Even when the contribution of purchased feed resources was considered, share of CR prevailed (Fig. 4b). Following CR, natural GL, crop aftermath and fallow land contribute to the bulk of on-farm annual feed supply in order of importance (Fig. 4a), whereas purchased feed resources take the second level of contribution except for the poor farmers group where it takes the fourth level, when the proportional contribution of feed resources was considered based on the on-farm produced and off-farm procured sources combined on aggregated at farm level of the different wealth groups (Fig. 4b). The contribution of fallow land was very limited as there was scarcity of cropland. Among CR that make up the largest part of the livestock feed resource base, cereals (barley and wheat) contribute more than legumes (faba bean and field pea). Moreover, the proportional contribution of barley straw was the highest followed by faba bean and wheat which have comparable contributions, whereas the contribution of field pea was the least, when the share of individual crops was considered irrespective of farmers' wealth status (Fig. 4a, b).

Seasonal feed resources availability

The seasonal availability of feed resources throughout the year is illustrated in Fig. 5. Crop residues obtained from on-farm crop production were the major feed sources, which were abundantly available from months of December to March and steadily decline from April to November. Grazing lands even though utilized throughout the year, feed availability is limited to the months of August to December. During the rest of the months, feeds available from grazing land were meagre. Availability of fallow land grazing coincides with the trend of grazing lands, but with very low contribution from February to August. However, the contribution of fallow land and natural grazing land is increasing from September to November. Availability of crop aftermath grazing follows harvesting periods of crops grown and it is short lived from December to February. Months from April to August are critical periods of feed shortage when farmers used most of purchased feed resources. During these critical feed shortage periods, conserved hay and crop residues were used, preferentially for feeding lactating cows and oxen used for cropland preparation.

Discussion

Household characteristics and farm resources: implications on livestock feed availability

The overall average family size of 5.86 in the present study is higher than the national average of 5.14 reported

Table 5 Mean annual livestock feed supply, demand and balance per household in the mixed crop–livestock system, central highlands of Ethiopia

Feed supply, livestock demand and feed balance	Wealth groups			Total ($n = 159$)
	Poor ($n = 50$)	Medium ($n = 58$)	Better-off ($n = 51$)	
DM demand (t/hh)	11.6 (0.4)^{a}	18.7 (0.6)^{b}	27.4 (0.8)^{c}	19.3 (0.6)***
DM supply (t/hh)				
On-farm	5.6 (0.2)^{a}	7.6 (0.2)^{b}	10.0 (0.3)^{c}	7.7 (0.2)***
On-farm and purchased	6.3 (0.2)^{a}	9.4 (0.4)^{b}	12.6 (0.4)^{c}	9.5 (0.3)***
Balance (t/hh)				
On-farm	− 6.0 (0.5)^{c}	− 11.2 (0.7)^{b}	− 17.4 (0.7)^{a}	− 11.5 (0.5)***
On-farm & purchased	− 5.3 (0.5)^{c}	− 9.3 (0.7)^{b}	− 14.8 (0.7)^{a}	− 9.8 (0.5)***
ME demand ('000 MJ/hh)	54.9 (1.8)^{a}	86.4 (2.7)^{b}	122.8 (2.9)^{c}	88.1 (2.6)***
ME supply ('000 MJ/hh)				
On-farm	42.5 (1.5)^{a}	57.5 (1.9)^{b}	75.9 (2.2)^{c}	58.7 (1.5)***
On-farm and purchased	47.5 (1.7)^{a}	71.0 (2.7)^{b}	94.4 (3.3)^{c}	71.1 (2.1)***
Balance ('000 MJ/hh)				
On-farm	− 12.3 (2.5)^{c}	− 28.9 (3.4)^{b}	− 46.9 (3.1)^{a}	− 29.5 (2.1)***
On-farm and purchased	− 7.3 (2.6)^{cb}	− 15.4 (3.8)^{b}	− 28.3 (3.5)^{a}	− 17.0 (2.1)***
DCP demand (kg/hh)	392.2 (14.6)^{a}	630.4 (23.5)^{b}	907.1 (21.8)^{c}	644.2 (20.2)***
DCP supply (kg/hh)				
On-farm	215.7 (6.8)^{a}	303.9 (9.3)^{b}	407.4 (11.8)^{c}	309.4 (8.2)***
On-farm and purchased	252.1 (8.3)^{a}	403.1 (16.3)^{b}	543.4 (21.9)^{c}	400.6 (13.3)***
Balance (kg/hh)				
On-farm	− 176.4 (16)^{c}	− 326.5 (24.7)^{b}	− 499.7 (17.3)^{a}	− 334.9 (15.5)***
On-farm and purchased	− 140.0 (16.9)^{c}	− 227.2 (26.4)^{b}	− 363.7 (20.2)^{a}	− 243.6 (14.6)***

