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Livestock nutrition and feed balance on smallholder farms in Tanqua-Abergelle district, northern Ethiopia

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ABSTRACT

The present study examined the livestock feed balance of smallholder farmers in Tanqua-Abergelle district of central Tigray, northern Ethiopia. Sixty livestock households were randomly selected from two farmer associations chosen systematically based on their livestock production potential. Data were collected on household characteristics, land holding, livestock ownership, feed inventory, feed supply and feed demand using household interviews (N = 60). Field feed samples were collected and representative samples analysed for dry matter content (DM), metabolizable energy (ME) and digestible crude protein (DCP). Annual DM, ME and DCP supply and demand were estimated using proper scientific procedures. Feed balance was quantified by comparing the feed demand with the supply. Data were analysed using descriptive statistics of SPSS statistical software. Crop residues, grazing lands, crop stubble and mixed hay were investigated as the major feed resources for livestock. On average, annual feed production was 3.96 tonnes DM, 30,138 MJ ME and 171 kg DCP at household level for 4.85 TLU. Crop residues contributed to 52 % of the total annual feed supply and grazing lands to 29 %. The feed requirement for maintenance of the livestock holding was estimated at 11.06 tonnes DM, 45,580 MJ ME and 253 kg DCP. The feed balance analysis estimated a 64 % deficiency of dry matter, 34 % of ME and 32 % of protein. Based on the present findings, it is clear that either the quantitative and qualitative feed supply of the livestock must be improved or the number of livestock kept in Tanqua-Abergelle district must be reduced in order to close the feed gap.

1. Introduction

Livestock rearing is an important economic activity in the Tanqua-Abergelle district of central zone of Tigray, northern Ethiopia. Livestock provide many functions like draft power, food, income and saving to the smallholders in the mixed crop-livestock farming system of the district. Smallholder farmers rear different species of livestock including cattle, goats, sheep and donkeys. The district is well noted for livestock production, especially small ruminants [1]. Livestock production is based on various feed resources consisting of crop residues, natural pastures, crop stubble, hay and browse plants [1,2]. Feed shortage both in terms of quantity and quality is a key problem. Negative livestock feed balance was reported by Ref. [3] with a deficit of 9 % dry matter (DM), 45 % energy and 42 % protein in Ethiopia. This makes it difficult to optimize livestock productivity levels. Proper supplemental feeding interventions are required to explore the full genetic potential of the animal and thereby increase productivity [4].

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The availability and distribution of the different feed resources vary within season and area. There is variation in contribution of each feed type to the total feed resource base [2,5,6]. The contribution of feed depends on the farming system, agro-ecological zone, land use pattern and climatic condition. Natural pastures are the main feed resources for livestock in the pastoral areas while crop residues hold significant contributions in the mixed crop-livestock farming system. A recent report of [6] showed that natural pastures and crop residues appear to be the major feed sources for livestock in Ethiopia. Tremendous efforts have been made by government offices, non-government organizations and projects to improve feed availability. The efforts focused on introducing improved forages, improved feed management and utilization, providing technical training to farmers and delivering necessary inputs. However, despite these efforts, feed development has not been successful, and thus feed shortages remain a feature of livestock production systems in the Tanqua-Abergelle district.

The livestock feed problem requires a holistic approach with comprehensive and detailed understanding of the existing feed situation in the area. Making the greatest use of the feed resources needs an accurate analysis of feed supply and feed requirement [3,7]. Much research has highlighted the importance of feed balance analysis as an indicator of livestock nutrition status [3,8–11]. The feed improvement endeavour demands a clear strategy that guides the proper way of feed production, management and utilization. Undertaking a feed situation analysis that can identify the available feed resources, potential feed supply and feed gap are necessary to explore the available resources for feed supply improvement. To create and implement sustainable feed improvement plans, information on feed inventory and feed balance would be beneficial with the introduction of specific and strategic interventions [3]. Moreover, feed balance can be used as a potential indicator to examine sustainability of farms. Hence, this study aimed to investigate the major feed resources and to analyse livestock feed balance under the smallholder farmers in Tanqua-Abergelle district of central Tigray, northern Ethiopia.

