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REGULAR ARTICLES

Seasonal variations in the availability of fodder resources and practices of dairy cattle feeding among the smallholder farmers in Western Usambara Highlands, Tanzania

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Abstract

The aim of this study was to assess the seasonal effects on quantity and quality of fodder resources and associated utilization practices among smallholder dairy farmers in Western Usambara Highlands (WUHs) in Tanzania. The WUHs are among the major milk producing areas under smallholder dairy farming systems (SDFS) in Tanzania. Dry season fodder scarcity is a widespread problem affecting the East African SDFS and has been shown to contribute to over 40% reduction in milk yield. There is limited information with regard to seasonal fodder fluctuation and its effects on productivity of dairy cows in different landscape levels of Tanzania. Field and household surveys were conducted in 150 dairy cattle farming households from five villages in three wards located in WUHs. Survey data were analyzed using IBM SPSS version 21. In addition, remote sensing techniques were employed on gap-filled and smoothed Landsat data to generate land cover maps and bimonthly normalized difference vegetation index—time series for the 2009–2016. SDFS landscape was highly heterogeneous typified by crops, bushes, and forests. On average, the household landholding was 1.3 ha, while herd size was three cattle. About 87% of household land was devoted to crop growing with limited pasture along the farm margins and contour strips. Fodder scarcity was the major challenge during the dry season (July to October) as indicated by 87% of the respondents. On-farm fodder resources contributed most of the cattle diet (73%) while rangeland, forest, and purchased feed provided small amount. Natural pasture and napier grass (*Pennisetum purpureum*) were the most important feeds in wet season while maize stover was most significant during the dry season. Maize stover was profusely stored for dry season feeding and neither silage nor hay making was practiced. The nutritional values of the fibrous feeds declined during the dry season, whereby the metabolizable energy and crude protein contents were 6.0 MJ/kg and 10.1% dry matter, respectively, during wet season compared to 4.8 MJ/kg and 7.8% dry matter, respectively, during the dry season. Consequently, milk yield drops from 5.6 l per cow per day in the wet season to 3.0 l in the dry season. It is concluded that dry season fodder scarcity is a major problem in the WUHs and it hinders sustainable dairy production. It is therefore suggested that increase in fodder production as well as adoption of fodder conservation and feeding technologies are

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inevitable if sustainable dairy production is to be met in the Western Usambara Highlands and elsewhere with similar environments.

Keywords Smallholder dairying · Feed availability · Milk yield · Land cover · Lushoto · Tanga

Introduction

There are approximately 150 million smallholder dairy farming (SDF) households (hh) worldwide, which employ about 750 million people, mostly in developing countries (FAO 2010). Moreover, the smallholder dairy farming systems (SDFS) in these countries particularly in South Asia, South America, and sub-Saharan Africa contribute significantly to the global milk production. For example, India and Pakistan alone provide around 23% of the global annual milk yields and most being produced under SDFS (FAO 2010). Smallholder dairy farms are characterized by (i) small landholdings (< 2 ha), (ii) few number of cattle (1–3 dairy cows), and (iii) modest daily milk yield per farm averaging 11 l (FAO 2010). In addition, under SDFS, family labor is a vital element and the use of modern technology such as tractors and milking machines is uncommon. The key components of SDFS's cattle diet are on-farm feed resources including pastures, crop residues, fodder trees, and agricultural by-products. Usually, fodder resources are extracted from the fields and carried to the animals (i.e., cattle, goats, or buffalo) kept in stables at the farmers' homestead (Herrero et al. 2010). Nevertheless, SDFS are characterized as rain-fed, low-input-low-output production systems and are regarded as very sensitive to precipitation and temperature fluctuations.

In Tanzania, dairy farming has been mainly adopted by smallholder farmers in densely populated high rainfall areas such as highlands, where crops, few livestock, timber, and fruit trees are integrated into small land units. Most smallholder farmers rely on on-farm resources for feeding their livestock, often fluctuating seasonally both in terms of quantity and quality (Lukuyu et al. 2016). In these communities, fodder is usually plentiful during the wet season, often exceeding animal requirements, but scarce in the dry season. At times of fodder scarcity, most smallholder farmers are forced either to purchase fodder and concentrates to supplement their animals or to just underfeed them with available feeds. Both cases are challenging such that when purchasing of animal feeds is unaffordable, the majority of smallholder farmers underfeed the animals with available resources resulting in a reduction of productivity (Lukuyu et al. 2015). For example in Tanga region, Tanzania, Cadilhon et al. (2016) reported variation in daily milk yields of 8 l during the wet season and 4 l in dry seasons.

The Western Usambara Highlands (WUHs) are mountains range located in north eastern Tanzania and are among the major milk-producing areas under SDFS in Tanzania. Like other SDFS in developing countries, WUHs face the challenge of fodder seasonality. However, there are little data available with regard to seasonal fodder fluctuations in these landscapes and little is known on how to respond to these challenges. Certainly, without reliable data on seasonal fodder production, it is unattainable to estimate livestock carrying capacity. Likewise, it is challenging to plan for the quantity of forage which should be conserved in terms of hay, silage, stover, or straw for dry season feeding.

This study was set with the aim of characterizing the fodder production and performing land cover classification in the key SDF areas in WUHs. The information gathered is beneficial to a range of stakeholders, including dairy farmers, land planners, and policy makers. In particular, the information is essential for informing decisions aiming at fostering sustainable dairy production in WUHs and other places with similar environments.

Materials and methods

Description of the study area

The WUHs are located at latitudes 4° 38′ S and 4° 53′ S and longitudes 38° 14′ E and 38° 22′ E (Fig. 1) in the administrative districts of Lushoto and Bumbuli, Tanga region, north eastern Tanzania. Elevation of the WUHs ranges between 1200 and 1800 m above sea level (a.s.l) or an average of 1498 m a.s.l, resulting in a tropical savanna climate (Rubel and Kottek 2010). Three wards in the WUHs, namely Shume, Ngulwi, and Mbuzii, were selected for this study; the wards were selected based on the highest adoption of dairy cattle farming (Fig. 1).

The WUHs experiences bimodal rainfalls in which long rainfalls occur between March and June, while the short rains take place between late October and December. The average annual precipitation is around 1100 mm, while average temperature is 17 °C (Fig. 2). This climate supports production of various crops including maize, banana, beans, fruits, and vegetables. Moreover, the WUHs are an ideal area for intensive mixed smallholder farming involving crop and highly productive livestock species such as dairy cattle and goats.

