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Livestock feeding systems and feed gaps in East African smallholder farms

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Livestock feeding systems and feed gaps in East African smallholder farms

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Citation

Paul, B.K., Birnholz, C., Nzogela, B., Notenbaert, A., Herrero, M., Bwire, J., Groot, J.C.J., Tittonell, P.A. (2021). Livestock feeding systems and feed gaps in East African smallholder farms. The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), Nairobi, Kenya

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Abstract

Dairy development is a promising pathway out of poverty for smallholder farmers as demand for animal-sourced foods is projected to rise. Feed is a critically limiting factor in productivity of smallholder dairy systems in East Africa. This study aims to introduce and provide proof-of concept for a relatively simple approach to quantify feeding systems and feed gaps in data-scarce smallholder systems. Feed gap here is defined as the difference between livestock feed demand for an attainable milk production level (attainable feed demand) and actual feed supply at individual herd level. The approach is illustrated with pilot evidence from crop-livestock production systems across three agro-ecological zones in Tanzania, which broadly represent the diversity found in East Africa. Data was collected during the rainy season of 2016 and included on-farm feed and milk measurements, household surveys and farm observations. A diversity of livestock and feeding systems along an intensification gradient were found, ranging from exclusively zero-grazing of few cross-bred cows on small land sizes to mostly grazing of larger local cattle herds and a mix of both systems. Native vegetation formed the bulk of feed resources everywhere while planted forages was only common in the cut-and-carry site. Grazing systems were more labour intensive per tropical livestock unit than cut-and-carry systems, and most feeding-related labour was provided by men. 61% of all herds faced an ME feed gap, and 55% a CP gap between actually supplied feed and calculated requirements at attainable milk production levels. Feed gaps were more prevalent in the grazing than in the cut-and-carry site, although feed losses are likely to be high (up to 30-50%) in cut-and-carry systems. 24% of herds did not experience a feed gap, and other yield limiting and reducing factors might be explaining the low milk production levels. Possible causes for persisting feed gaps include that farmers might prioritize other functions of livestock such as risk management and wealth storage over productivity. The approach presented in this paper complements others that are more time, data and resource demanding. Suggestions for future improvement include capturing seasonal variability of feed gaps through repeated feed measurements across the year, and reducing output uncertainty through targeted increase of accuracy of feed supply and livestock requirement calculations. Decision-makers can use the generated insights to prioritize feeding technologies and target investments, and researchers to improve and validate modeling approaches that require detailed feed baskets.

Keywords: Crop-livestock systems; metabolizable energy; crude protein; tropical forages; Tanzania; smallholder dairy production

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Farmers in Lushoto are working with researchers to test different forage varieties like Brachiaria for yield and drought resilience. Livestock farmers in the district of Lushoto, in the Tanga region of Tanzania, are finding ways of boosting their production and lowering their environmental impact by planting improved forages. Georgina Smith/ CIAT

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Testing different forage varieties like Brachiaria for yield and drought resilience. Local livestock feed does not have the same nutritional value as improved varieties. Livestock farmers in the district of Lushoto, in the Tanga region of Tanzania, are finding ways of boosting their production and lowering their environmental impact by planting improved forages. Georgina Smith/ CIAT

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1. Introduction

Livestock are a global resource of significant benefit to society in the form of food, income, nutrition, employment, insurance, traction, and clothing (Herrero *et al.*, 2012). By 2050, the total demand for meat, milk and eggs is projected to almost double worldwide, with the largest increases expected in the developing world. This 'livestock revolution' is driven by population growth, urbanization, income increase and change in dietary preferences by the growing middle class (Delgado *et al.*, 1999; Herrero & Thornton, 2013). Combined with the importance of livestock for household income in smallholder systems, the livestock revolution may provide a unique pathway out of poverty for poor livestock keepers, provided that pro-poor policies and investments can support smallholder participation in the related value chains. Especially for ruminants, the prospects for smallholders to be competitive primary meat and milk producers are good due to low economies of scale, under-utilized family labour and the ability of ruminants to utilize low-quality roughage (McDermott *et al.*, 2010).

Smallholder livestock production and associated feeding systems in East Africa vary widely, depending on socio-economic, cultural and agro-ecological factors. Livestock systems in East Africa can be distinguished as follows: a) pastoral and agro-pastoral with larger livestock herds, mainly composed of local breeds, grazed on natural public, private or communal grassland in areas with low agro-ecological potential; b) intensive crop-livestock systems based on stall-feeding (also called cut-and-carry or zero-grazing) of 1-5 cross-bred or exotic cattle, forage cultivation and concentrate supplementation in high potential agro-ecological areas where manure is highly valued as crop fertilizer; c) semi-intensive mixed crop-livestock systems where the animals split their time between enclosures and grazing and/or being tethered; d) others including forest-based, urban and landless systems. In pastoral and agro-pastoral systems, the main objective is meat production with milk as by-product, whereas in intensive and semi-intensive mixed crop-livestock systems the focus is often on dairy (Sere and Steinfeld, 1996; Robinson *et al.*, 2011; McDermott *et al.*, 2009). In Africa, 60% of ruminants are found in mixed crop-livestock systems, occupying 20% of the total area (Herrero *et al.*, 2008). It commonly assumed that the shortage of sufficient quantity and quality feed on a consistent basis is a key constraint facing smallholder dairy farmers. In (semi-) intensive systems, it constitutes major production cost and absorbs much of the available on-farm labour (Bebe *et al.*, 2002). Feed links livestock to land use and requirements, directly through grazing and forages, and indirectly through residues and grains. Diet quality also is the basis of feed use efficiency, which determines greenhouse gas emission intensity through non-CO_2 emissions from enteric fermentation and manure (Herrero *et al.*, 2013). Despite the importance of feed baskets for livestock productivity and environmental impacts, empirical measurements of feed quantities supplied in smallholder systems in East Africa are rare.

The concept of yield gap has become increasingly popular in the last decade, witnessing a large number of applications in the realm of food crops. Yield gap is the difference between potential and actual crop yield. Potential yields are obtained with a specific crop cultivar when water and nutrients are non-limiting and biotic stresses are controlled; while actual crop yields are those effectively achieved in farmers' fields (van Ittersum *et al.*, 2013). The production ecology principles underlying crop yield gaps have also been applied to livestock production systems, as outlined by van de Ven *et al.* (2003) and van der Linden *et al.* (2015). Other approaches to livestock yield gaps were employed to estimate how livestock production can be made more efficient, including in India and Ethiopia (Mayberry *et al.*, 2017); Kenya, Tanzania, Uganda, Ethiopia, Senegal and Burkina Faso (Henderson *et al.*, 2016); and Mexico (Cortez-Arriola *et al.*, 2014). Moore *et al.* (2009) introduced the specific concept of a 'feed gap', defined as times of the year when feed supply is insufficient to meet livestock demand. However, the existing approaches to feed gaps either rely on extensive available data to calibrate various time-intensive models, or use survey data and assumptions on feed baskets without measured feed quantities.