2. Materials and methods

2.1. Descriptions of the study area

The study was carried out in Tanqua-Abergelle district of central zone of Tigray, northern Ethiopia. The district is geographically located at 13°14′06″ N latitude and 38°58′50″ E longitude. The area receives an annual rainfall of 370–700 mm with an average daily minimum temperature of 21 °C and a maximum temperature of 41 °C. Rainfall distribution is unimodal with the single maximum rains occurring from June to the beginning of September. The district is located at an altitude range of 900–1800 m above sea level, and classified as hot to warm sub moist lowland with 95 % lowland and 5 % mid-altitude [12]. The area is characterized by mixed crop-livestock farming where cropping and livestock are highly integrated and interdependent. Sorghum (*Sorghum bicolor*), teff (*Eragrostis tef*), maize (*Zea mays*), finger millet (*Eleusine coracana*), pulses and groundnut (*Arachis hypogaea*) are the dominant crops produced in the area. The area has immense livestock resources with 73,465 cattle, 91,848 sheep, 235,013 goats, 18,542 donkeys and 137,750 chickens. The land mass cover is 144,563 ha, of which 31,532 ha are farm lands (22 %), 36,141 ha grazing lands (25 %), 2453 ha sown pastures (2 %), 29,820 ha reforestation areas (21 %) and 44,614 ha miscellaneous lands (31 %) [12].

2.2. Sampling and data collection

2.2.1. Household interviews

The study district was selected purposely for its major livestock producing potential. As a follow up to the livestock system description by Ref. [1], the gap between feed supply and demand was quantified. The diagnostic feed survey study was conducted from February to November 2013 by selecting two farmer associations (Lemlem and Gera) using a purposive sampling method considering the livestock production potential. From the district, sixty livestock households (30 from each farmer association) were selected randomly. Face to face interviews were conducted with the selected households using a semi-structured questionnaire by the researchers. Data were collected on the following topics at the farm level: types of crops produced, area cultivated for each crop type, crop yield, and other pertinent information. Household profiles, land size, livestock holding, species composition, feed inventory, feed production, and livestock herd structures were also included. Each respondent was taken as a unit of analysis. Focus group discussions were held with farmers at each farmer association to collect qualitative data like feed types, ranking feeds and livestock types. The conversion factor used to convert livestock holdings to tropical livestock units (TLUs, 250 kg in weight) was 0.7 for cattle, 0.1 sheep, 0.1 goats, and 0.5 donkeys [8,13].

2.2.2. Estimation of feed production and supply

Crop residue production was estimated from grain yield using standard conversion factor which varies with crop type with a multiplier of 1.5 for teff, 2 for sorghum and maize, and 1.2 for pulse and oil crops [14,15]. Ref. [16] noted that about 90 % of the collected crop residues are utilized as animal feed while the other 10 % is wasted during collection and feed processing and/or used for other purposes. The 10 % wasted was accounted for when estimating crop residues production. Feed available from stubble grazing was estimated using 0.5 tonne DM ha^{-1} multiplied by cultivated landholding per household as described by Ref. [14]. Here 75 % utilization factor was used to determine the actual consumable feed from aftermath grazing [17]. Similarly, feed supply from grazing land was estimated using 2 tonne DM ha^{-1} multiplied with grazing land holding [14,18]. Grazing land was obtained from private and communal ownership. While communal grazing was shared from accessible communal grazing lands, private grazing land was acquired through household interviews. The share of communal grazing per household is assumed to be a function of livestock density. A livestock density of 10.21 TLU/ha was derived from livestock number and accessible grazing size and used to allocate the communal

grazing to each livestock holder. Utilization factor of 75 % was used to quantify the available feed resources from extensive grazing [17]. Hay dry matter production was estimated following a formula recommended by Fourth Livestock Development Project [18] and household interviews. The feed availability estimate did not take into account feed dry matter that could be obtained from other unconventional feed resources, such as household wastes, *Atella* (residues of the local brewery), browse plants, kitchen wastes, mill by-products, and the like. This was due to their occasional and negligible availability, and also their reliable production data are not available. This can cause the annual feed supply at farm level to be underestimated.