Values in parentheses indicate standard errors (SE)

n number of respondents, *DM* dry matter, *ME* metabolizable energy, *MJ* mega joules, *DCP* digestible crude protein, *kg* kilogram, *t* ton, *hh* household

^{a,b,c} Means in a row with different superscripts differ significantly ($P < 0.05$), *NS* not significant at the 0.05 probability level

***Significant at 0.001 probability level

by [28], which is closer to the poor but lower than the wealthier group of farmers in the study area. It is still much higher compared to the average family size for both the Amhara Region of 4.62 and the North Shewa Zone of 4.45, where the study site is located [28]. The lower family labour force availability among the poor farming families than the other wealth groups could be explained by the observed small number of family size coupled with higher age dependency ratio attributed to the presence of more productively inactive dependent family members, especially children under 15 years of age. The age distribution of family members and the consequent state of age dependency ratio, particularly among the poor farming families, are in agreement with the national demographic characteristics reported by [1], which explains that about 45% of the population are under 15 years of age, reflecting the dominance of young section of the population with less contribution to the farming labour force requirement.

Availability of farm resources such as family labour, land and livestock has an influence on the level of production and availability of CR for livestock feeding. The limited availability of family labour force in the poor family group may have restrained their capacity to intensify human labour use in the farming operation, which may negatively contribute to the cause for lower farm productivity. It influences farmers to apply adequate labour input for optimum agronomic activities like tillage frequency, timely land cultivation and weeding that are required to increase crop biomass productivity. In addition, farming families with small size of cropland ownership are hardly able to diversify and increase the crop grain yield and associated CR biomass production due to limitation of available cropland and subsequent allocation of smaller plots for the intended crop types. Moreover, the small number of livestock ownership, especially oxen among poor farming families, has a limiting influence on the use of needed animal labour for traction services, such as timely cultivation of cropland with optimum tillage frequency required for the crop type grown. On the contrary, wealthier farming families with relatively better availability of ploughing oxen