Methods to quantify feeding systems and feed gaps for smallholder systems in data-scarce environments are currently lacking. In this context, this study aims to introduce and test a relatively simple approach to quantify feeding systems and feed gaps in East African farms, comparing feed demand and supply at the individual herd level. The approach is illustrated with pilot evidence from various crop-livestock production systems across three agro-ecological zones in Tanzania, which broadly represent the diversity found in the region. The paper concludes with discussing feeding system diversity and intensification, magnitudes of feed gaps and their causes, and the usefulness of the approach including shortcomings and recommendations for future research.

Local livestock feed does not have the same nutritional value as improved varieties. Livestock farmers in the district of Lushoto, in the Tanga region of Tanzania, are finding ways of boosting their production and lowering their environmental impact by planting improved forages. Georgina Smith/ CIAT

2. Material and methods

2.1 Conceptual approach

In this study, feeding systems comprise feed quantity and quality, but also feed management (grazing vs. cut-and-carry) as well as required labour. Livestock feed gaps are defined as the difference between attainable feed demand and actual feed supply at the individual herd level. Attainable feed demand refers to calculated feed requirements to support a locally attainable milk production level, while actual feed supply is the feed offered to a specific herd on farm (Figure 1). The approach to match 'feed demand' and 'feed supply', and define the difference between both as 'feed gap', originates from Moore *et al.* (2003) and Bell *et al.* (2018). The use of 'attainable' and 'actual' feed supply and demand concepts is based on production ecology principles. Applied to livestock production systems, they differentiate between potential/attainable, limited and actual livestock yields. Potential production is solely defined by temperature, day length, and animal genetics, while actual yields are those achieved in farmers' fields. Limiting factors (water, feed quantity and quality) and reducing factors (e.g. diseases, pollutants) explain the difference between potential and actual yields (van der Ven *et al.,* 2003; van der Linden *et al.,* 2015). In places where potential yields are far from actual yields, it is more useful to work with a locally attainable yield that can be achieved by resource-endowed smallholder farmers in their most productive fields (Tittonell & Giller, 2013). Different from van de Ven *et al.* (2003) and van der Linden *et al.* (2015), this approach to feed gaps does not consider growth limiting and reducing factors other than feed. In contrary to Moore *et al.* (2003) and Bell *et al.* (2018), we test our approach with a one-time pilot measurement only, thus ignoring the time scale of magnitude and variability of feed gaps. For this approach to yield comprehensive insights into seasonal feed gaps, the data collection has to be repeated as needed. This approach is designed to operate in data-scarce environments such as smallholder farming systems in East Africa, focusing on relatively simple calculations and minimum measured data without time and resource-intensive calibration of multiple models.

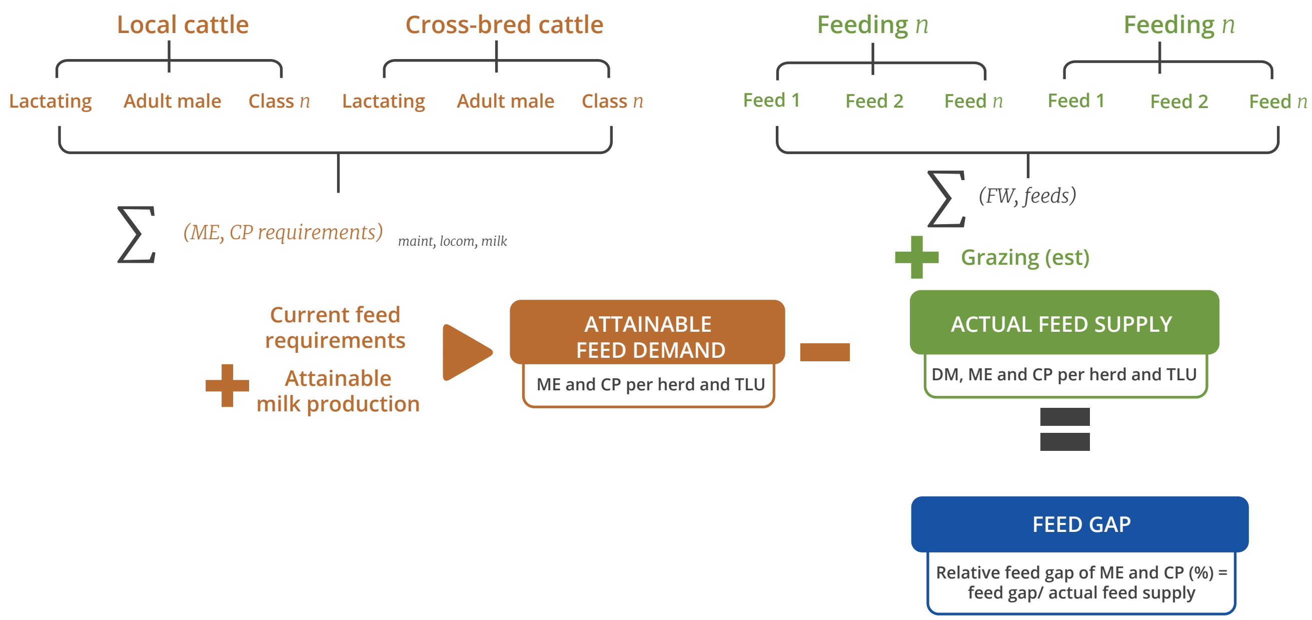

Figure 1 Conceptual overview of the feed gap approach to smallholder dairy farms in East Africa. *n* indicates additional feedings, feed items or livestock classes. FW = fresh weight, DW = dry weight, ME = metabolisable energy, CP = crude protein, TLU = Tropical Livestock Unit. Requirement calculations include maintenance, milk production and locomotion.

2.2 Pilot study sites and farm selection

Three study sites in Tanzania were selected for the pilot study, spread over three administrative regions: Lushoto in Tanga, Mvomero in Morogoro, and Babati in Manyara region (Figure 2).

Babati

Ward	Bashnet	Dabil	Dareda	Galapo	Magugu
Village	Long	Sabilo	Seloto	Hallu	Matufa
Elevation (masl)	2055	1617	1657	1193	1148
Annual precipitation (mm)	844	743	785	685	700
Mean temperature (°C)	16	19	19	21	21
Population density (persons/km2)	165	98	286	34	39

Lushoto

Ward	Gare	Mbuzii	Ubiri
Village	Yamba	Mbuzii, Boheloi	Ubiri
Elevation (masl)	1502	1154	1016
Annual precipitation (mm)	1095	1109	813
Mean temperature (°C)	17	19	20
Population density (persons/km2)	323	339	274

Morogoro

Ward	Diongoya
Village	Mvomero
Elevation (masl)	600
Annual precipitation (mm)	1043
Mean temperature (°C)	23
Population density (persons/km2)	119