2.2.3. Chemical analysis and nutrient supply estimation

Eight different feed samples were taken from the field expedition using paper bag that were labeled carefully to have full information. Three samples were taken from each feed type for laboratory chemical analysis. Partial dry matter analysis was carried out for high moisture containing feeds using an air drying method. The feed samples were sent to a nutrition laboratory for chemical analysis. Dry matter and nitrogen were analysed following the procedures of [19]. Crude protein, metabolizable energy and digestible crude protein were calculated from equations. Crude protein (CP) was calculated as:

$$CP = N \times 6.25 \quad (1)$$

Where: CP = Crude protein (g/100 g DM); N = Nitrogen (g/100 g DM).

In vitro DM digestibility was determined by the Tilley and Terry method as modified by Ref. [20]. Metabolizable energy (ME) was calculated from *in vitro* DM digestibility (IVDMD) using a formula [21]:

$$ME = 0.17 * IVDMD\text{-}2.0 \quad (2)$$

Where: ME = Metabolizable energy (MJ/kg DM); IVDMD = *In vitro* DM digestibility (g/100 g DM).

Similarly, digestible crude protein (DCP) was computed from crude protein (CP) using an equation [22]:

$$DCP = 0.929 * CP\text{-}3.48 \quad (3)$$

Where: DCP = digestible crude protein (g/kg); CP = Crude protein (g/kg).

Energy supply was measured as metabolizable energy (ME) and protein supply as digestible crude protein (DCP). The nutrients available from each feed source were computed to get the total DM and nutrients yields. The amount of DM and nutrients supplied by each type of feed was determined by multiplying the total DM output by the feed's nutrient concentration [23]. For grazing lands, ME of 7.10 MJ/kg DM and CP of 51 g/kg DM were taken from a literature [3].

2.2.4. Estimation of dry matter and nutrient requirements

Daily DM requirement of one TLU is estimated at 2.5 % of its body weight [13,24]. This amounts to 6.25 kg DM per day and 2281 kg DM per year. The daily ME and DCP maintenance requirements were calculated as described by Ref. [24]. Based on metabolic body weight, 0.49, 0.39 and 0.43 MJ of ME and 2.86, 1.72 and 2.51 g of DCP per kg metabolic weight per day were used for maintenance for cattle, sheep and goats, respectively. The daily ME maintenance requirements for non-ruminants like a donkey was estimated based on the formula given by Ref. [25].

$$DE = [0.975 + (0.021 * BW)] * 4.187 \quad (4)$$

Where: DE = Digestible energy (MJ/day); BW = Body weight (kg).

An adult donkey was estimated to weigh 150 kg. As a result, the daily DE requirement was calculated as 17.27 MJ. Thereafter, the DE was converted to ME by multiplying by a factor of 0.87 (ME = 0.87 × 17.27 MJ = 15.02 MJ). A value of 2.2 g DCP per kg metabolic body weight was used for daily maintenance requirements of the donkey [25]. Accordingly, the daily maintenance requirements of all animal types multiplied by 365 days was used to calculate the annual ME and DCP requirement for maintenance [24].

2.3. Feed balance analysis

The annual feed yield contributed from each category of feed resource was estimated using appropriate conversion factors from the land use pattern as described above. Similarly, the annual feed demand was estimated using appropriate procedures as mentioned above. The feed supply and demand were calculated by taking the household as a unit of analysis. Following this, the total annual feed supply was compared against the annual demand of the animals to examine the feed balance in terms of dry matter, metabolizable energy and digestible crude protein. The feed supply, demand and balance were computed using the following equations.

$$\text{Feed supply(t DM)} = \text{Crop residues(t DM)} + \text{Grazing lands(t DM)} + \text{Stubble grazing(t DM)} + \text{Natural mixed hay(t DM)} \quad (5)$$

$$\text{Feed demand(t DM)} = \text{Cattle feed demand(t DM)} + \text{Goat feed demand(t DM)} + \text{Sheep feed demand(t DM)} + \text{Donkey feed demand(t DM)} \quad (6)$$

$$\text{Feed balance(t DM)} = \text{Feed supply(t DM)-Feed demand(t DM)} \quad (7)$$

2.4. Data statistical analysis

The collected data were analysed using descriptive statistics of the [26] computer statistical software. Descriptive statistics such as number of observations, percentage, mean and standard error were used to describe variables and summarize the results.