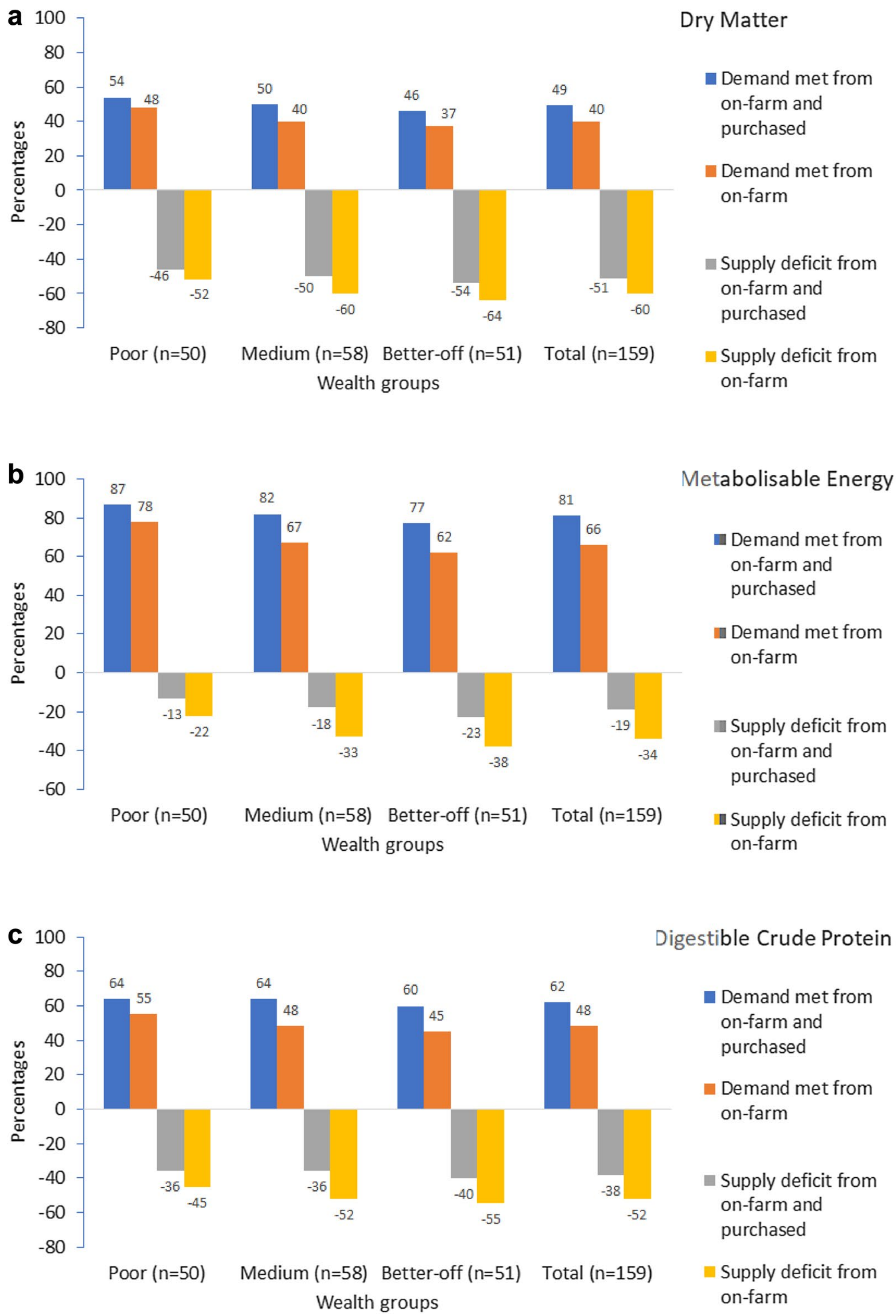

Fig. 3 Percentages of dry matter (**a**), metabolizable energy (**b**) and digestible crude protein (**c**) supply and demand balances of farm households categorized into wealth groups in the mixed crop–livestock system, central highlands of Ethiopia

Table 6 Numbers and proportions of farmers with positive livestock feed balance in the mixed crop–livestock system, central highlands of Ethiopia

Feed nutrients	Feed sourced from	Wealth groups			Total ($n = 159$)
		Poor ($n = 50$)	Medium ($n = 58$)	Better-off ($n = 51$)	
DM	On-farm	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	On-farm and purchased	2 (4.0)	0 (0.0)	0 (0.0)	2 (1.3)
ME	On-farm	15 (30.0)	3 (5.2)	0 (0.0)	18 (11.3)
	On-farm and purchased	23 (46.0)	17 (29.3)	7 (13.7)	47 (29.6)
DCP	On-farm	2 (4.0)	0 (0.0)	0 (0.0)	2 (1.3)
	On-farm and purchased	7 (14.0)	7 (12.1)	0 (0.0)	14 (8.8)

Values outside and inside parentheses indicate frequencies (*n*) and percentages (%), respectively

n number of respondents

are able to cultivate their cropland adequately in time and acquire additional cropland for share cropping from other farmers through local lease agreement and attain more feed from the share of CR attained in part or as a whole depending on the agreement with the cropland owners. In support of the present study, several studies reported that inadequate cropland preparation due to limited access to production factors such as land, human and animal labour affect the food-feed crop biomass production [29–32]. The wealthier are also relatively more efficient in collecting hay from private GL and store for later use in times of scarcity or practice strategic feeding by providing for the more productive animals such as milking cows and working oxen [8, 9].