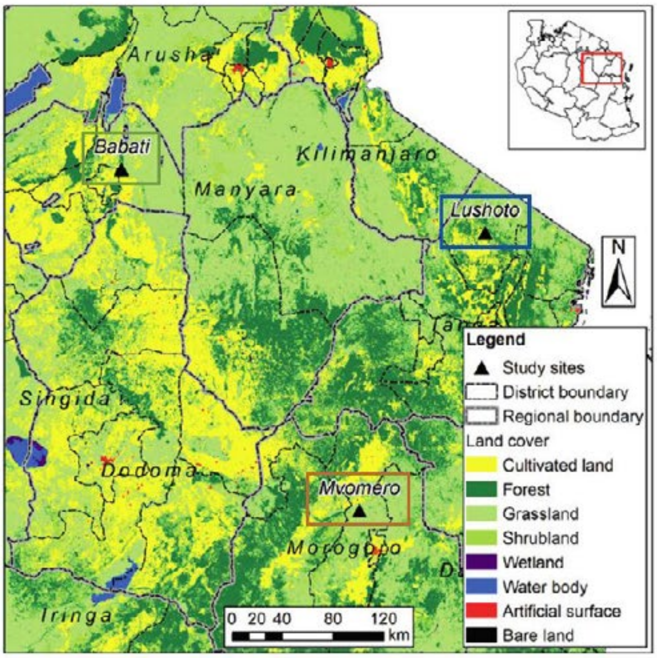

Figure 2 Locations of study sites Lushoto, Mvomero and Babati in Tanzania, and their general characterization. On-farm data collection for the pilot study took place in ten villages across nine wards in the three pilot study sites. Data for the site characterization was retrieved from the following sources: Funk *et al.*, 2015; Hijmans *et al.*, 2005; Jarvis *et al.*, 2008; Linard *et al.*, 2012. Data for the map was retrieved from Chen *et al.*, 2014; GADM 2017.

Data collection took place in different villages in five wards in Babati, one ward in Morogoro and three wards in Lushoto, which differed in average elevation, precipitation and temperature, and population density (Figure 2). The sites represent different (sub)-humid agro-ecological zones and dairy-oriented production systems, excluding (semi)-arid, pastoralist systems. Mvomero and Lushoto are sites of the Tanzania dairy value chain under the CGIAR Research Program on Livestock, and were selected through a systematic process of spatial map overlays, stakeholder consultations, scoping visits and partner preferences to represent areas with intensive/more commercial rural producers who are significantly engaged in selling milk to urban consumers (https://livestock.cgiar.org/). Babati is one of the sites of the AfricaRISING research program in Tanzania, representing a high socio-economic and agro-ecological diversity and potential for sustainable intensification. Dairy production takes place in agro-pastoral, semi-intensive and intensive mixed crop-livestock systems (https://africa-rising.net/).

We hypothesized to find diversity of feeding systems and feed baskets in the different study sites, as the relative use of different feed types differs with level of farming intensity. In sites with lower agro-ecological potential and levels of intensification, grazing would prevail, complemented with crop residues in the dry season. With increasing potential for crop production, grazing land diminishes and crop residues, collected or tethered natural vegetation, and planted forages increase. In areas with highest level of farming intensity and market connection, concentrate feeding also gains importance (Tittonell *et al.*, 2014; Figure 3). Lushoto was expected to have the most intensified feed baskets, with the highest percentages of planted fodder and supplements, and no grazing. Mvomero was estimated to have the most extensive feeding systems, relying mostly on grazing, while Babati was thought to be in between both systems with grazing as well as large reliance on crop residues but little planted fodder (Figure 3).

In total, 28 farms were sampled, with eight farms in Lushoto, nine farms in Mvomero and eleven farms in Babati. In each site, farmers were stratified according to existing farming system typologies. In Babati, three farm types were picked from Paul *et al.* (in review), namely smallest (n=5), dairy (n=3) and large livestock (n=3) farms. In Lushoto, the typology was based on an unpublished participatory typology, and included small (n=2), medium (n=3) and large (n=3) farms. One of the targeted small farmers was not available at the time of data collection, and no replacement could be identified. In Mvomero, no pre-existing typology was available so in discussion

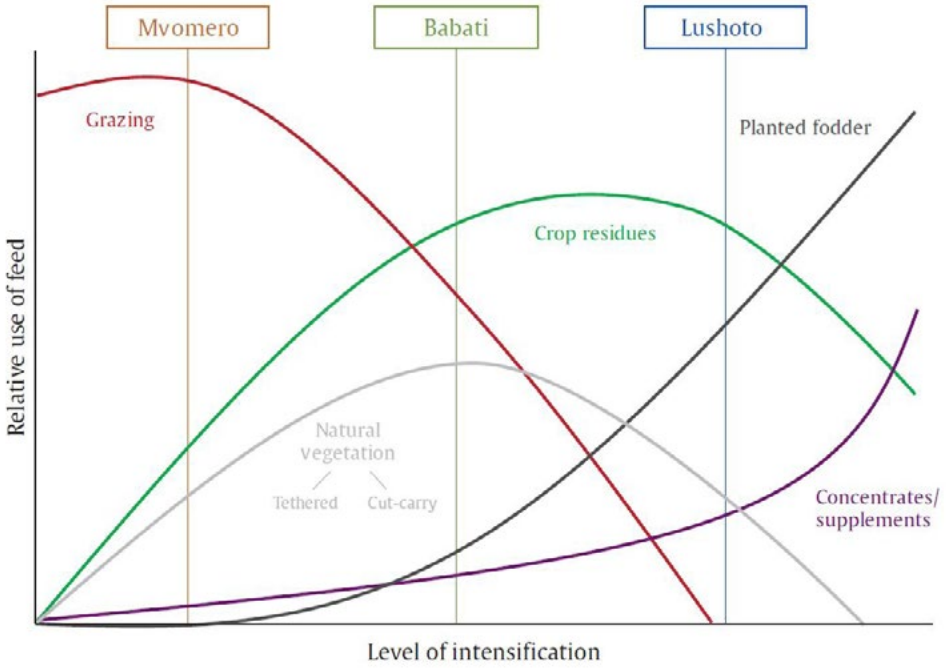

Figure 3 Conceptual diagram of changing feed baskets following intensification. Colours denote various types of feed and the change of their relative use with level of intensification. Tanzania pilot study sites Mvomero, Babati and Lushoto were expected to be positioned along the gradient with different corresponding feed baskets.

with extension officers and local scientists, farmers were stratified into small (n=2), medium (n=3) and large (n=4) farms. One of the large farmers was intended to be a small farmer, but was reclassified during data analysis. GPS locations of all farms were recorded.

2.3 Data collection

On-farm data collection was carried out in Babati from 20 to 24 April 2016, Mvomero from 28 April to 2 May 2016, and in Lushoto from 16 May to 2 June 2016 with four trained extension officers. The timing corresponded to the peak of the rainy season in Mvomero and Babati. In Lushoto, sampling was performed after the rains had just stopped but feed availability was still similar to the rainy season.

Empirically measured data included the number and breeds of all cattle, quantity of fresh feeds, milk production, and labour spent on animals. Farmers were asked to not alter their usual feeding and management practices during the day of data collection. Amount of feeds supplied to cattle were weighted and recorded in fresh weight (FW) with a hanging scale during all feedings in the course of an entire day (6am to 7pm). Feeds were separated into identifiable groups, weighed separately, and returned to the feeding trough. Sub-samples of approximately 200 gr were taken, and analyzed with near infrared spectroscopy (NIRS) for dry matter (DM) and crude protein (CP) content at the Ministry of Livestock and Fisheries' Tanzania Veterinary Laboratory Agency (TVLA) in Temeke District, Dar es Salaam. Milk production was measured with a measurement cup after each milking. Time for different livestock related activities (feed collection, chopping, milking, herding) was measured with a stopwatch, and the household member performing the task was recorded.