3. Results

3.1. Household socioeconomic profile

Information about socioeconomic characteristics of the sampled households is presented in Table 1. Of all sampled households, 83 % were male-headed and 17 % female-headed. The average age of the household head was 42 years, ranging 21–84 years. The age distribution shows that the majority of household heads were in the active age category. Those who were in the age category of 51–70 years old accounted for considerable number while household heads aged above 70 years old accounted for only few of the total sample households. The average household family size was 4.45 persons. Most households owned 5–8 family sizes while some had 1 - 4 persons and others 9–12 persons. Half of the household heads attended primary school, some household heads attended secondary school while illiterate household heads held a significant number.

3.2. Land ownership

Land holding size and land use pattern of the sampled households is presented in Table 2. On average, a household owned about 1.44 $\pm$ 0.12 ha land size. Households owned different sizes of land with majority of them having below 1 ha land size. Some of the households possessed above 2 ha land. The available land is used for different purposes such as cropping, irrigation and grazing. The available land was predominantly allocated for crop cultivation while insignificant land was devoted for grazing and irrigation. This indicates that farmers give priority to food crop production to get sufficient cereal grains (sorghum, maize and teff) for their family. Of the sampled households, no one was observed allocating land for improved forage cultivation and fallowing.

3.3. Livestock holding

The average household livestock holding was 4.85 $\pm$ 0.46 TLU (Table 3). Cattle were observed to be the dominant species amongst the livestock types with average cattle holding size per household of 2.96 TLU accounting for 61 % of the total herd size. The cattle herd is composed of local breeds like Abergelle cattle with very less exotic/crossbred. Goats and sheep together made a significant magnitude of the livestock herd following cattle. However, small ruminants outnumbered cattle in absolute numbers. The donkey holding per household was 0.57 TLU sharing about 12 % of the total livestock holding. The donkeys found in the study area are all indigenous types called Abyssinian donkey (medium size gray coat colour).

3.4. Quantification of major feed resources

The total annual feed production for the livestock at household level is presented in Table 4. As it can be seen in the table, the available feeds are derived from different sources such as crop residues, grazing lands, stubble grazing and natural mixed hay. The mean feed supply per household was estimated to be 3.96 tonnes DM. Crop resides dominantly contribute to the annual feed supply of the household. On average, a household produces about 2.07 tonnes DM crop residues, consisting of residues of different crop types

Table 1
Socioeconomic characteristics of sampled households in Tanqua-Abergelle district, Northern Ethiopia.

Household characteristics	Percent (%)
Household head sex	
Male	83
Female	17
Household head age	
20–30 years	17
31–50 years	49
51–70 years	32
Above 70 years	2
Household size	
1 - 4 family size	22
5 - 8 family size	72
9 - 12 family size	7
Household head education level	
Illiterate	37
Primary school (1–6 grade)	50
Secondary school (7–10 grade)	13

Table 2
Land holding size and land use pattern per household in Tanqua-Abergelle district, Northern Ethiopia.

Land holding size (ha/HH)	Percent (%)	Land type	Mean ± SE (ha)
0.01–0.50	20	Cultivated land	1.94 ± 0.14
0.51–1.00	24	Private grazing	0.03 ± 0.01
1.01–1.50	18	Irrigated land	0.02 ± 0.01
1.51–2.00	18	Forage land	0.00 ± 0.00
>2.00	20	Fallow land	0.00 ± 0.00
		Own crop land	1.39 ± 0.11
		Own total land	1.44 ± 0.12
		Rent in crop land	0.55 ± 0.09
		Communal grazing*	0.73 ± 0.07
		Grazing land	0.76 ± 0.08

HH = household; ha = hectare; SE = standard error; * Share of communal grazing per livestock holder.