Types and availability of feed resources

The types and amount of feed obtained per household depend on land use, size of land ownership and cropping pattern during the production season. Irrespective of wealth status, large proportion of land is allocated for crop cultivation than other land use types including grazing, which is in agreement with reports of [14, 6]. The increasing expansion of land cultivation for crop production at the expense of GL has resulted in shrinkage of the area and productivity of GL [14]. Consequently, CR generated from production of food-feed crops comprise the largest proportion of livestock feed resources. In agreement, [33] reported the progressive decline of GL and the use of CR as the major source of livestock feed particularly during the dry season in the mixed farming system of the *Bale* highlands of Ethiopia. In addition, [9] also observed the heavy reliance of farmers at *Debre Derhan* in the central highlands of Ethiopia on CR for feeding their livestock.

Besides the suitability of the local agro-climate for barley growing [8, 14], the higher quantity of barley straw collected is associated with the preference of farmers and the consequent allocation of larger plots of cropland for the barley crop cultivation. Apparently, the remaining smaller plots of land are shared for other crop types, which correspondingly leads to lesser quantity of straw obtained from crop types such as wheat, faba bean and field pea. In line with the present study, [33] explained the variation in the quantity and quality of CR produced could be due to the cropping intensity besides the variations in altitude, soil type and rainfall patterns where the crop has been grown.

In relation to the size of cropland ownership and parcel allocated to a specific crop type, higher volume of biomass is harvested by better-off and medium wealth groups than poor farmers. This crop biomass productivity is accordingly translated into the higher amount of CR harvest which reflected the gradient of farmers' wealth status. In addition to the plot of cropland allocation, the availability of family labour force, size of livestock owned particularly oxen, natural fertility of the cropland and other variable factors associated with the capacity of farmers to afford various inputs and manage timely agronomic practices influence the volume of CR produce per household. Moreover, the amount of feed derived from the crop field in the form of crop aftermath grazing is intrinsically influenced by the cropping pattern and plot of cropland allocation, as part of the feed recovered, is the remainder of the parent crop obtained after harvest in addition to the different weeds and other herbaceous plants grown on the crop field. In line with this, [34] reported the quantity and quality of stubble left varies considerably depending on the harvesting techniques applied for the various crops and the grass weeds grown underneath the main crop. Therefore, it is predictable that the wealthier could be able to benefit more than the poor farmer groups from crop aftermath grazing which is attributed to the larger size of cropland ownership.