The total number of cattle in 2016 was reported to be 85,846 of which 22,846 were dairy cattle. The dairy cattle are predominantly crosses of Friesian or Ayrshire breeds with the indigenous Tanzania Shorthorn Zebu cattle. Other livestock species in the district included goats (79,614), sheep

Fig. 1 A section map of Western Usambara Highlands (WUHs) showing the study sites (Shume, Ngulwi, and Mbuzii wards) in Lushoto and Bumbuli districts, Tanga region, Tanzania. The base map (elevation) was obtained from the globe map datasets namely ASTER GDEM V1

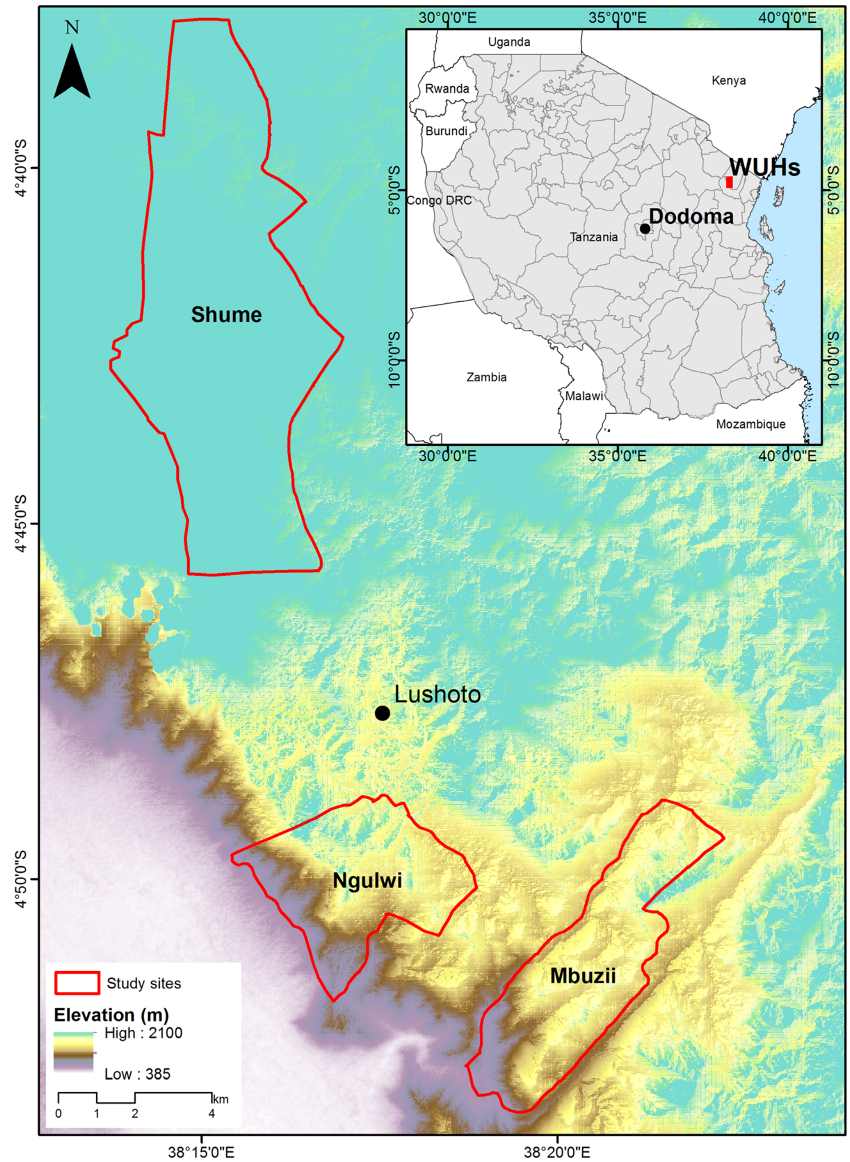
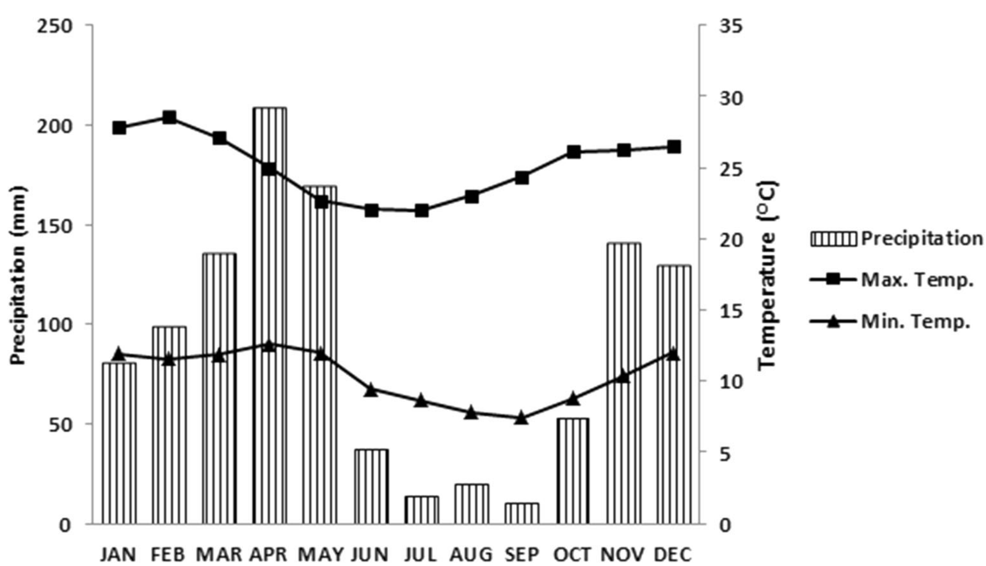


Fig. 2 Average monthly precipitation and temperature between 2006 and 2016 in West Usambara Highlands, Tanga, Tanzania (source: Lushoto District Council 2017)



(68,573), pigs (3634), and chickens (435,000) (The data were obtained from Lushoto District Council office in 2017). Essential established fodder grass species in the district include napier (*Pennisetum purpureum)* and guatemala (*Tripsacum laxum*). The aforementioned grass species are widely grown around farm borders and along contour strips. Apart from fodder provision, these grass species also reduce soil erosion and surface runoff in steep slopes (Mwango et al. 2014).

Household survey

A cross-sectional design was employed in this study whereby a structured questionnaire was administered to respondents, representing 150 hh picked from the three wards. The questionnaire was first scrutinized in five smallholder dairy farming hh before the actual hh survey. In the study wards, a total of five villages (the smallest units of administration) were selected for conducting hh interviews. The villages were Viti and Hambalawei (Shume ward), Ngulwi and Bombo (Ngulwi ward) in Lushoto district, and Mbuzii village (Mbuzii ward) in Bumbuli district. Moreover, the criteria for enrolling hh into the study included possession of at least one dairy cow and dairy farming experience of minimum 3 years. Therefore, hh satisfying the aforementioned criteria were randomly selected using the village residence list obtained from the village government offices. The maximum number of hh enlisted for the survey was 30 based on the criteria developed by Angelsen et al. (2012). In a village with 100 to 500 hh, a sample size of 25 to 30 hh is adequate for meeting the assumptions of basic statistical tests. The IBM Statistical Package for the Social Sciences (SPSS) program version 21 (IBM Corp 2013) was used to manage and analyze the collected data. Descriptive statistics including frequencies, means, and percentages were generated. Moreover, the independent *t* test also found in IBM SPSS 21 was used to test the effect of fodder seasonality and feeding related parameters including fodder availability and milk productivity. One way analysis of variance in IBM SPSS 21 was used to test the effect of location (wards) on some selected parameters (family, farm and cattle herd size, and fodder yields).