Table 3
Livestock holding per household in number and TLU in Tanqua-Abergelle district, Northern Ethiopia (mean ± SE).

Animal type	Head	TLU	TLU share (%)
Cattle	4.23 ± 0.07	2.96 ± 0.30	61
Goat	7.25 ± 1.35	0.72 ± 0.13	15
Sheep	6.08 ± 1.05	0.60 ± 0.10	12
Donkey	1.13 ± 0.10	0.57 ± 0.05	12
Total	–	4.85 ± 0.46	100

TLU = Tropical Livestock Unit (Live weight of 250 kg); SE = standard error

Table 4
Annual feed supply of major feed resources at household level in Tanqua-Abergelle district, Northern Ethiopia.

Feed type	Feed supply (tonne DM/year)	Contribution (%)
Crop residues	2.070	52
- Sorghum stover	0.923	23
- Groundnut straw	0.459	12
- Maize stover	0.309	8
- Teff straw	0.275	7
- Cow pea straw	0.071	2
- Barley straw	0.030	1
Grazing land	1.140	29
Stubble grazing	0.728	18
Natural mixed hay	0.021	1
Total	3.959	100

DM = dry matter

such as sorghum, groundnut, maize, teff, cowpea and barley in the order of their importance. The proportional contribution of crop residues to the total feed resource base was greatly significant followed by grazing lands and stubble grazing. The proportional share of hay in meeting the feed demand of the animals was less.

3.5. Nutrient contents of major feed resources

Table 5 provides information on nutritional composition: ME, CP and DCP of major feed resources available in the study area. ME

Table 5
Nutrient contents of major feed resources in Tanqua-Abergelle district, Northern Ethiopia.

Feed type	IVDMD (g/100 g DM)	ME (MJ/kg DM)	CP (g/kg DM)	DCP (g/kg DM)
Sorghum stover	57	7.68	27.60	22.16
Groundnut straw	66	9.28	91.80	81.80
Maize stover	54	7.22	49.10	42.13
Teff straw	62	8.56	44.30	37.67
Cow pea straw	61	8.39	81.10	71.86
Barley straw	52	6.87	54.10	46.78
Natural mixed hay	51	6.70	62.90	54.95
Green grass	70	9.83	132.00	119.15

DM = Dry matter; CP = Crude protein; IVDMD = *In vitro* dry matter digestibility; ME = metabolizable energy; DCP = digestible crude protein

was higher for green grass followed by groundnut straw, teff straw, cowpea straw, sorghum stover, maize stover, barley straw and mixed grass hay in descending order. Likewise, DCP was greater for green grass followed by groundnut straw, cowpea straw and natural mixed hay in decreasing order. Barley straw, maize stover, teff straw and sorghum stover contained lower DCP in that order.

3.6. Nutrient yield from major feed resources

Crop residues, natural pastures, stubble grazing and hay were identified as the major feed resources for livestock in the study area. Total ME and DCP availability of the feed resources at farm level is presented in Table 6. Crop residues dominantly contributed to the total ME availability, followed by pasture grazing and crop stubble. Among the residues, sorghum stover availability in terms of ME was the highest, followed by straws of oil crop, maize, teff, cowpea and barley in descending order. Likewise, the highest magnitude of DCP came from crop residues, followed by those of grazing lands, stubble grazing and hay in the order of their proportional contribution. This shows that crop residues remain to be the main energy and protein sources for animals in the study area.

3.7. Estimation of nutrient requirement

The mean annual DM, ME and DCP requirement for maintenance per household were found to be 11.06 tonnes of DM, 45,580 MJ ME and 253 kg DCP (Table 7). As shown in the table, cattle require more feed, 61 % of the total DM, 56 % of ME and 59 % of DCP required, followed by goats, donkeys and sheep in that order.