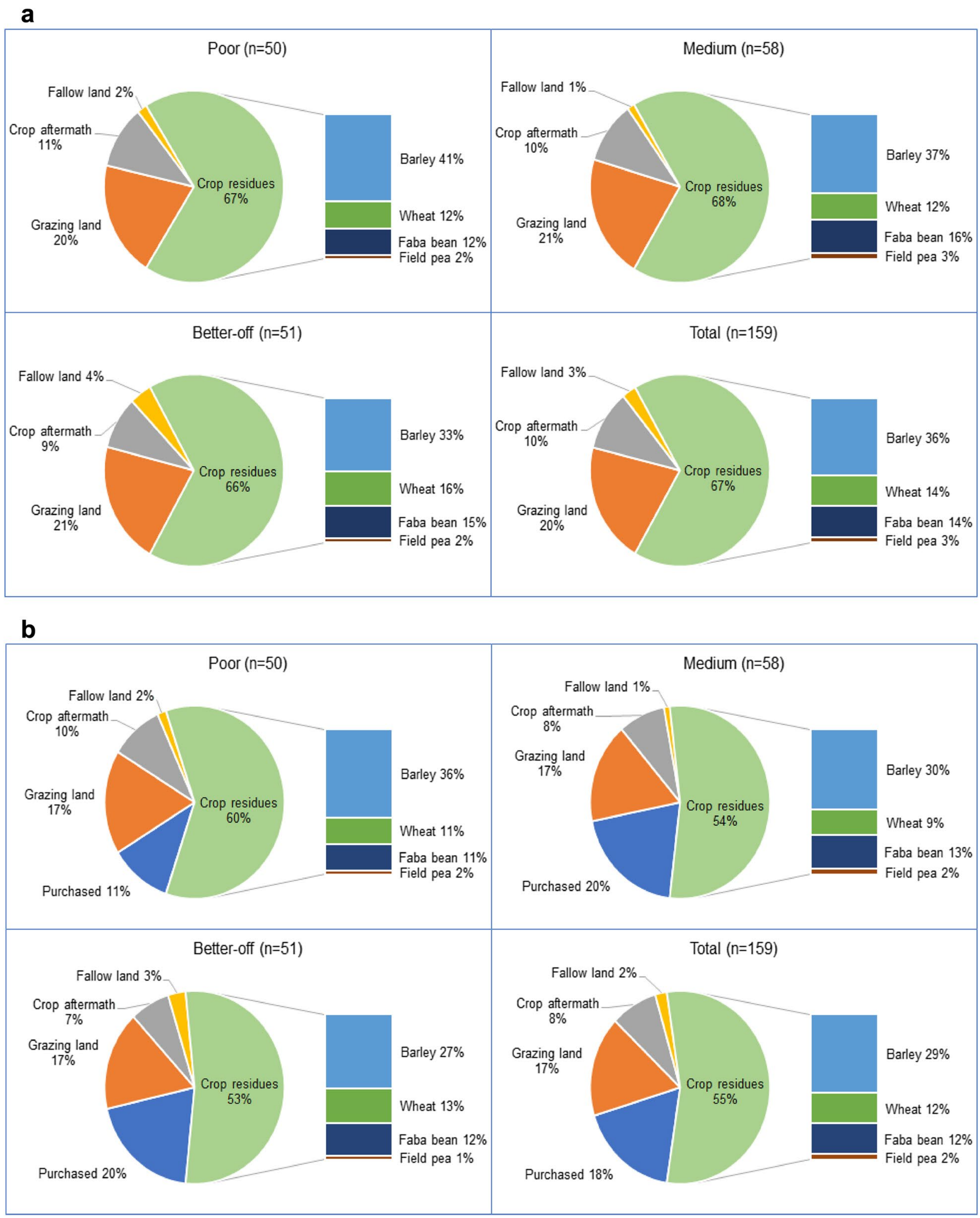

Fig. 4 Relative contributions of feed resources **a** obtained on-farm and **b** obtained on-farm combined with purchased feeds to the total annual livestock feed dry matter supply in the mixed crop–livestock system, central highlands of Ethiopia