Quantification and chemical analysis of fodder resources

The above ground dry matter (DM) yield (DM kg/ha) of natural and improved pastures (grass, herbaceous legumes, and forbs) was estimated according to the procedures described in Crowder and Chheda (1982). The systematic random sampling techniques were employed in which a line transect was established across fodder plots/fields, and along fodder lines for napier and guatemala grass strips, and natural grasses in public lands. Five representative sampling sites for each fodder species were surveyed in each study village. The length of line transect was defined by farm or strip size (length and width) in which the total distance across the center of the farm or strip was divided by 3 to generate 3 spots where a 0.25-m^2 quadrant metal frame was placed for destructive sampling. Within the quadrant frame, the forage was cut using a sharp bush knife at 5 cm above the soil surface. Thereafter, the harvested forage was weighed to get the total fresh weight. Sub-samples of about 0.5 kg (fresh weight) were packed in labeled paper carrier bags then weighed immediately to get sample fresh weight. Thereafter, the sub-samples were oven dried at 80 °C to constant weight for DM content determination. The univariate general linear model in IBM SPSS 21 was used to test the interactions effects between location (wards) and seasons (wet and dry) on fodder yields.

In addition, mixed fodder samples (average 500 g) were collected at 15 farms (3 farms in each of the 5 study villages) in both dry (October 2016) and wet (May 2016) seasons for analyses of nutritive values. The maize stover DM yields were estimated in similar farms following the procedures described by Mussa (1998). The chemical composition of the samples was analyzed at the Analytical Animal Nutrition Laboratory of Sokoine University of Agriculture (SUA) located in Morogoro, Tanzania. Crude protein (CP), ether extract (EE), and ash contents were determined according to the standard procedures of AOAC (1990). In vitro dry matter digestibility (InvDMD) and in vitro organic matter digestibility (InvOMD) were determined according to Tilley and Terry (1963). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to the Van Soest et al. (1991). Calcium (Ca) was determined by a UNICAM 919 atomic absorption spectrometer (AAS). Phosphorus (P) was analyzed by calorimetric method using a PU 8620 UV/VIS/NIR spectrophotometer in accordance with AOAC (1990), and metabolizable energy (ME) was calculated by the formula (Eq. 1) by MAFF (1975).

$$\mathrm{ME} = \frac{\mathrm{InvDMD} \times (100-\mathrm{Ash}\%)}{100} \times 0.15 \tag{1}$$

NDVI time series analysis

The normalized differentiated vegetation index (NDVI) as proposed by Rouse et al. (1974) is the most applied vegetation index for remote sensing. Its effectiveness for fodder and biomass monitoring in combination with livestock keeping has been described by Kawamura et al. (2005). To obtain high-quality time series, for the generation of the vegetation indices, the smoothing and gap-filling algorithm as proposed by Vuolo et al. (2017) was applied. This method utilizes the entire Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) Climate Data Records (CDR) archive, i.e., Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+), and Operational Land Imager (OLI) to generate bimonthly cloud-free time series of Landsat like Earth Observation (EO) products, at 30-m spatial resolution and covering 6 spectral bands, namely red, blue, green, near infrared 1, near infrared 2, and shortwave infrared (SWIR). Cloud-free input data covering the period from 2008 to 2016 were used to create a temporal stack. Miss data (i.e., pixel affected by cloud cover or no observations) were replaced by pixel derived from a series of templates, which were smoothened using the state-of-art Whittaker smoother (Atzberger and Eilers 2010). This method allows the creation of bimonthly reflectance outputs, mostly free from clouds, cloud shadows, or the scan-line corrector (SLC)-off striping effects. Finally, the smoothed and gap-filled data was used to generate the NDVI using the formula (Eq. 2), by Rouse et al. (1974).

$$\mathrm{NDVI} = \frac{(\mathrm{NIR}-\mathrm{VIS})}{(\mathrm{NIR}+\mathrm{VIS})} \quad (2)$$

Land cover classification

Two images from the EO time series (wet season April 2017 and dry seasons October 2016) were selected to perform a land cover classification. These two images, including the NDVI, were used as input features in a random forest (RF) classifier presented by Breiman (2001), and implemented in the R package "randomForest" version 4.6-12 by Liaw and Wiener (2002). RF is a high-performance state-of-the-art machine learning algorithm, based on an ensemble of decision trees, and numerous papers describe its successful applications (Immitzer et al. 2012; Meroni et al. 2016; Ng et al. 2016a, b). The classification results were validated by applying a tenfold cross validation (Kohavi 1995), where the reference dataset was split into training (90%) and validation (10%). The classification and validation were automated by using a script developed in the open source statistical software R version 3.2.3 (R Core Team 2015). Based on the land cover classification, the two main land cover types (smallholder farms and bushland/forest) were selected for comparison. Ten random points per class within each study site were empirically selected and a time series analysis was performed on extracted NDVI values of 2009–2016.

Secondary data

Livestock population and cattle production data (2010–2014), and the precipitation and temperature data (2006–2016) were obtained from the Lushoto District Council.

Results

Cattle commercial products

Three main commercial products, namely milk, beef, and hides, were provided by cattle in the WUHs (Table 1). Manure is also crucial resource derived from cattle but its data was scant.

Table 1 Production of cattle products (2010–2014) in the study area (source: Lushoto District Council 2017)

Animal product type	Amount produced between years 2010 and 2014				
	2010	2011	2012	2013	2014
Milk ($\times 10^5$ l)	7.92	5.60	6.99	6.97	7.80
Beef ($\times 10^5$ kg)	5.94	5.75	5.59	5.32	6.00
Hide ($\times 10^3$ pieces)	4.57	4.42	4.30	4.10	4.62

Characteristics of smallholder dairy farms

The average family size at WUHs consists of six individuals comprising of parents, children, and relatives. Crop farming and livestock keeping were the major livelihood income-generating activities. About 95% of the respondents reported mixed farming as their primary occupation. Zero grazing (cut and carry of fodder) was the dominant dairy cow feeding system as confirmed by 87% of our respondents. Other dairy farms' feeding systems included tethering (11% respondents) and field grazing (2% respondents). The number of cows per farm was less than two (2) in the surveyed hh. A summary of hh characteristics in the study sites are presented in Table 2. Surprisingly, there was no significant correlation between number of cattle per farm and family size, or versus household farm size. The mean family sizes and total number of cattle per farm differed significantly across the three wards. However, farm size (ha) per household and number of cows per farm did not differ significantly (Table 2).