3.8. Feed balance analysis

Based on the above supply and demand estimates, the DM available from the major feeds at household level satisfies only 36 % of the total annual DM requirement of the animals while the rest 64 % signifies a deficit (Table 8). Likewise, the energy requirement of the animals is by far above the supplied one in the study area. The animals get only 66 % of their metabolizable energy requirement showing 34 % deficiency. The protein supplied is below the maintenance requirement with deficiency of 32 % in the area. This reveals that the area is deficient in feed, energy and protein for feeding livestock.

4. Discussion

4.1. Land and livestock holding

The average land holding obtained in this study was comparable with other previous studies. A survey done in rural areas of Ethiopia reported 1.48 ha as total household land holding size [27]. The figure was 1.15 ha for Tigray region. As compared to the present study, more livestock holding per household was reported by other researchers. Average herd size of 7.22 TLU was reported by Ref. [28] in the north western zone of Tigray. Similarly, [11] found 8.50 TLU in the central highlands of Ethiopia. The observed difference could be related with variation in production system, production environment, land and feed availability, production objective and other factors. Cattle herds are highly dominated by local breeds indicating the livestock rearing is being practiced using local animals. Similar result was reported by Ref. [6] in which 98 % of the cattle population are local or indigenous breeds while exotic/crossbreed are only 2 %. Sheep and goats together hold a significant proportion of the total livestock holding, implying the importance of small ruminants as the major enterprise in the lowland areas. It also displays the ecological suitability of the area for these animals. All the sheep and goats are indigenous types and no farmer was observed having exotic or crossbred ones.

4.2. Estimation of feed supply

Crop residues, grazing lands, stubble grazing, and mixed hay are the main feed resources that contribute to Tanqua-Abergelle district's overall feed availability. The contribution of these feed types varies with the highest share by crop residues, followed by

Table 6
Annual average nutrient yield/supply per household from various feed resources.

Feed type	ME (MJ)	ME share (%)	DCP (kg)	DCP share (%)
Crop residues	16,735	55	87.88	51
- Sorghum stover	7089	23	20.45	12
- Groundnut straw	4259	14	37.55	22
- Maize stover	2231	7	13.02	7
- Teff straw	2355	8	10.36	6
- Cowpea straw	596	2	5.10	3
- Barley straw	206	1	1.40	1
Grazing land	8094	27	50.04	29
Stubble grazing	5169	17	31.96	19
Natural mixed hay	141	1	1.15	1
Total supply	30,139	100	171.04	100

Table 7
Annual maintenance requirement of livestock types per household in Tanqua-Abergelle district, Northern Ethiopia.

Animal type	DM (tonne)	Share (%)	ME (MJ)	Share (%)	DCP (kg)	Share (%)
Cattle	6.75	61	25,568	56	148	59
Goat	1.64	15	7730	17	45	18
Sheep	1.37	12	6087	13	27	11
Donkey	1.30	12	6195	14	33	13
Total requirement	11.06	100	45,580	100	253	100

DM = dry matter; ME = metabolizable energy; DCP = digestible crude protein

Table 8
Livestock feed balance at household level in year base in Tanqua-Abergelle district, Northern Ethiopia.

Major nutrients	Feed demand	Feed supply	Feed balance	Feed deficit (%)
DM (tonne)	11.06	3.96	−7.10	64
ME (MJ)	45,580	30,138	−15,442	34
DCP (kg)	253	171	−82	32

DM = dry matter; ME = metabolizable energy; DCP = digestible crude protein

grazing lands. This indicates that crop residues are the major feed resources in the area. In favour of this study, a study in the central highlands of Ethiopia showed that crop residues can contribute 50–80 % of the total feed supply for animals [5]. However, the current finding was higher as compared with the recent 41 % report of [6] for Tigray region. There could be a variety of reasons for the observed variation in crop residue availability at the farm level, including variations in land holding, crop type, amount of precipitation, soil conditions, and input utilization.