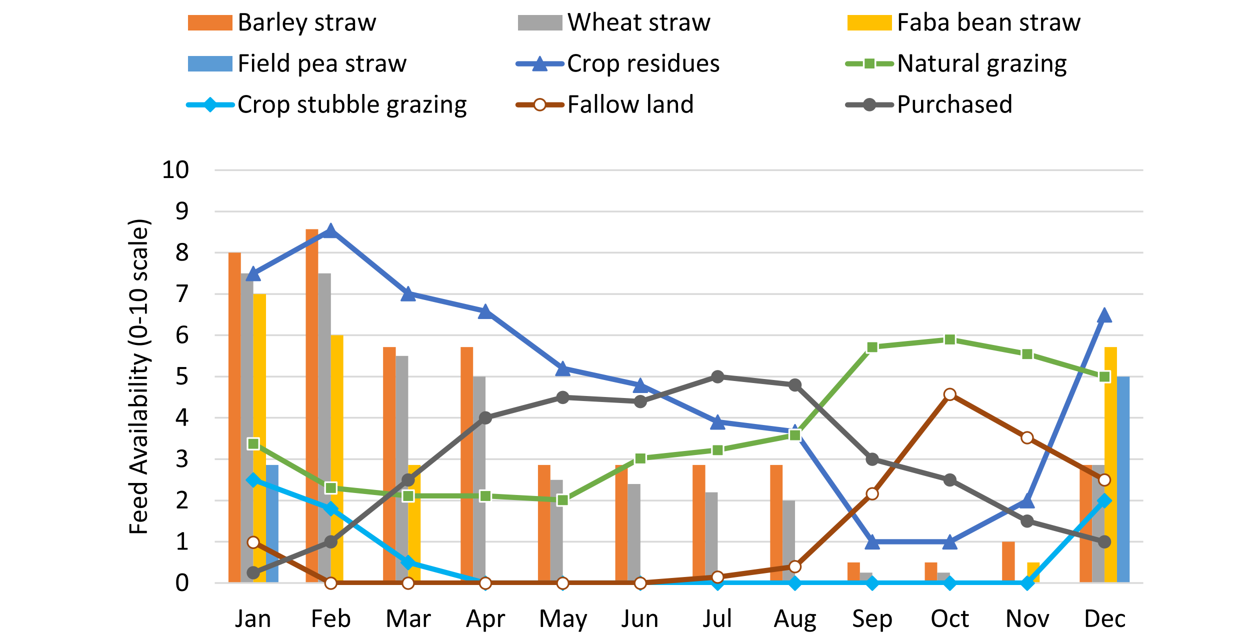

Fig. 5 Seasonal availability of feed resources as perceived by farmers in the mixed crop–livestock system, central highlands of Ethiopia. Availability of feed over the year on a scale of 0–10, where 10 = excess feed available, 5 = adequate feed available and 0 = no feed available

The size of available GL in the study area is small irrespective of wealth status, though the wealthier are more favoured to exploit available feed resource from freely grazing the communal land due to ownership of relatively larger livestock herd size. Moreover, fallow lands as livestock feed source were very rare, as there is critical land shortage for crop cultivation as well. In agreement, [34] reported that it was in the past that GL, hay and fallow land grazing were the main sources of feed; however, at present the situation has changed due to the rapidly increasing human population and expansion of crop production in the grazing areas. Same author asserted that there is very little that livestock can forage from the limited communal grazing due to continuous grazing and the mismatch between the feed supply potential of the land and the number of animals kept. Consequently, crop residues are increasingly becoming the main sources of livestock feed resources in the MCL systems [34–36]. Other several studies have also disclosed that, in recent years, GL in the MCL systems are devastatingly overstocked and that the herbage biomass productivity is declining both in quantity and quality [8, 11, 37–40]. Therefore, expansion of GL to increase feed availability is not a practical option as the increasing trends of both the human and livestock population are going to claim more additional land further for crop production, settlement and feed sourcing.

Hence, strategic options to improve the availability of CR and other alternative and/or additional feed resources should be intervened. From evidences captured in the present study which are supported by several other findings, most of smallholder farms in the MCL systems are dependent on CR as the main source of feed for livestock. Moreover, nowadays straws have also become an important source of revenue [34] and used for other purposes that compete livestock feed supply. References [41, 34] suggested close collaboration of crop and livestock scientists aimed at multidimensional crop improvement to increase the quantity and feeding value of CR without negatively affecting the grain yield and quality. In addition, Tolera [34] further suggested the introduction of cover crops that could be grazed after short rainy season, high yielding forage crops with possibility of multiple harvests per year and multipurpose leguminous trees used as supplemental green fodder could be explored to alleviate the feed shortage pertaining to the existing situation. In addition, interventions to increase feed biomass per unit area of GL, proper grazing management and purchase of supplemental feeds whenever possible would be among the options that help to reduce the influence of feed shortage on livestock health and productivity.