2.4 Data analysis

Households with several herds of cattle which were managed and fed differently were analyzed and presented separately. Herd IDs are composed of household number and small letters (a, b, c) which indicate several herds per household.

Feed supplied per individual feed items in FW were summed up to a total amount of feed per day. Total feed supplied per day was then converted into DM, CP and metabolizable energy (ME). Feed parameters were taken from the sample analysis, literature, feed databases and expert knowledge (Table 1). If species from several genus were found (e.g. Amaranthus, Brachiaria, Cynodon and Desmodium), nutritional values were found comparable in all cases and values from one species was picked to represent the mix. Among the cut and carry grasses fed to the livestock there were local grasses that could not be identified, and are presented as "mixed unknown species". Estimation of their feed properties was based on comparable feeds found in the area such as planted grasses and validated with experts. In Babati and Mvomero sites where livestock were grazing and feed intake could not be measured, DM intake was estimated assuming 3% of livestock body weight (BW) under medium quality of natural pastures.

Table 1 Feed parameters for dry matter (DM), crude protein (CP) and ME (metabolisable energy) and their sources as used in the analysis.

	DM	CP	ME	Source
	%	% of DM	MJ/kg DM	
Banana leaves *(Musa spp)*	20.7	9.5	9.9	Feedipedia: https://www.feedipedia.org/node/12458
Bean residues *(Phaseolus vulgaris)*	88.0	7.1	7.4	Feedipedia: https://www.feedipedia.org/node/12006
Brewers' waste	85.0	10.0	12.0	Expert estimation
Comellina *(Comellina benghalensis)*	8.3	13.3	8.6	Sample Lushoto, expert estimation
Cynodon *(Cynodon dactylon, plectostachyus)*	30.6	9.9	8.6	Feedipedia: https://www.feedipedia.org/node/12125
Guatemala grass *(Tripsacum andersonii)*	22.0	8.8	8.4	Feedipedia: https://www.feedipedia.org/node/12169
Maize bran *(Zea mays)*	83.3	11.4	11.0	Sample Mvomero; Feedipedia: https://www.feedipedia.org/node/12280
Maize residues *(Zea mays)*	80.0	1.3	7.6	Sample Babati; Feedipedia: https://www.feedipedia.org/node/12874
Mixed unknown species	25.0	9.1	7.3	Lukuyu *et al.* (2016)
Napier grass *(Pennisetum purpureum)*	15.0	11.0	9.9	Duncan *et al.* (2012)
Natural pasture	25.0	9.1	7.3	Lukuyu *et al.* (2016)
Sugarcane leaves *(Saccharum officinarum)*	28.6	4.0	6.9	Sample Lushoto; Duncan *et al.* (2012)

Actual feed supply is presented as two indicators: Per herd, and per Tropical Livestock Unit (TLU). Livestock body weight (BW) were estimated by extension officers and local researchers per site. BW for adult male and female cross-bred and local cattle varied between 315 kg in Lushoto (lcoal breed not present), 355 and 225 kg in Babati and 330 and 245 kg in Mvomero. BW for the remaining animal classes (heifer, yearling bull, calf) was set proportionate to adult cattle weights (heifer and yearling bull 75% of adult weight, calf 35%). One TLU was defined as 250 kg BW, resulting in different TLU units per livestock class and site.

Current feed requirements were calculated based on Paul *et al.* (2008). According to this study, 6.27 g CP and 0.589 MJ per kg metabolic weight (MW) are required for maintenance, while 82 g CP and 5.023 MJ are required per kg milk produced. The above-mentioned livestock BW and the measured milk production level of the day was used in the calculations. In grazing cattle, ME and CP requirements were increased by 30% and 5% due to higher energy demands of locomotion. The energy requirements of grazing correspond to a median value of various estimations given in Vallentine (1990). Attainable target milk yield levels were set at 5 kg/day/cow for all adult female local breeds and 15 kg/day/cow for all adult female improved breeds, irrespective of their lactation state at the day of measurement (Wassena *et al.*, 2015). Feed requirements for the attainable target milk yield were added to current feed requirements and presented as attainable feed demand, expressed in ME and CP.

Feed gaps were quantified as the difference between attainable feed demand and actual feed supply. We express the relative feed gap in percentage by dividing the feed gap by attainable feed requirement for ME and CP (Figure 1). Positive numbers denote a feed gap, the situation when actual feed supply is insufficient to meet attainable feed demand. Negative numbers indicate a feed surplus when actual feed supply exceeds attainable feed demand.

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3. Results

3.1 Livestock production and feeding systems

Different livestock production systems were present in the three pilot sites (Table 2). Mvomero was the most extensive site, with largest farm areas (average 6.2 ha) and herd sizes (9.7 TLU). In Lushoto, exclusive zero-grazing systems with 1-2 cross-bred cows (1.7 TLU) and relatively small farm sizes (3.2 ha) were dominant, while Babati had a mixture of both systems (3.9 ha, 5.9 TLU). Grazing on both private and communal pastures and cropland was common in Babati, while in Mvomero only communal pastures were used. Grazing took on average between 6.5 – 11 hours a day. Despite the focus on dairy production, only two farmers in Lushoto had lactating cows at the time of data collection, producing on average 2.8 kg/day/cow. Average daily milk production per cow was lower in Babati (2.7 kg/day) and Mvomero (1.5 kg/day). Livestock systems in Babati were most labour-intensive (3.2 h/TLU/day), while the cut-and-carry systems in Lushoto required least labour (1.4 h/TLU/day). Most livestock-related labour was supplied by men, especially for collecting feed and grazing, while women provided almost exclusive care (>95%) for 18% of herds (Table 2).

Table 2 Key data describing the livestock production and feeding systems in the pilot sites in Tanzania. TLU = tropical livestock unit, h = hours, FW = fresh weight.