Dairy cattle fodder types and fodder sources

Five main types of fodder found in the WUHs were identified: (i) natural pastures both grasses and legumes; (ii) established pasture (napier and guatemala grasses); (iii) crop residues mainly maize, beans, and vegetable residues; (iv) fodder trees including mulberry (*Morus alba*), leucaena (*Leucaena* spp.), and avocado (*Persea americana*); and (v) crop weeds. Napier and guatemala grasses were mainly found at farm boundaries and contour strips and their cover was estimated to be only 8 to 13% of the total household farmland. In addition, only 6% of the respondents were found to have set aside pasture plots often less than 0.13 ha. Natural pastures were restricted to fallowed farms and uncultivated public lands such as play grounds, steep and rocky hills, riparian areas, forest reserves, and along the roadsides. Weeds were mainly found in maize (*Zea mays*), bean (*Phaseolus vulgaris*), and round potato (*Solanum tuberosum*) farms. The most common weed species included *Commelina bengalenisis*, *Bidens pilosa*, *Galinsoga parviflora*, *Ageratum conyzoides* and *Tegetus minuta*. Surprisingly, planting of forage legumes both herbaceous and woody was very uncommon.

Table 2 Mean values of size of families, farms, and cattle herds of the smallholder farmers in the study area

Parameter	Ward			Min. statistics	Max. statistics	Overall mean ± SEM	*P* value
	Shume	Ngulwi	Mbuzii				
Family size	6.3	6.2	4.9	2.0	14.0	6.0 ± 0.2	0.02
Farm size (ha) per household	1.5	1.2	1.3	0.2	8.1	1.3 ± 0.1	0.42
Total number of cattle per farm	3.2	3.0	2.3	1.0	12.0	2.9 ± 0.1	0.03
Number of cows per farm	1.5	1.6	1.2	1.0	6.0	1.5 ± 0.1	0.15

P value is the probability for statistical significant difference at 95% confidence limit ($P = 0.05$)

SEM standard error of the mean

Dairy cattle fodder was obtained from six sources, namely crop fields, road side areas, uncultivable lands, open areas, forest reserves, and fallowed lands. In particular, this study found out that most of the smallholder dairy farmers in the study sites were mainly sourcing fodder from their own farm or neighboring farms (Fig. 3). In addition, lands that are not suitable for agriculture including steep hillsides, valleys, and rocky areas were reported to act as important sources of fodder at Mbuzii and Ngulwi wards. The respondents at Mbuzii (76%) and Ngulwi (24%) wards reported to source natural pasture from uncultivable stony and rocky areas during the dry season.

Roadside reserves and open areas including play grounds were reported to provide fodder to dairy cattle through either cutting for stall feeding or tethering. Roadside reserve fodder sourcing was more prominent at Mbuzii ward (41%), followed by Ngulwi (36%) and least at Shume (24%). The practices of promoting vegetation cover including fodder species for controlling erosion and improving road safety were also common. Fodder sourcing from fallow lands was mainly reported at Shume (50%) and Mbuzii (38%) wards, while at Ngulwi (13%), this practice was unpopular. Forest reserves, in particular forest plantations, were among important sources of fodder at the Shume ward. It was reported that farmers are allowed to grow seasonal crops and collect fodder in areas where trees were felled or newly planted in forest plantations (Fig. 3). Fodder sourcing from fallow lands was minimal due to few numbers of fallow fields. Fallow lands were limited to hillsides or areas where crop was prone to wildlife damage and none was reported in fertile valley areas.

Seasonal variations in quantity and quality of fodder resources

About 86.60% of the respondents reported dry season (July to October) fodder scarcity as a major challenge. It was further revealed that with the advance of the dry season, the availability of both pastures and crop residues declined (Fig. 4a). Crop residues in particular maize stover was accentuated as the key important dry season livestock feed (Fig. 4a). The maize stover yield for the 2016–2017 long rain season cropping (November to June) was estimated at 4014 kg DM/ha. In addition, it was observed that during dry season, unusual livestock feeds including sedges (*Typha latifolia* and *Cyperus exaltatus*) and vegetable residues (cabbage, broccoli, cauliflower, and carrot) are fed to dairy cattle (Fig. 4a). During the wet season (March to May), on-farm fodder both natural and established pasture was reported to be plentiful (Fig. 4b).

Nonetheless, about 80.10% of the respondents reported higher costs in terms of labor and time for feeding dairy cows especially

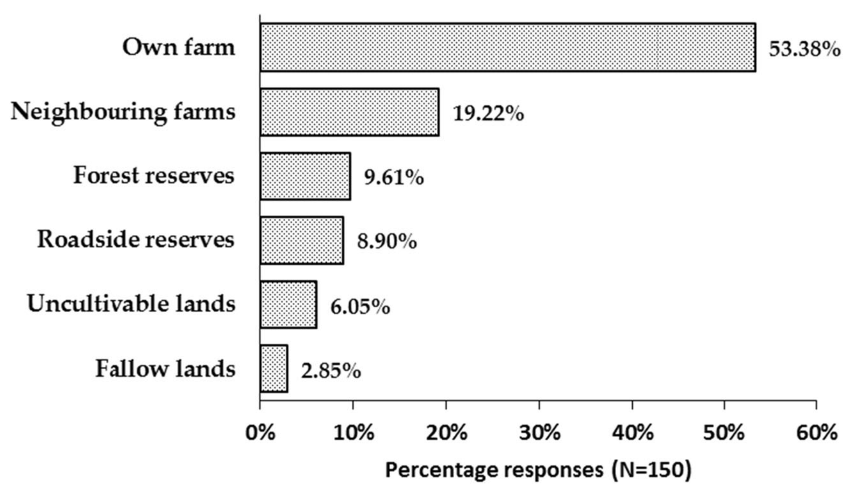


Fig. 3 Fodder sourcing areas by smallholder dairy farmers in the study area

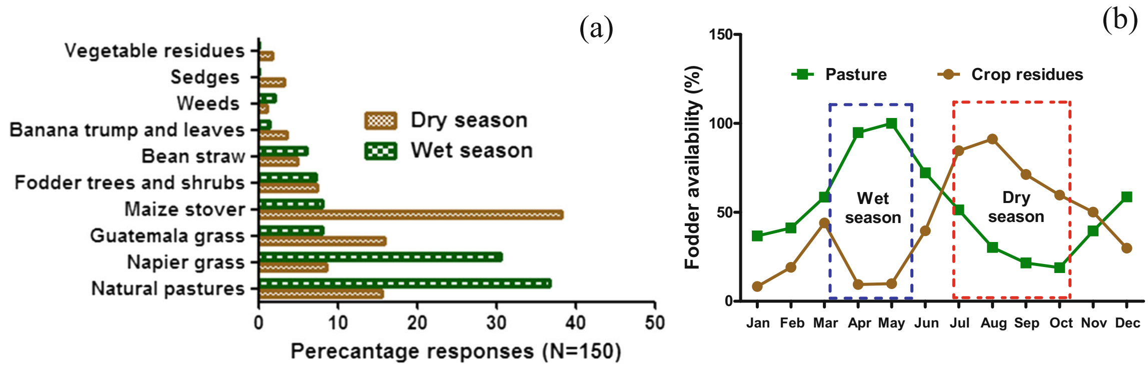


Fig. 4 Seasonal dairy cattle fodder availability (**a**), and annual profile of pasture and crop residues availability (**b**) to dairy cattle in the study area ($N = 150$). Note that pasture is highly available between March and June (growing season) and availability of crop residues tends to increase from June to August (harvesting season)

during dry season. Whereby, during dry season, farmers reported to walk longer distances in search of fodder in uncultivable stony hill areas for Mbuzii and Ngulwi, while in Shume, farmers sourced fodder from forest reserves. Consequently, the decreased amount of feed offered to dairy cattle resulted in an eventual decline in milk production during the dry season (Table 3).