The share of crop residues showed increment while natural grazing showed decrements when comparing the present study with previous study of [29,30]. The difference is likely to be due to shifting of grazing areas to crop lands with time and resulting in increased crop residues. Ref. [2] argues that with the rapid increase in human population and expansion of arable land and with the steady decrease in grazing land, the use of crop residues is increasing. The same scenario was noted by Ref. [31] in which the proportional contribution of grazing lands to the feed demand is decreasing from time to time mainly due to land use change, shifting from grazing to crop lands. Grazing lands contributed significant magnitude towards the feed availability following crop residues. Similarly, natural pastures are noted for their immense value as feed sources in other parts of Ethiopia [5,6,11]. According to Ref. [6], at national level, grazing is the major type of feed with 56 % contribution followed by crop residues that is 30 %. The CSA value for natural pastures was 40 % for Tigray, which is bigger than this study.

The present study also revealed that the proportional contribution of crop stubble and hay was less when compared to other feeds. Improved forages and agro-industrial by-products like cereal bran and oilseed cake were not taken into account for their insignificant contribution to the feed demand. This is in accordance with the reports of [3,6]. The percentage shares of hay, improved feeds and by-products towards the total feed availability were reported to be 12, 0.24 and 2 % for Tigray, respectively [6]. The feed supply estimation did not account for the contribution of non-conventional feed resources such as kitchen wastes, *Atella*, mill by-products, and household wastes. This is because of their negligible contribution to the potential feed availability and it was also difficult to quantify these feeds at farm level due to their occasional availability. It is possible that the annual feed supply at the farm level could be underestimated. Future studies are sought to quantify their contribution in the feed inventory and feed balance. If crop residues account for more than 10 % of an area's animal demand, it is classified as a mixed crop-livestock system [32]. This information leads to the classification of the study area as a mixed farming system with high interaction between the two sub-sectors (crop and livestock).

4.3. Nutrient contents of major feed resources

The relatively higher energy contents of green grass and oil seed straw show their potential use as energy supplement for crop residues based ruminant animals. Comparative values were reported by Ref. [33], 6.2–6.8 MJ/kg DM, and [34], 7.2–7.8 MJ/kg DM for cereal straws. On the other hand, the ME value of stover was higher than that of [9] with 4.56 MJ/kg DM for maize stove in the highland of Bale, central Ethiopia. The difference could be related with variation in plant variety, management practices, soil type and other factors. The ME contents of stover and natural mixed hay are in accordance with the observation of [9] who found energy concentration of 7.96 MJ ME/kg DM for standing hay. As expected, green grasses and legumes own higher DCP value as compared with cereal straw and stover. According to Ref. [35], feeds that have <12 % are classified as low protein sources, 12–20 % as a medium and >20 % as high. Based on this category, green grass is classified as medium protein source and other feeds are as low protein sources. This implies that green grass can be utilized as a source of protein to supplement poor quality feeds in the animal feeding system.

4.4. Estimation of nutrient yield from major feed resources

The current study indicated that crop residues are the major source of nutrients to the animals. Crop residues contribute high magnitude to the total ME availability. This shows that crop residues are the mainstay for livestock for survival. This finding was in

good agreement with the report of [3] in which crop residue based forages are the dominant suppliers towards the total ME availability. However, the contribution of crop residues obtained in this study was found to be larger when compared with other research works [9,23] in which the share of crop residues was reported to be 45–55 % of the total ME available at household level in the central highlands of Ethiopia. This can be explained by differences in the size of land holdings, patterns of land use, feed quality, and other characteristics between the counterpart areas.

Following crop residues, grazing lands share more of the ME availability. The study also revealed that among the feeds, crop residues have the highest contribution towards the total protein demand. Like this study, [3] also found crop residues to be the key contributor of protein requirement in Tigray. This shows that crop residues remain to be the main protein sources for animals in the study area. Similar to this study, natural pastures largely supply the major nutrients required for ruminant animals in other parts of Ethiopia [3,5,9,23]. Differences in land size, land use pattern, crop type, cropping pattern, feed quality, and other factors may account for the variation in the proportional contribution of different feeds to the available nutrients with location.