						Men			Women						
	Type	Herd ID	Farm size (ha)	TLU	Milk production (kg/herd/day)	Collecting (h/day)	Chopping (h/day)	Grazing (h/day)	Collecting (h/day)	Chopping (h/day)	Grazing (h/day)	Total labour per herd (h/day)	Total labour per TLU (h/day)	Total labour per feed supplied (h/100kg FW/day)	Female labour (% of total labour)
Lushoto	Small	1	1.8	2.2	0	0	0	0	0	1.0	0	1.0	0.5	1.4	96
		2	1.2	0.9	0	2.0	0.5	0	0	0	0	2.5	2.6	6.7	0
	Medium	3	1.5	1.7	6.3	3.5	0	0	0	0	0	3.5	2.1	2.3	0
		4	4.5	2.2	2	1.7	0	0	0	0	0	1.7	0.8	2.0	0
		5	4	1.3	0	0.6	0.1	0	0.8	0	0	1.5	1.2	2.0	56
	Large	6	2.6	2.5	0	1.1	0	0	0	0	0	1.1	0.4	0.5	0
		7	6.7	0.9	0	2.1	0.1	0	0	0	0	2.1	2.2	3.1	0
		8	3.2	2.2	0	0	0	0	3.1	0	0	3.1	1.4	4.2	100
Babati	Poor	9a	2.1	4.5	1.3	0	0	8.2	0	0	0	8.2	3.7	8.7	0
		9b	ibid	4.7	13.1	3.9	0	0	2.7	0	0	6.5	5.2	16.9	41
		10	1.6	4.5	0	0	0	8.4	0	0	0	8.4	4.9	16.3	0
		11	1.2	9.1	1.2	0	0	9.8	0	0	0	9.8	3.9	16.5	0
		12	2.4	9.2	0	0	0	8.8	0	0	0	8.8	7.0	29.7	0
		13	0.8	5.9	0	0.1	0	6.5	0	0	0	6.6	2.6	8.3	0
	Large	14	12	2.6	4.4	0	0	0	0	0	11.0	11.0	8.7	32.7	100
		15	3.9	2.9	4.0	0	0	9.0	0	0	0	9.0	4.1	12.7	0
		16	11	13	4.7	0	0	9.5	0	0	0	9.5	2.1	6.4	0
	Dairy	17a	2	4	1.0	3.5	0.3	0	0.1	0	0	3.8	0.8	2.2	2
		17b	ibid	1.4	7.1	4.5	0.3	0	0	0	0	4.8	1.1	3.6	1
		17c	ibid	6.4	0.9	0	0	10.9	0	0	0	10.9	1.2	4.0	0
		18a	4	8.2	0	0	0	0	1.0	0	0	1.0	0.1	0.3	100
		18b	ibid	9.7	0	0	0	9.4	0	0	0	9.4	1.6	4.3	0
		19	2	2.8	0	1.2	0	0	0	0	0	1.2	0.4	1.0	0
Mvomero	Small	20	0.1	1.8	6.0	0	0	0	1.0	0	0	1.0	0.3	1.2	100
		21a	3.2	2.6	6.8	0.8	0	0	0	0	0	0.8	0.1	0.2	0
		21b	ibid	1.9	0	1.3	0	0	0	0	0	1.3	0.3	1.3	0
	Medium	22	1.2	8	1.5	0	0	8.0	0	0	0	8.0	5.6	13.5	0

Type	Herd ID	Farm size (ha)	TLU	Milk production (kg/herd/day)	Men: Collecting (h/day)	Men: Chopping (h/day)	Men: Grazing (h/day)	Women: Collecting (h/day)	Women: Chopping (h/day)	Women: Grazing (h/day)	Total labour per herd (h/day)	Total labour per TLU (h/day)	Total labour per feed supplied (h/100kg FW/day)	Female labour (% of total labour)
Large	23	0.1	15	7.0	0	0	8.5	0	0	0	8.5	1.3	4.4	0
	24	21	6.8	7.0	0	0	7.0	0	0	0	7.0	0.9	5.3	0
	25	0.4	8.3	1.0	0	0	8.5	0	0	0	8.5	0.9	2.9	0
	26	18	25	4.5	0	0	8.3	0	0	0	8.3	2.9	10.1	0
	27	9.3	19	6.5	0	0	9.0	0	0	0	9.0	5.1	21.0	0
	28	2.4	7.9	0	0	0	0	0	0	9.0	9.0	3.4	15.1	100

Feed in Lushoto was exclusively supplied as cut-and-carry, while in Mvomero grazing dominated except among small farmers. Only in Babati some farmers kept two separate herds of local grazing cattle and cross-bred zero-grazing cattle (Figure 4). Total daily DM supplied per TLU varied per site, from average 12.6 kg DM in Lushoto to 10.5 kg DM in Babati and 7.3 kg DM in Mvomero. The bulk of feed in all sites (Lushoto 51.3%, Babati 58.2%, Mvomero 94.7%) originated from natural vegetation either grazed or cut-and-carry. Planted forages only constituted 3.8 and 4.2% in Babati and Mvomero respectively, and 31.2% in Lushoto, with Napier grass (*Pennisetum purpureum*) being the most common species. Maize and to a lesser extent bean residues and banana leaves were important feeds in Babati (35.5%) and Lushoto (16.4%), while no residues were fed in Mvomero. Less than 3% of total feeds were local concentrates, with brewers' waste (millet and wheat remains of local beer brewing) in Babati, and maize bran in Lushoto (Figure 4).

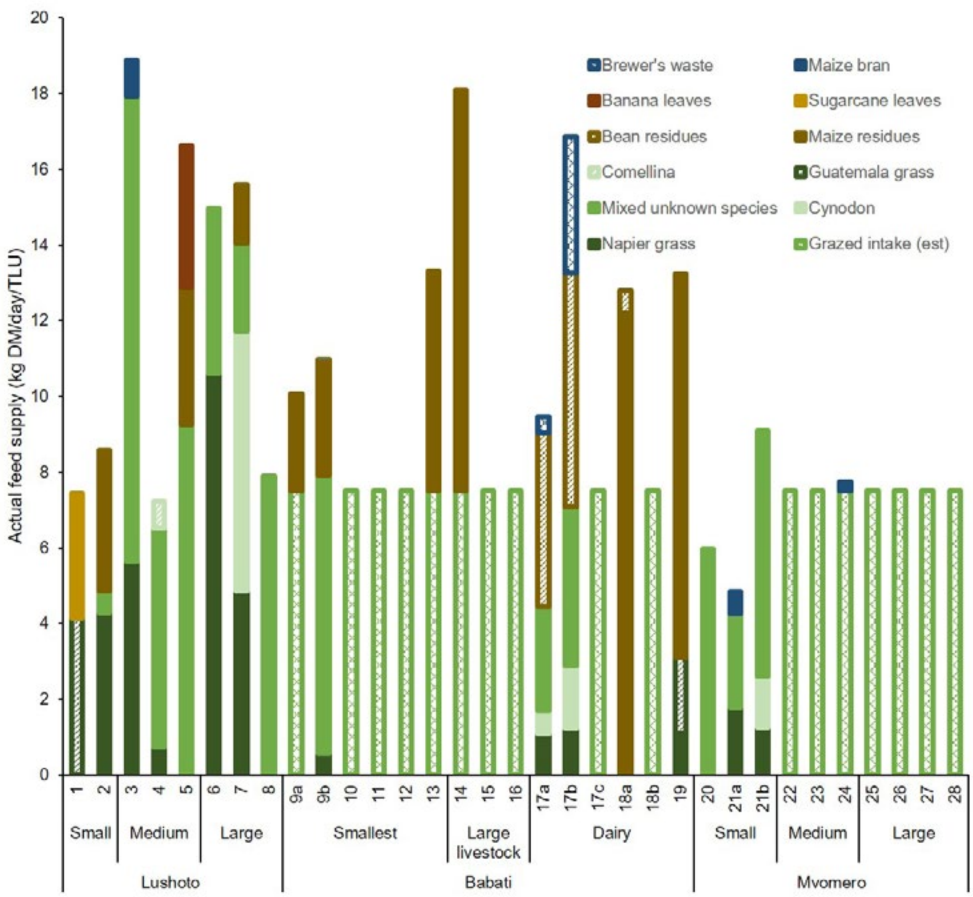

Figure 4 Dry matter (DM) of actual feed supply per day and Tropical Livestock Unit (TLU) to individual herds across individual farms. Numbers on x-axis denote herd IDs. In green colours all green forages (darker green planted forages, medium green grazing natural pastures, and light green natural grasses cut-and-carry), brown colours crop residues, and blue colours commercial feeds.