All parameters differed significantly between the wet and dry seasons. Although a number of coping strategies to shortage of forage in dry season were identified, searching and sourcing of fodder anywhere within a farmer's reach were the major strategy (Table 4).

Regarding quantity, established pasture (napier and guatemala) had the highest dry matter (tDM) yields per hectare, while weeds had the least (Table 5). Fodder yields differed significantly between wet and dry seasons ($P < 0.05$), whereby the yields declined during the dry season with exception of that of guatemala. In addition, seasonality was found to affect the CP and ME contents among other nutrients of the fibrous feed offered to dairy cattle. Both protein and energy contents of the fodder declined while fiber content increased during the dry season (Table 6).

Dairy cattle feeding practices and related constraints and opportunities

About 53% of the respondents reported that they were supplementing poor roughages with a small amount of maize bran (less than 2 kg/day) and mineral premixes during milking. Only 38% of the respondents reported chopping forages before feeding to dairy cattle. None of the respondent(s) reported to spray molasses or treating dry crop residues with urea or alkali.

Land scarcity, inability to construct large barns, limited agricultural advisory services, and low milk prices (ranging from 0.27–0.45 USD/l) were among the major constraints contributing towards ineffective dairy cattle feeding (Fig. 5). In addition, unaffordability of farm machinery such as forage choppers, balers, and feed mixers were among other constraints (Fig. 5). While, good climatic conditions (67%) and fertile soils (54%) capable of supporting various fodder species (both grasses and legumes) were identified as positive contributors to dairy cow feeding.

Land cover classification

The land cover classification (Fig. 6) consists of six classes: smallholder farms, irrigated farmlands, build-up and soils, bushland, transition between bushland and forest, and forest. The map results (overall accuracy 67%) reveal that Mbuzii (73%) and Ngulwi (51%) consist of mostly smallholder farms, followed by Shume (23%). Based on the land cover classification, a number of points for both the smallholder farms class and non-agriculture classes (i.e., bushland/forest) were selected and used these to extract NDVI values from the time series;

Table 3 Seasonal variations in fodder sourcing distance, gathering time, amount of fodder offered, and milk yields in Lushoto

Parameter	Season		***P* value**
	Wet	Dry	
Distance to source fodder (km)	0.7 ± 0.1	1.6 ± 0.2	< 0.001
Time for gathering fodder (h)	0.7 ± 0.1	2.0 ± 0.1	< 0.001
Amount of fodder offered (kg/cow/day)	45.2 ± 2.8	33.6 ± 2.3	0.003
Milk yield (l/cow/day)	5.6 ± 0.2	3.0 ± 0.1	0.001

Table 4 Coping strategies to the scarcity of fodder during the dry seasons among the smallholder dairy farmers in the study area

Parameter (% respondents)	Ward			Overall mean
	Shume	Ngulwi	Mbuzii	
Source fodder from distant locations	30	38	51	40
Purchase feeds	21	30	23	25
Feed unusual feedstuffs	21	18	11	17
Sale some animals	19	12	11	14
Out migrate to search pasture	9	2	4	5

then, per study site, mean NDVI values were created (plotted left of the land cover maps). Note that the agricultural areas consistently have lower values compared to the more natural bushland/forest areas.

Discussion

Land cover classification, climatic data, and implications to sustainability

There is good agreement between the climate record and the NDVI time series. The correlation between droughts in 2010 and 2011 and a drop in vegetation vigor can be clearly noted. Also, the effects on the dairy production can be observed through the decline in milk production by 29% in 2011 and thereafter rising again by 20% in 2012 (Table 1).

When analyzing the mean NDVI time series and more precisely the difference between the SDFS/smallholder farms and the non-agriculture (bushland and forest), a difference was observed, in which relatively higher mean NDVI values were noticed in non-agriculture areas. The higher abundance of non-agriculture (i.e., bushland, forest) at Shume (76%) is thought to have reduced pressure on SDFS. In Ngulwi (25%) and Mbuzii (12%), the non-agricultural areas are fairly marginal and utilization of these lands reflects in the NDVI.

As our study sites are located in a region which is affected by cloud cover frequently and within a continent which has poor storage infrastructure (Wulder et al. 2016), there is very little high-quality satellite data available. This affects the filtering smoothing and gap-filling algorithm as there are periods without sufficient observations, which cause some sharp borders in the surface reflectance products. Overall, the time series are beneficial to this work and the NDVI products are less affected by the bordering effect.

Limitations of spatial resolution reduce the effectiveness of the analysis. The SDFS are typified by its high heterogeneity and mix of crops. These subtle vegetation changes can not detected by the Landsat sensors and also influenced our by GPS reference points, which often were clustered within a couple of pixels. Nevertheless, ground surveys revealed that the seasonal crop farming practices left most of the SDFS landscape bare during dry season with exception of few scattered trees and perennial grasses in farm margins and contour strips, thus being in agreement with the observation that reserved dry crop residues are essential dry season livestock feed resource in the WUHs.

Milk production and implications to sustainability

The reported smaller landholdings and low milk productivity implied that most farmers were practicing subsistence small-scale dairy production. The smaller landholdings coupled with low milk prices were deemed to discourage intensification of dairying in the WUHs. The observed tendency of most smallholder farmers' land in WUHs to be devoted to household food crop production is in concurrent with Waithaka et al. (2006) opinions. Waithaka et al. (2006) asserted that hh food security is the major determining factor for land use decisions among smallholder farmers.

Moreover, the reported low milk production under this study was far less than that reported by Cadilhon et al. (2016) who reported 8 and 4 l/cow/day for wet and dry seasons respectively. Reasons for low milk productivity apart

Table 5 Estimated average yield (tDM/ha) of different on-farm feed resources during wet and dry seasons in the study area

	Wet season fodder yield			Dry season fodder yield				
Fodder type	Shume	Ngulwi	Mbuzii	Shume	Ngulwi	Mbuzii	SEM	*P* value
Guatemala grass	6.4^{c}	4.1^{d}	3.4^{d}	13.7^{a}	11.2^{b}	3.5^{d}	0.45	< 0.001
Napier grass	5.5^{b}	6.1^{a}	5.8^{ab}	2.3^{e}	3.5^{d}	4.6^{c}	0.13	< 0.001
Natural pasture	2.1^{a}	0.6^{c}	0.8^{b}	0.4^{d}	0.6^{c}	0.6^{c}	0.06	< 0.001
Weed	1.3^{a}	0.2^{c}	0.4^{b}	0.1^{d}	0.06^{d}	0.1^{d}	0.04	< 0.001

Mean in the same row with different superscripts differs significantly ($P < 0.05$)

Table 6 Mean nutritive values (%) of mixed fodder samples collected from the feeding troughs during wet and dry seasons in the study area