The fluctuations in the seasonal availability of major feed resources are mainly associated with the rainfall distribution and cropping pattern of food-feed crops. Crop residues are plenty during the dry season, which is the period of threshing for harvested crops. Availability and utilization of crop aftermath grazing is aligned with harvesting periods of crops in the dry season. Crop residues and hay are also conserved for mitigating feed shortage, especially during peak periods of cropland ploughing in the wet season. Forages from grazing lands and fallow lands are available following the main/long and short rainy seasons, when the moisture is sufficient enough to support plant growth.

Livestock feed demand and feed balance

In the present study, livestock feed balance evaluated is generally found to be negative irrespective of farmers' wealth status, indicating the critical feed shortage in the system to fulfil the DM, ME and DCP requirement for the prevailing livestock. Overall, only about 49, 81 and 62% of DM, ME and DCP requirements are fulfilled, respectively, with the current amount of feed supply from on-farm production combined with purchased feeds. Several previous study findings support the present report in that in the MCL system where land is limited, the contribution of CR is prominent and GL are deteriorating in size and productivity, and the livestock production is performed under annual feed deficit. For instance, Wondatir et al. [9] reported that around Debre Birhan the annual feed supply only satisfies 64% of the maintenance DM 81% ME and 66% DCP requirements of the animals per farm. Study by Amsalu et al. [11] in Gummara-Rib watershed of the Lake Tana sub-basin in Amhara Region shows that the available feed sources address only 72% of the annual DM requirement per household. These studies confirmed the long-standing impediments for increasing livestock productivity consistently claimed by smallholder farmers and development practitioners in the MCL systems, where seasonal feed shortage both in quality and quality coupled with inadequate successful interventions, which are remained unabated.

This study and others mentioned here used same amount of average daily DMI for a standard TLU of 250 kg at 2.5% of live body weight suggested by [25], which is 6.25 kg/day, to arrive at an aggregated demand for feed DM at household level per year. However, the daily DM feed intake is affected by various animal and feed-related factors. FAO [42] described where there is good access to feed, and health and welfare are optimum, the DM intake for young ruminant animals is likely to be 4% of body weight and decline to 2–2.5% as animals are getting mature. Moreover, where feeds of low digestibility are the main or only sources, voluntary intake will be significantly influenced due to the longer time it takes to progress through the digestive tract, and as a result low digestibility is reflected in lower intakes.

Livestock feed balance reported under smallholders in the MCL system is frequently negative [10, 43, 44], and even so many times declared as below the maintenance requirements [6, 9, 11]; however, in fact livestock continued to survive, reproduce, provide and perform their vital functions, whereas the different products and services obtained cannot be imagined at maintenance requirement level let alone when an overwhelming annual feed deficit below maintenance is revealed. Hence, series of critical questions could arise on the assumptions, methods and validations of livestock feed balance estimations, which were also iterated by Kassa et al. [10]. For instance, is the suggested daily DMI amount at 2.5% of live body weight is limited to only satisfy the maintenance requirement, as described in various livestock feed balance studies? To what extent the suggested daily allowance fulfils the animal requirement? Do feed types of any quality and form can be ingested at the suggested rate by any type and/or class of livestock throughout all seasons of the production year? Is that amount of feed could be affordable daily by smallholders in the MCL system consistently throughout the production year? etc.