ME and CP of actual feed supplied was compared to calculated livestock requirements under current production levels (Figure 5). 90.9% of the herds were supplied with more ME and CP in their feed than they currently require (Figures 5a, 5b). Two herds in Mvomero provided less ME and CP than currently required, while two different herds in Babati were insufficiently fed with ME or CP. Farmers in Lushoto all supplied more ME and CP than required under current milk production levels (Figure 5).

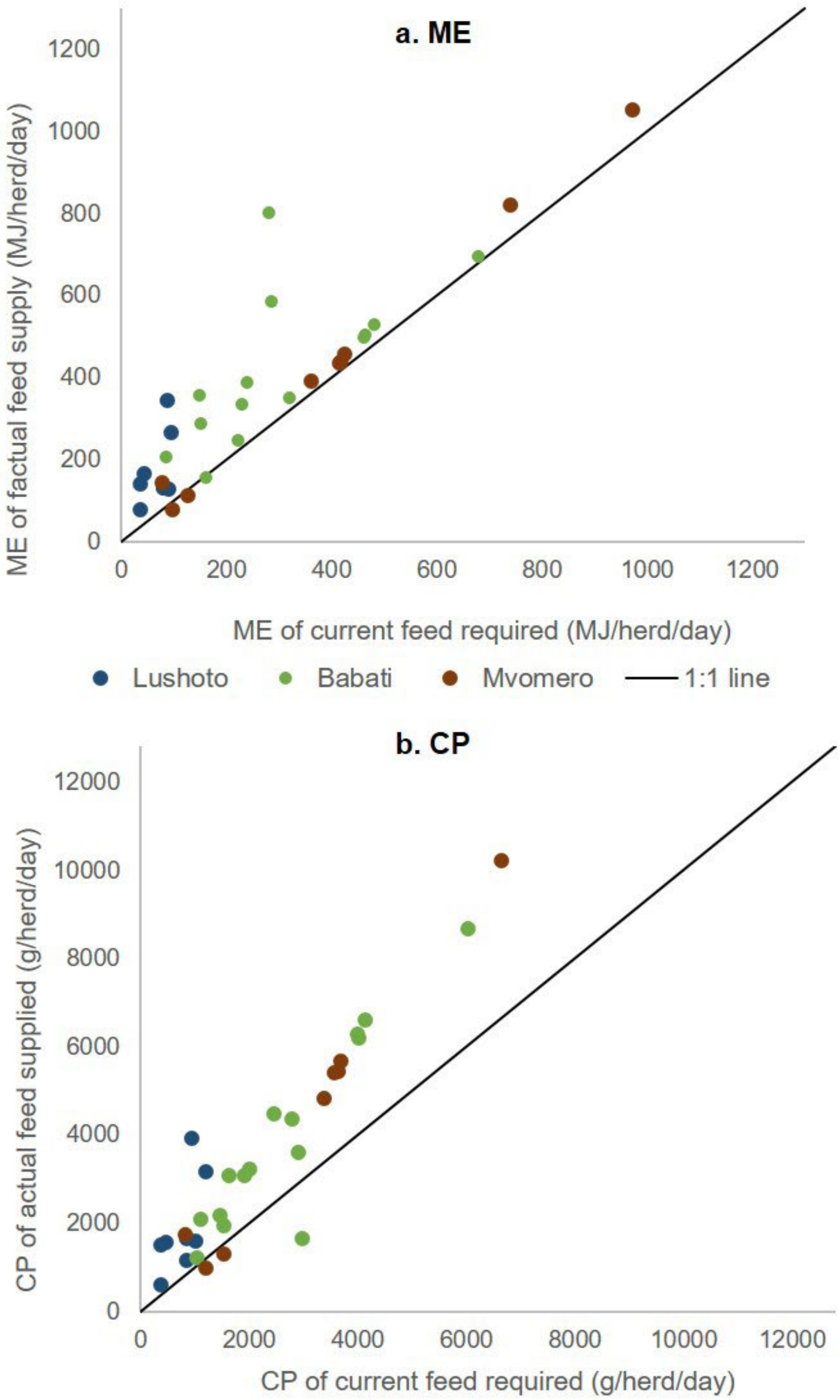

Figure 5 Actual feed supply versus calculated current feed requirements at the actual production level in ME (metabolisable energy) (a) and CP (crude protein) (b) per TLU (Tropical Livestock Unit) and day across the three sites. The line represents 1:1, where ME and CP in actual feed supply corresponds to calculated feed requirements.

3.2 Feed gaps

ME and CP of actual feed supplied to cattle herds was compared to attainable feed demand, the calculated ME and CP requirements under attainable milk production levels (Figure 6). Overall, the ME feed gap was -20.6% and CP -9.5, thus total feed supplied across sites would suffice to satisfy cumulative attainable feed demand. However, 61% of herds in all sites faced a ME feed gap, and 55% a CP feed gap. Feed gaps differed per site, with most herds facing a feed gap in Mvomero (90% ME, 70% CP) (Figure 6c) and the fewest in Lushoto (38% ME, 50% CP) (Figure 6a). In Babati, two herds (herd IDs 18a, 19) had no ME but large CP gaps due to low feed quality provided (predominantly maize and bean residues) while having several adult non-lactating cows (Figure 6b). Only 24% of herds did not have any ME nor CP feed gap (Figure 6).