Parameter (%)	Wet season (n = 15)	Dry season (n = 15)	P value
DM	28.5 ± 1.0	46.1 ± 2.9	0.001
CP	10.1 ± 0.4	7.8 ± 0.5	0.01
NDF	53.2 ± 1.5	62.4 ± 2.1	0.01
ADF	36.1 ± 1.4	41.3 ± 1.0	0.005
EE	1.6 ± 0.1	1.7 ± 0.2	0.69
Ash	8.7 ± 0.6	8.2 ± 0.8	0.61
Ca	0.5 ± 0.04	0.5 ± .03	0.79
P	0.2 ± 0.02	0.2 ± 0.2	0.68
IVDMD	43.6 ± 1.1	34.6 ± 1.3	< 0.001
IVOMD	50.1 ± 1.4	43.5 ± 0.9	< 0.001
ME (MJ/kg DM)	6.0 ± 0.2	4.6 ± 0.2	< 0.002

from being caused by poor feeds were also attributed to other factors including inferior crosses of dairy cattle breeds, diseases (mastitis and helminthiases), and poor cowsheds (earthen floor and lack of feeding trough). Whereby, most farmers mentioned poor cattle breeds as the major driver for low milk yields and demanded for superior dairy cattle breeds. Nonetheless, the finding that in WUHs fodder fluctuates seasonally both in terms of quantity and quality, with eventual variations in seasonal milk production, implies that fodder/feed is important driver for milk production. Henceforth, even if the cattle breeds will be improved and diseases controlled, still, the year-round proper feeding of dairy cattle is a crucial factor if sustainable high milk production is to be achieved in WUHs.

Fodder production and implications to sustainability

The small farm sizes averaging 1.3 ha/hh coupled with the non-existence of pasture plots implied that the own farm-produced fodder is incapable of meeting the year-round dairy cattle fodder demand. Thus, smallholder farmers were forced to diversify the fodder sources. For example, most smallholder dairy farmers reported a practice of making arrangements with nearby farmers who do not keep livestock to collect fodder and crop residues from their farms in exchange for money, manure, or labor. The key role of crop residues in particular maize stover as dry season dairy feed was justified by its higher yields of about 4014 kg DM/ha. However, lack of processing and its high fibrous nature might have attributed to dry season decline in milk productivity. Thus, capacity building to smallholder dairy farmers towards proper harvesting, storage, processing, and feeding of maize stover will enhance sustainable dairy production in WUHs.

Despite higher diversification of fodder sources, on-farm production was most important and relatively reliable compared to other sources including reserved, uncultivable, and fallowed lands. This is due to direct control of the farmer to fodder resources within his/her farm, while other sources such as roadsides, reserved land, and uncultivable land are opportunistic in nature. For instance, at Mbuzii ward, dry season pasture in communal rangelands was reported to be unreliable due to wildfires. While, at Shume ward, pasture access in forests was limited only to newly harvested or planted areas and access permits are required. Crop cultivation and fodder collection in forest plantations aim at reducing grass weeds that poses wildfire risks. The importance of forest reserve fodder source is in agreement with large shrub-forest cover (75.67%) in the Shume ward.

Heemskerk (2016) estimated that yearly about 1800 kg DM of natural pasture per farm is sourced from public lands for livestock feeding under zero grazing in WUHs. This is in compromise with the sustainability of cattle dairying in WUHs given the fact that human and livestock populations are increasing within the limited lands. Also, the sharp decline in milk production in 2011 due to drought despite the presence of forests and bushlands implies that uncultivated areas supply a limited amount of fodder. Additionally, this indicates that the resilience of the WUHs' SDFS is in compromise if adequate on-farm feeds are not produced and stored for feeding at times

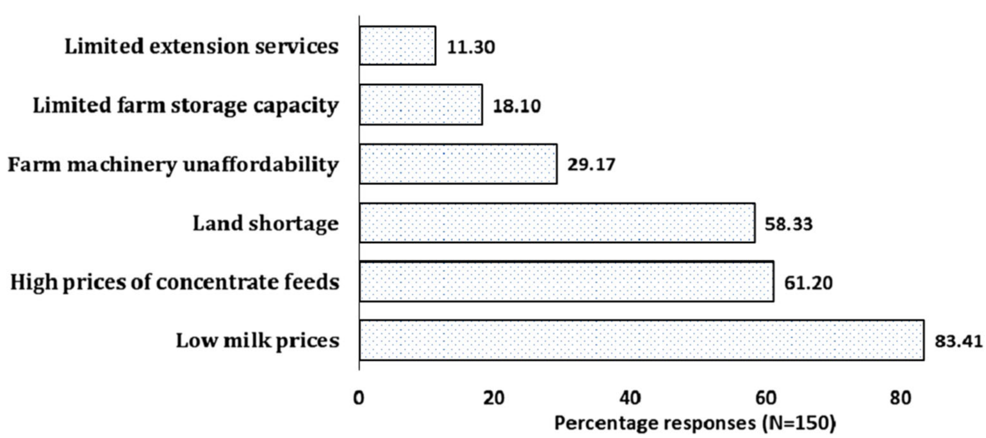
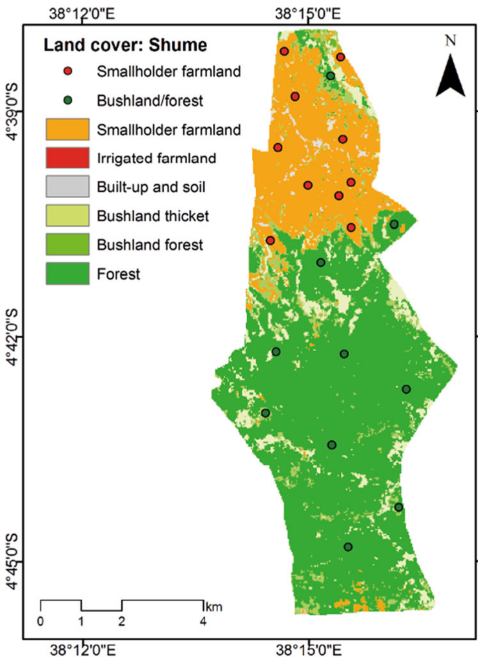
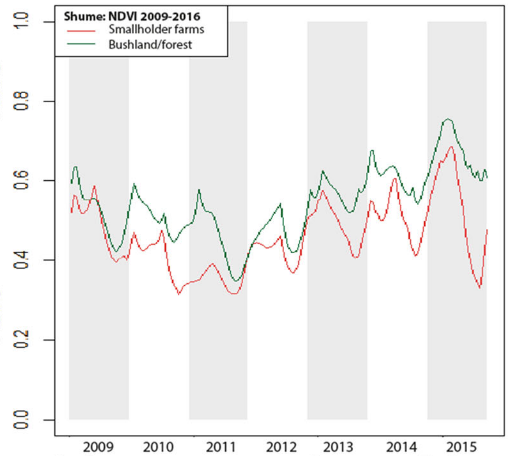
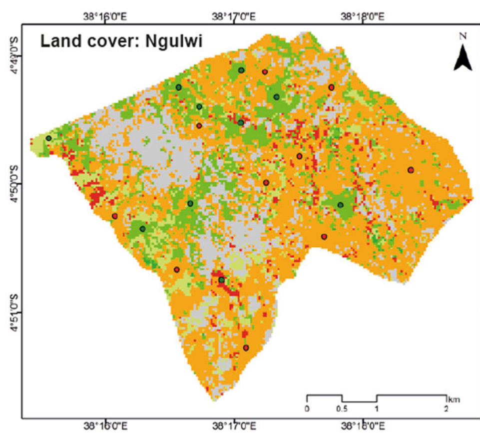