The feed balance results should be cautiously interpreted, in that the livestock production system is running in an annual feed deficit does not mean that the livestock are currently without any benefit to offer. It is not unimportant either, since it quantitatively unveils the picture of what farmers and experts claim to be the most important determining factors of livestock production, which are feed shortage and the increasing trend of land scarcity on which to produce livestock feed. First of all, the suggested rate for the DMI of feed does not indicate the quality of the feed supplied but the average quantity that the animals could potentially consume daily. In addition, it does not mean that whatever is ingested is equally available to all types of animals. This is because the nutritional requirement of an animal depends on several factors: species, size, age, weight, physiological status (pregnancy, lactation, etc.), level of production (rate of gain, amount of milk produced, etc.), general health, amount of work, weather condition and season [19, 42, 45].

Secondly, there is a need to closely observe the dynamics of farm elements and situation analysis throughout the production year. Actually, the feed balance estimate showed the situations aggregated on annual basis, as if the feed availability and livestock DM, ME and DCP requirements per day are distributed evenly throughout the production year. However, a lot of dynamics can happen in the seasonal feed sources availability, nutritional composition and quality, and in the individual animal body and in the livestock herd in the course of the annual production process. It is an established fact that quantity and quality of feed available from natural pasture are affected by season [10, 35, 43–46]. Feed sourced from crop production is also affected by type of crop, cropping pattern, amount of input used like fertilizers and agronomic practices applied [36, 47, 48]. Different feed sources of varied quantity and quality may be available to livestock across different seasons, which could be produced on-farm or purchased depending on the capacity of producers to afford. The animals may undergo the phenomenon of compensatory growth, i.e. lose weight during periods of feed scarcity and put on weight (gain) during times of good feed availability. In the meantime, livestock could deliver any forms of products and services during periods of feed availability and/or mobilize what is deposited during good times of the year. At herd level, an inflow from natural perpetuation and purchase of animals, and an outflow due to death, sell and slaughter, and shared rearing of animal in either case could all happen within the year following the scarcity and availability of feed at household level. Hence, the seasonal feed availability coupled with farmers feeding practice and coping mechanism of feed shortage, the productivity gain or loss and the inflow and outflow dynamics of livestock at household level should be considered, while interpreting the livestock feed balance.

Conclusions

The available annual feed dry matter, metabolizable energy and digestible crude protein supplies and requirements of livestock did not match at present, in the study area characterized by smallholder mixed crop–livestock production system. Livestock feed insufficiency unanimously affects the whole group of smallholder farmers irrespective of wealth status. However, the wealthier group of farmers which owned larger size of livestock collected more quantity of feed on-farm and acquired additional feed through purchase found to suffer more in terms of feed deficit than the poor farmers, when livestock feed balance was assessed. Scarcity of GL due to expansion of cultivation on GL coupled with low productivity of biomass from grazing and food-feed crops production further exacerbate the mismatch between feed supply and demand. The trend of land scarcity testifies that smallholder livestock production in the MCL system is likely to continue to rely upon CR. Crop residues which are claimed to have suboptimal feeding value due to the high fibre content and low digestibility comprised the major portion of annual feed supply, and thus the inherent limitations of CR should not be ignored. Farmers who promoted cross-breeding of local animals with breeds of temperate origin to increase milk production are found unable to supply sufficient quantity and quality of feed to achieve the anticipated level of productivity. The present evidences implied that unless the feed deficit is relieved through increasing the availability and quality of feeds and practicing strategic feeding the productivity of livestock will be more profoundly affected.

Abbreviations

ADR: age dependency ratio; CR: crop residues; DM: dry matter; DMD: dry matter demand; DMI: dry matter intake; ME: metabolizable energy; MJ: mega joules; DCP: digestible crude protein; kg: kilogram; t: ton; hh: household; GDP: gross domestic product; GL: grazing lands; masl: metres above sea level; MCC: milk collection centres; MCL: mixed crop–livestock; *n*: number of respondents; SD: standard deviations; SE: standard errors; TLU: tropical livestock unit.

Authors' contributions

MBT designed the study, collected and analysed the data and drafted the manuscript. AMW and BTM supervised the design of the study and data analysis and revised the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

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