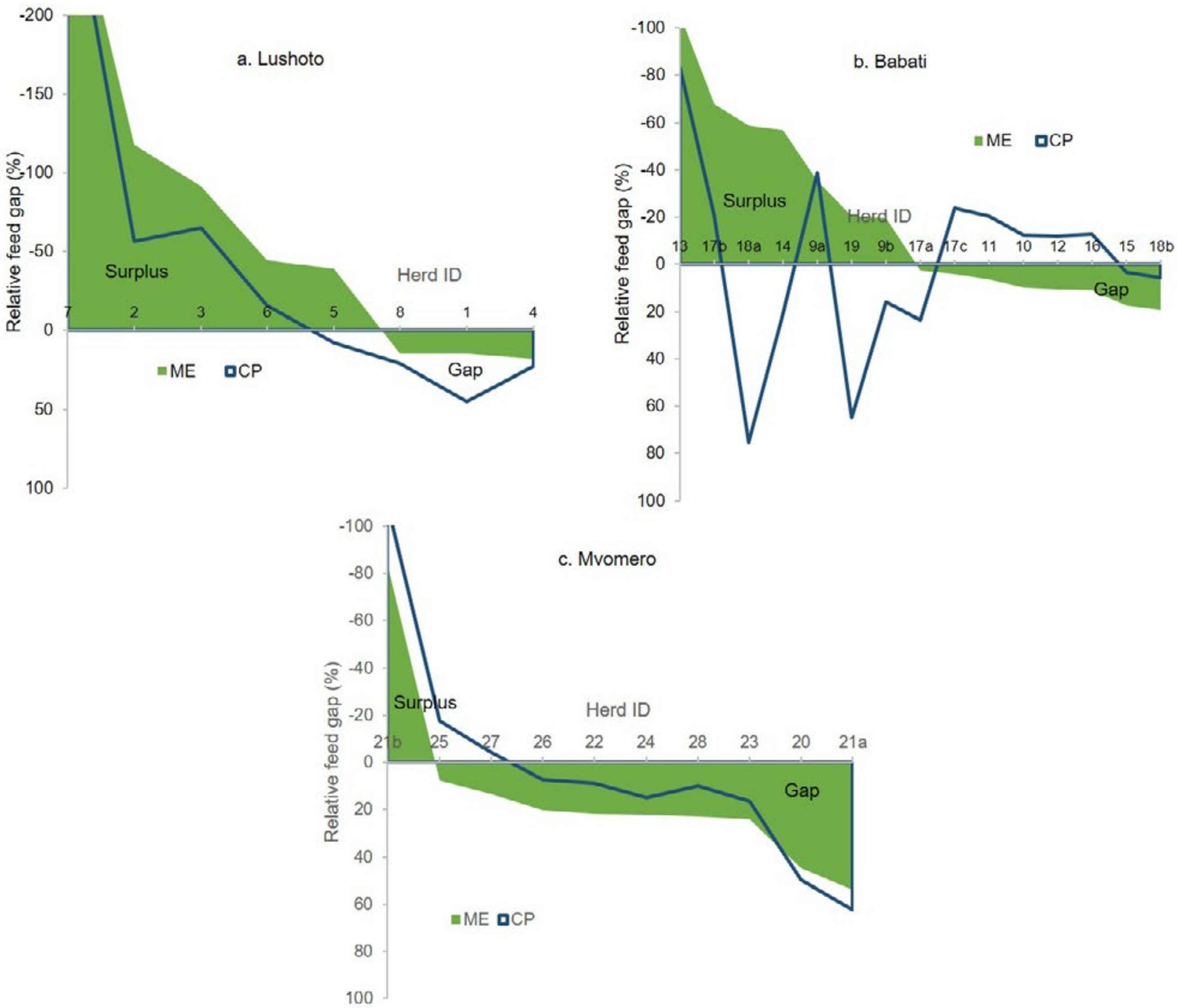

Figure 6 Relative feed gap in metabolisable energy (ME) and crude protein (CP) for herds in Lushoto (a), Babati (b) and Mvomero (c). Positive numbers denote a feed gap, the situation when actual feed supply is insufficient to meet attainable feed demand. Negative numbers indicate a feed surplus when actual feed supply exceeds attainable feed demand. Herds are sorted on x-axis from smallest to highest ME gap.

4. Discussion

4.1 Feeding systems and feed gaps in East Africa

Pilot evidence from three sites in Tanzania provided insights into feeding systems and feed gaps in East Africa. As hypothesized, the research sites were positioned on a gradient of feeding intensification (Figure 3). Natural vegetation continued to play an important role in livestock's diet in both grazing and cut-and-carry systems. However, their future supply is not guaranteed with continued privatization of land and increasing population densities. Planted forages constituted considerable part of the feed basket only in Lushoto, while supplementary feeding with purchased feed was not common and only occasionally provided in Babati and Lushoto. Residue feeding was more common in Babati where farm sizes are comparably large and mechanized agriculture is present. In general, a diverse feed basket seems to be a consequence as well as a necessity in smallholders mixed crop-livestock systems. During the dry season, the variety of the feed baskets is likely to be even higher as smallholders are struggling to find sufficient feed (Lukuyu *et al.*, 2011).

The trend towards livestock intensification, away from agro-pastoral systems towards (semi)-intensive crop-livestock systems to maximize use of scarce resources, has been observed across East Africa. Intensification in this context refers to increasing the output per animal and labour unit through increased use of inputs or change of management techniques. In the Kenyan highlands for example, over three-quarters of the smallholder dairy farms already fall under semi-intensive or intensive systems. Various factors influenced this intensification: if land was limiting, more farmers moved towards stall-feeding systems, while grazing was predominant if labour was scarce. In general, increasing population density, market access, conducive policies and favourable agro-ecology have been identified (Bebe *et al.*, 2002; Lukuyu *et al.*, 2011). However, the mix of systems in Babati suggests that the transition towards feeding intensification is not as gradient as presented in Figure 3, but rather a switch or entire re-organization of production systems (Green, 2017).

Most on-farm cattle-related labour was provided by men in this pilot study, not only for grazing but also for fetching feed in cut-and-carry systems. Elsewhere, livestock-related decision-making and labour in Tanzania has been reported to be strongly gendered. Cattle tends to be a male asset, and men tend to care for cattle in terms of grazing, buying/selling, and veterinary treatment. Women mostly took care of the dairying aspect of cattle, including sometimes even control over income from milk (Galiè *et al.*, 2018). Systematic and reliable labour data is however hard to come by as it often collected through survey, and difficulties to recall make farmer-reported labour data error-prone. Questions on gender distributions of labour suffer in addition from socially-desired responses. Comprehensive data from Africa suggests that women's share of labour is rather around 50% in Tanzania instead of the often assumed 60-80% (Palacios-Lopez, 2016). The cut-and-carry systems in Lushoto required less labour per farm and TLU than the mixed systems in Babati and grazing systems in Mvomero. However, this does not depict the difference in type of labour, with fetching feed being more physically demanding labour than grazing.

61% of herds in all Tanzanian sites faced a ME feed gap, and 55% a CP feed gap. However overall, total actual feed supplied across all sites and herds would suffice to satisfy the cumulative attainable feed demand. Fewest herds faced a feed gap in Lushoto (38% ME, 50% CP), although it is important to take into account that actual feed supplied is considerably reduced through high feed losses due to poor cattle housing and feeding techniques under zero-grazing. In the dry season, when feed availability is more constrained, the ME gap is likely to be much wider calling for quantity-focused technologies such as drought-resistant planted forages or forage conservation techniques. In Babati, two herds had no ME but large CP gaps due to low feed quality provided (predominantly maize and bean residues), pointing to the need for higher quality feed such as forage legumes or purchased supplements. 24% of herds did not experience a feed gap, meaning that feed quantity and quality were not limiting the production. Other yield limiting factors such as lack of sufficient drinking water provision, or reducing factors such as diseases, might be the reason (van der Ven *et al.*, 2003).

Possible causes for such persisting feed gaps are manifold. Farmers are not always primarily aiming at closing yield gaps and therefore could decide not to adopt improved technologies. Sumberg (2002) argued that low adoption of improved livestock nutrition technologies may not be due to poor communication or extension services but farmers that prioritize other economic, cultural and social aims over productivity increase. Policies including subsidies can also act as disincentive to maximization of production. In Tanzania, cattle are not necessarily kept to maximize income, but also perceived as a safe way to store wealth, currency for dowries, risk management strategy, status symbol as well as means of transport and draft power (Galiè *et al.*, 2018). Therefore, Snyder *et al.* (2016) argue to include into yield gap analysis the wider social, economic and political context that shapes farmers' decisions.