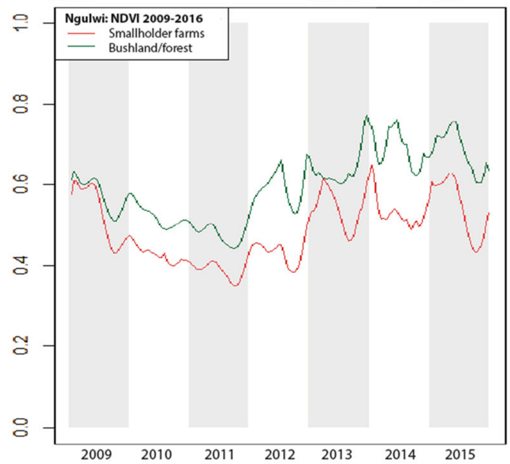
Fig. 5 Constraints towards adoption of effective dairy cattle feeding practices among smallholder dairy farmers in the study area



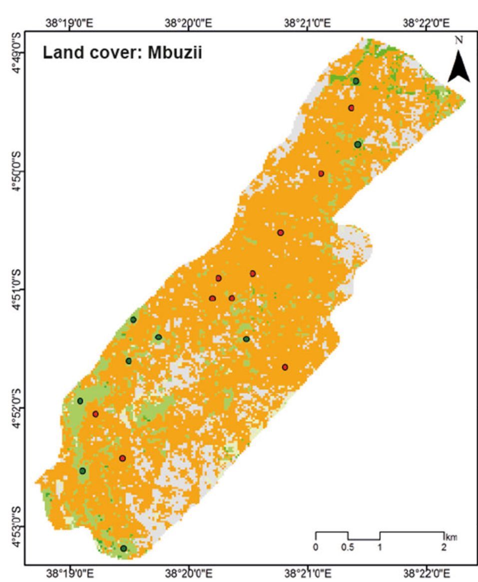


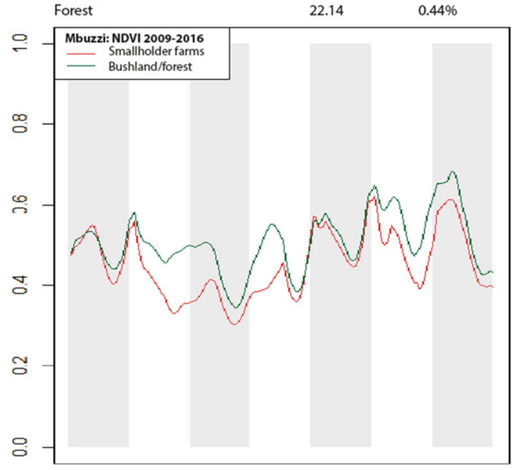
Land cover	ha	Total
Smallholder farmland	3477.6	23.31%
Irrigated farmland	42.12	0.28%
Built-up and soil	109.08	0.73%
Bushland thicket	1068.39	7.16%
Bushland forest	1019.25	6.83%
Forest	9199.98	61.68%





Land cover	ha	Total
Smallholder farmland	2559.33	51.41%
Irrigated farmland	203.31	4.08%
Built-up and soil	942.3	18.93%
Bushland thicket	1409.59	8.23%
Bushland forest	841.86	16.91%
Forest	22.14	0.44%





Land cover	ha	Total
Smallholder farmland	4268.43	72.57%
Irrigated farmland	72.36	1.23%
Built-up and soil	860.22	14.63%
Bushland thicket	123.66	2.10%
Bushalnd forest	545.94	9.28%
Forest	11.07	0.19%

◀ **Fig. 6** Land cover classification of Shume (top), Ngulwi (middle), and Mbuzii (bottom); extracted points (smallholder farmlands/SDFS, red; bushland and forest, green); statistics (ha and percentage of total land cover); and mean time series of NDVI values of smallholder farmlands and non-agriculture in the study area

of scarcity. Henceforth, initiatives for improving on-farm fodder production and adhering to carrying capacity are inevitable if SDFS in the WUHs is to be sustained.

Farm surveys revealed that napier and guatemala grass had highest yields both in the dry and wet seasons compared to natural pasture and weeds. The importance of napier grass for feeding dairy cows was highly emphasized by the smallholder dairy farmers in which it was testified that upon feeding napier grass the milk yields increases twofold. However, guatemala grass was avoided based on low response in milk yields and it was testified that it is fed only during dry seasons. This implies that promotion of napier grass and further research on locally high-yielding and nutritive varieties are worth undertaking in the WUHs.

Seasonal variations in fodder nutritive values and implications to sustainability

According to National Research Council (2001), in order for the dairy cow to meet the energy requirements for both maintenance and effective production, cow requires a feed with at least 10 MJ/kg DM of ME, while the observed ME values under this study for both dry and wet seasons were about 5 MJ/kg DM implying that the observed low milk yields might have been caused by low ME values. In addition, the dry season CP value of about 8% observed under this study is less than the recommended range of 10 to 16%. Henceforth, this implies that the decline in milk production during dry season is due to low CP contents.

Nevertheless, the recommended fiber contents are 30% NDF and 19% ADF; however, under this study, they were found to be relatively higher (Table 5). The higher fiber contents of the fodder implies low digestibility which was also reflected in the abnormally low IVOMD and IVDMD values. Henceforth, these nutritive results imply that dairy cows in the study sites will not meet their potential productivity in both wet and dry seasons unless the feed is improved. For example, one smallholder farmer reported an average milk yield of 10 l per cow per day in dry season. This farmer testified that provision of supplementary energy and mineral premixes as well as practicing night feeding was the secret behind higher milk production. Also, an average milk yield of 15 l per cow per day was reported in a commercial dairy farm located in WUHs. In this commercial farm, provision of about 6 kg supplementary concentrate (maize bran 90%, sunflower seedcake 9%, and mineral premix 1%) per milking cow per day was reported, and feeding of fresh protein-rich leucaena leaves and twigs was observed. Thus, it is imperative to investigate on economic, social, healthy, and environmental friendly local sources of protein, energy, and minerals to improve dairy productivity in WUHs.