4.5. Feed balance analysis

The feed balance analysis indicated that the livestock are suffering from critical feed shortage. The area is highly deficient in DM, ME and DCP for feeding animals. A negative feed balance is frequently reported in the smallholder livestock production system [3,10,11]. According to Ref. [3], among the ten regions available in Ethiopia eight of them including Tigray region are deficit in feed resources. Feed deficit was estimated at 50 % in the Tigray region two and half decades ago [29]. This was less when compared with the present feed balance analysis. Ref [3] reported a negative livestock feed balance in Tigray region with deficiency of 17 % DM, 51 % ME and 49 % CP. According to a study conducted in Ethiopia's central rift valley, the yearly feed supply only meets 64 % DM, 81 % ME, and 66 % DCP maintenance needs of the animals per farm [10]. In the Ethiopian central highlands [11], reported 51 % DM, 19 % ME, and 38 % DCP deficiencies at the farm level. The report of [3] showed the feed deficiency to be 9 % DM, 45 % ME and 42 % CP in Ethiopia.

The negative livestock feed balance can be interpreted in contextual bases as feed balance depends on current feed availability and livestock population. However, it is obvious that feed availability in terms of quantity and quality largely depends on season. In addition, herd dynamics, feeding practices and feed shortage coping mechanisms adopted by farmers could have an impact on the status of feed balance. Hence, all these factors and others must be considered while interpreting feed balance. With this cognizant, the negative feed balance observed in the present study does not mean that livestock have no value to the smallholder farmers. Rather, it can be interpreted that the animals are not fed to the required level as per the scientific recommendations. This implies that the productivity of livestock could be adversely affected unless the feed deficit is addressed through improving feed availability.

Moreover, the critical feed gap can halter the interaction between the components (crop and livestock) of the mixed farming system. Under negative feed balance, animals are not exploited to their maximum potential. Livestock, especially oxen, are highly engaged in crop production activities. If oxen are not well fed, they can not perform farm operations properly, resulting in late land ploughing and planting. This causes low grain yield and residues production. The reduced crop residues production aggravates the feed shortage problem. This can lead to unsustainable production and system failure. Feed deficit is the root cause of the poor performance of animals. It is obvious that the negative feed balance can also impair the growth, reproduction and production of the livestock. This can compromise the overall contribution of the livestock sector in the economic development of the nation.

The present study indicated that there is a mismatch between feed supply and animal holding. This implies that livestock are exposed to critical feed shortage. It is obvious that the variation has negative implications in livestock productivity and natural resource management. Livestock have low performance and health status with reduced milk and meat production. This calls for devising a proper mechanism to narrow the feed gap. Strategic intervention options are needed to improve feed availability at household level through introducing improved feed production, management and utilization practices. A change in the existing livestock feeding system is required with emphasis to cut and carry feeding methods. In addition to this, farmers should focus on high yielding animals instead of holding more low producing and unproductive animals. The livestock extension system must consider these mechanisms in its program. Moreover, the existing improved forage production activities should be implemented in a better way. In addition to this, the feed deficiency is not expected to be equal in all areas or districts of the region. There could be wastage of feed in areas like western Tigray with extensive grazing lands. It is believed that a large amount of grass is available in these areas. The feed gap problem can be solved by transporting feed from surplus areas to these areas or districts with critical deficits in livestock feed resources.

5. Conclusions

In the present study, crop residues, grazing lands, crop stubble and mixed hay were identified as the main livestock feed resources. There is feed deficit in terms of DM, ME and DCP in the smallholder mixed crop-livestock production system. This suggests that there is an annual feed deficit in the livestock production system. The current low productivity in the production of livestock serves as proof of this. Balanced feeding is required to explore the full potential of the animals. The present findings would help to make informed decisions in addressing feed shortage problems under smallholder livestock producers. Innovative feed production and feeding strategies that are suitable for smallholder farmers must be devised and implemented for efficient use of available resources and to fill the observed feed gap.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Tikabo Gebremariam: Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Shumuye Belay:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Appendix A. Supplementary data

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