4.2 Assessing feed gaps – approaches and future improvements

This study aimed to introduce a quantitative approach to assessing smallholder dairy feeding systems and feed gaps in data-scarce environments, which was illustrated using pilot evidence from Tanzania. The approach complements other approaches, which are more time, data and resource demanding. Van der Ven *et al.* (2003) and van der Linden *et al.* (2015) provided the theoretical foundation for livestock yield gap analysis by applying production ecology concepts. In contrary to this study that focusses on feed only, they include various growth defining (genotype, climate), growth limiting (feed, water), and growth reducing (diseases, stress) factors. Based on these principles, the dynamic LiGAPS-Beef model was developed using daily climate data, which can be seen as analogous to mechanistic crop models in data requirements, functionality and detail of results (van der Linden *et al.*, 2018). Henderson *et al.* (2016) and Mayberry *et al.* (2017) worked with a combination of household and livestock models with a more limited data demand. However, as these studies mainly rely on survey data complemented with expert opinion, assumptions are made on supplied feed quantities supplied. Common farming systems surveys (e.g. ImpactLite, https://ccafs.cgiar.org/impactlite-tool) often leave out planted and collected forages and focus on residue feeding and grazing. If dedicated feed surveys are available (such as FEAST, https://www.ilri.org/feast), they mostly rely on farmer recall data for feed baskets which is sufficient for participatory technology testing and research, but of limited use for productivity and environmental estimations. The approach of Moore *et al.* (2009) and Bell *et al.* (2017) is similar to this study in taking a relatively simple demand versus supply approach. However, they rely on long-term simulations of a variety of forages to identify the time during the year where forage supply cannot meet livestock demand. The lack of quantitative survey data on feed baskets as well as the lack of large agronomic datasets for multiple model calibration makes it challenging to apply the existing approaches to data-scare smallholder environments. The feed gap approach piloted in this study can work where such data is not available as it is based on relatively simple calculations without time, data and resource-intensive calibration of multiple models. However, on-farm feed measurements would have to be repeated as needed, but at least a few times a year to capture seasonal variations.

Deviations, both positive and negative, between actually supplied ME and CP and calculated current feed requirements (Figure 5) point to uncertainties in underlying data and calculations. On the livestock requirement side, exact body weight was not measured, and temporary weight gain and loss was not taken into account. On the feed supply side, varying storage time of feeds might lead to different DM contents of the same feeds between different feedings and farms, leading to uncertainties in conversions to total ME and CP contents. Moreover, feed losses in smallholder zero-grazing systems might be high, up to 30-50% of total feed. Lastly, the intake through grazing and the quality of natural vegetation fed under grazing or cut-and-carry is unknown and challenging to estimate. Lukuyu *et al.* (2016) found a high variability when testing the quality of natural vegetation used as feed across Tanzania.

Methods to quantify feeding systems and feed gaps for smallholder systems and data-scarce environments such as in East Africa are currently lacking. Therefore, the approach presented in this paper complements other approaches, which are more time, data and resource demanding. Suggestions for future improvements of this approach include: a) Conduct a sensitivity analysis to identify the parameters and inputs that contribute most to output uncertainty and that would merit dedicated follow-up research; b) Include seasonal variability of feed gaps through monitoring feed supplied across different wet and dry seasons; c) Reduce uncertainty in actual feed supply estimations by increasing empirical verifications of DM content throughout the day, and measuring quality of natural pastures at various points across seasons; d) Reduce uncertainty in livestock requirement calculations by basing the grazing estimations on production values, improving how locomotion is being accounted for, empirically verifying livestock BW, and including requirements for BW changes.

Farmers in Lushoto are working with researchers to test different forage varieties like Brachiaria for yield and drought resilience. Livestock farmers in the district of Lushoto, in the Tanga region of Tanzania, are finding ways of boosting their production and lowering their environmental impact by planting improved forages. Georgina Smith/Alliance of Bioversity International and CIAT

5. Conclusions

Feed is a critically limiting factor in productivity of smallholder dairy systems in East Africa. This study aimed to introduce and provide proof-of concept for a relatively simple approach to quantify feeding systems and feed gaps in data-scarce smallholder systems, comparing feed demand and supply at the individual herd level. The approach was illustrated with pilot evidence from crop-livestock production systems across three agro-ecological zones in Tanzania, which broadly represent the diversity found in East Africa.

A diversity of different livestock and feeding systems along an intensification gradient were present in the three study sites in Tanzania. Mvomero was the most extensive site, with largest farm areas, herd sizes, and communal grazing systems. Lushoto was dominated by cut-and-carry feeding of small crossbred dairy herds and small land sizes. Babati represented a mixture of both systems that were present concurrently. Natural vegetation contributed the largest part to cattle's feed baskets in both grazing and cut-and-carry systems, while planted forages only played a significant role in Lushoto. Grazing systems were more labour intensive per TLU than cut-and-carry systems. Most labour for feeding was provided by men, which contrasts findings from other studies in the region. Although the trend seems to go towards intensifying feeding systems, the co-existing mix of systems however suggests that the transition might be less gradient than commonly suggested.

61% of all herds faced an ME feed gap, and 55% a CP gap between actually supplied feed and calculated requirements at attainable milk production levels. Feed gaps were more prevalent in Mvomero than in Lushoto, although feed losses are likely to be high (up to 30-50%) in cut-and-carry systems. 24% of herds did not experience a feed gap, and other yield limiting factors (e.g. lack of sufficient drinking water provision) or reducing factors (e.g. as diseases) might be the reason for the low milk production levels. Possible causes for persisting feed gaps are manifold, and include the importance of multi-functionality of livestock in Tanzania. Farmers might not primarily aim at closing feed gaps and maximizing production, but prioritize other functions such as risk management and wealth storage.

Methods to quantify feeding systems and feed gaps for smallholder systems and data-scarce environments such as in East Africa are currently lacking. Therefore, the approach presented in this paper complements other approaches, which are more time, data and resource demanding. Suggestions for future improvements of this approach include: a) Conduct a sensitivity analysis to identify the parameters and inputs that contribute most to output uncertainty and that would merit dedicated follow-up research; b) Include seasonal variability of feed gaps through monitoring feed supplied across different wet and dry seasons; c) Reduce uncertainty in actual feed supply estimations by increasing empirical verifications of DM content throughout the day, and measuring quality of natural pastures at various points across seasons; d) Reduce uncertainty in livestock requirement calculations by basing the grazing estimations on production values, improving how locomotion is being accounted for, empirically verifying livestock BW, and including requirements for BW changes.

A good handle on current feeding practices and feed gaps is necessary to dissect key issues and factors currently limiting livestock production in a smallholder farming context. Governments, private sector, development agencies and donors can use approach and insights presented to prioritize feeding technologies and target investments. Results can also inform and validate modeling approaches that require detailed feed baskets.

Acknowledgements

This work has been supported by the German Federal Ministry for Economic Cooperation and Development (BMZ), funding the project 'Potential farm to landscape impact and adoption of forage technologies in smallholder dairy systems in Tanzania' [Contract C-151-15]. The contribution of JCJG was supported by the Africa RISING project that was funded by the United States Agency for International Development (USAID) [AID-BFS-G-11-00002] as part of the US Government's 'Feed the Future' Initiative. This study was undertaken under the CGIAR Research Program on Livestock, which is carried out with support from the CGIAR Fund Donors and bilateral funding agreements. The funders had no involvement at any stage of the research process. John Mutua (CIAT) assisted with mapping and characterizing the research sites, and José Luis Urrea Benitez with design of the conceptual graphs. The help of extension officers in data collection is acknowledged: Anna Roman and Gilbert Mbesere in Babati, and Space Komba and Theobald Marcel in Mvomero. Thanks to all participating farmers for their willingness to provide time and information.

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