Conclusion

It is concluded that dry season fodder scarcity is a major problem in the WUHs and eventually hinders sustainable dairy production. This is further exacerbated by the prevailing poor fodder production and storage practices in the WUHs. Nevertheless, inadequate feeding of dairy cattle in terms of both feed amount and quality is omnipresent in the WUHs. Further research for enhancing environmentally, economically, and socially feasible fodder production, fodder conservation, and feeding technologies are worth undertakings if sustainable dairy production in the WUHs is to be met.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Angelsen, A., Larsen, H.O., C.S. Olsen., 2012. Measuring livelihoods and environmental dependence: Methods for research and fieldwork. Routledge. pp 55–59.

AOAC., 1990. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Washington, DC.

Atzberger, C., Eilers, P.H.C., 2010. A smoothed 1km resolution NDVI time series (1998–2008) for vegetation studies in South America. International Journal of Digital Earth, 4(5), 365–386.

Breiman, L., 2001. Random forests. Machine learning, 45(1), 5–32.

Cadilhon, J. J., Pham, N. D., & Maass, B. L., 2016. The Tanga Dairy Platform: fostering innovations for more efficient dairy chain coordination in Tanzania. International Journal on Food System Dynamics, 7(2), 81–91.

Crowder L.V. and Chheda H.R. (1982). Tropical Grassland Husbandry. Longman, London, U.K. Longman group Ltd.

FAO., 2010. Status of and prospects for smallholder milk production: A Global Perspective. Edited by Hemme, T. and Otte, J., Food and Agriculture Organization of the United Nations, Rome, Italy (pp. 28–29).

Heemskerk, S. J., 2016. Bio-economic evaluation of forage cultivation scenarios in crop-dairy systems in Lushoto District, Tanzania.

Farming Systems Ecology Thesis (MSc Thesis, Wageningen University).

Herrero, M., Thornton, P. K., Notenbaert, A. M., Wood, S., Msangi, S., Freeman, H. A., … & Lynam, J., 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science, 327(5967), 822–825.

IBM Corp., 2013. IBM SPSS Statistics for Windows, Version 21.0. IBM 633 Corp., Armonk, New York.

Immitzer, M., Atzberger, C., Koukal, T., 2012. Tree Species Classification with Random Forest Using Very High Spatial Resolution 8-Band WorldView-2 Satellite Data. Remote Sensing, 4, 2661–2693. doi:https://doi.org/10.3390/rs4092661

Kawamura, K., Akiyama, T., Yokota, H.O., Tsutsumi, M., Yasuda, T., Watanabe, O., Wang, S., 2005. Quantifying grazing intensities using geographic information systems and satellite remote sensing in the Xilingol steppe region, Inner Mongolia, China. Agriculture, Ecosystems and Environment, 107, 83–93.

Kohavi, R., 1995. A Study of Cross-Validation and Bootstrap for Accuracy Estimation and Model Selection. International Joint Conference on Artificial Intelligence 14, 1137–1143. doi:https://doi.org/10.1067/mod.2000.109031

Liaw, A., Wiener, M., 2002. Classification and Regression by random Forest. R news 2, 18–22. doi:https://doi.org/10.1177/154405910408300516

Lukuyu, B.A., Ravichandran, T., Maass, B., Laswai, G., Bwire, J. and Duncan, A.J., 2015. Enhancing livestock productivity through feed and feeding interventions in India and Tanzania. ILRI Project Report. Nairobi, Kenya: ILRI.

Lukuyu, M., Njehu, A., Mwilawa, A., Lukuyu, B.A., Omore, A.O. and Rao, J., 2016. A study to understand fodder markets and fodder trading patterns in MoreMilkiT sites and other selected regions in Tanzania.. ILRI Project Report. Nairobi, Kenya: ILRI.

MAFF., 1975. Energy allowances and feeding systems for ruminants. Ministry Of Agriculture, Fisheries and Food, Department Of Agriculture and Fisheries for Scotland and Department of Agriculture for Northern Ireland. 1975. Technical Bulletin 33: Her Majesty's Stationery Office, London.

Meroni, M., Ng, W.-T., Rembold, F., Leonardi, U., Atzberger, C., Gadain, H., Shaiye, M., 2016. Mapping Prosopis juliflora in west Somaliland with Landsat 8 satellite imagery and ground information. Land Degradation & Development, 28(2), 494–506.

Mussa, H.M., 1998. Smallholder dairy production feed budgeting strategy in the Southern Highlands of Tanzania. A case study of Rungwe and Mbozi districts. M.Sc. Dissertation. Sokoine University of Agriculture.

Mwango, S. B., Msanya, B. M., Mtakwa, P. W., Kimaro, D. N., Deckers, J., Poesen, J., … & Bethuel, I., 2014. Root properties of plants used for soil erosion control in the Usambara Mountains, Tanzania. International Journal of Plant & Soil Science 3(12),1567–1580.

National Research Council., 2001 Nutrient Requirements of Dairy Cattle. National Academy Press, Washington: DC, USA.

Ng, W.-T., Immitzer, M., Floriansitz, M., Vuolo, F., Luminari, L., Adede, C., Wahome, R., Atzberger, C., 2016a. Mapping Prosopis spp. within the Tarach water basin, Turkana, Kenya using Sentinel-2 imagery 9998, 99980L. doi:https://doi.org/10.1117/12.2241279

Ng, W.-T., Meroni, M., Immitzer, M., Böck, S., Leonardi, U., Rembold, F., Gadain, H., Atzberger, C., 2016b. Mapping Prosopis spp. with Landsat 8 data in arid environments: evaluating effectiveness of different methods and temporal imagery selection for Hargeisa, Somaliland. International Journal of Applied Earth Observation and Geoinformation, 53(2016), 76–89.

R Core Team, 2015. R: A Language and Environment for Statistical Computing. R Found. Stat. Comput. Vienna. doi:https://doi.org/10.1038/sj.hdy.6800737

Rouse, J.W., Haas, R.H., Schell, J.A., Deering, D.W., 1974. Monitoring vegetation systems in the Great Plains with ERTS. Third ERTS-1 Symp. 309–317.

Rubel, F., and M. Kottek, 2010. Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. Meteorologische Zeitschrift, 19(2), 135–141.

Tilley J.M.A. and Terry R.A., 1963. A two stage technique for the *in vitro* digestion of forage crops. Journal of British Grasslands Society 18, 104–111.

Van Soest P.J., Robertson, J.B. and Lewis, B.A., 1991. Methods for Dietary Fibre and Non-Starch Polysaccharides in Relation to Animal Nutrition. Dairy Science, (74) 3583–3597.

Vuolo, F., Ng, W., Atzberger, C., 2017. Smoothing and gap-filling of high resolution multi-spectral time series: Example of Landsat data. International Journal of Applied Earth Observation and Geoinformation, 57, 202–213.

Waithaka, M.M., Thornton, P.K., Herrero, M., Shepherd, K.D., 2006. Bio-economic evaluation of farmers' perceptions of viable farms in western Kenya. Agricultural Systems. 90, 243–271.

Wulder, M.A., White, J.C., Loveland, T.R., Woodcock, C.E., Belward, A.S., Cohen, W.B., Fosnight, E.A.,Shaw, J., Masek, J.G., Roy, D.P., 2016. The global Landsat archive: Status, consolidation, and direction. Remote Sensing of Environment, 185, 271–283.