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Research Article

A Monitoring Study on the Production Performance and Enteric Methane Emission from the Dairy Cows Under Smallholder Farms in Kilimanjaro Region, Tanzania

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Abstract

A total of 54 lactating dairy cows from 20 farms in Hai District were monitored to assess production performance and methane (CH_4) emission under different feeding practices and altitude zones. Of the selected farms 8 were in the highland zone and 12 in the lowland zone. In the lowland, cows were managed under zero grazing (FP1), grazing with supplementation (FP2) and extensive grazing (FP3), while all highland cows were managed under FP1. Measurements included body weight, nutrients intake, milk yield and composition and CH_4 emission. Feedstuffs were also analysed for their nutritive values. The results showed that, daily dry matter intake (DMI), crude protein intake (CPI) and metabolisable energy intake (MEI) were higher ($P<0.05$) in cows under FP1 (11.1 kg, 1.2 kg and 117 MJ, respectively) than those in FP2 (9.8 kg, 938 g and 90 MJ) and FP3 (7.5 kg, 539 g and 45.3 MJ). Similarly, cows in the highland zone had higher ($P<0.05$) DMI, CPI, and MEI (11.7 kg, 1.3 kg, and 121.9 MJ) than those in the lowland zone (11.1 kg, 1.18 kg, and 117.1 MJ). Weight gain was highest ($P<0.05$) in FP1 (0.35 kg/d), followed by FP2 (0.21 kg/d), and lowest in FP3 (0.11 kg/d). Cows in the highland zone had significantly higher weight gain 0.46 kg/d) compared to those in the lowland zone 0.35 kg/d). Daily mean milk yield followed a similar trend, with cows under FP1 producing the highest (9.0 kg), followed by FP2 (6.8 kg) and FP3 (4.7 kg). Across zones, milk yield was significantly higher ($P<0.05$) in the highland (11.2 kg) than in the lowland (9.0 kg). Milk from cows under FP3 had slightly higher ($P<0.05$) lactose content (4.4%) than those under FP1 and FP2, while cows under FP1 produced milk with higher solids-non-fat (SNF) content (8.5%). Milk from lowland cows contained more ($P<0.05$) fat (4.0%), protein (3.6%), total solids (12.0%) and solids-non-fat (8.5%) than milk from highland cows. Mean gross methane emission did not differ significantly among feeding practices but was higher ($P<0.05$) in the highland zone (265 g/d) than the lowland zone (149.9 g/d). Methane intensity was similar ($P>0.05$) across feeding practices and zones. It was concluded that cows under FP1 achieved higher production performance by producing higher milk yield per unit of methane emitted compared to other feeding practices. Further research is recommended to evaluate the effects of different supplementation levels on production performance and methane emission.

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Keywords

Feeding Practices, Altitude Zones, Feed Intake, Milk Yield and Composition, Methane Intensity

1. Introduction

Dairy production plays a crucial role regarding nutrition, employment, and economic contribution worldwide. In Tanzania, dairy industry is growing due to rise in number of improved dairy breeds managed under smallholder dairy farms [1]. Smallholder dairying contributes to 30 percent of total milk production in the country, which is equivalent to 1.2 billion litres [1] per year. Despite of the growth, the efficiency of production is still low due to limited feed supply, high cost of concentrate supplements, decreased size of the grazing land, poor breeding systems and diseases [2]. These resulting into huge milk deficit in the country of about 9 billion litres, leading to importation of 11.8 million litres from other countries, which cost about 8.8 million US dollars. Thus, there is a need to improve the performance of dairy cows in the milk shade areas.

Nutritional challenges significantly hinder the efficiency of dairy production. Many dairy farms face seasonal and year-round shortages of forages and concentrate feeds leading to underfeeding and nutrients deficiencies. With these situations the amount of feed and nutrients received by the animals could be different with regard to type of feeding practice used and geographical location such as altitude zones. These are known to affect the availability of feeds in terms of quantity and quality [3]. [4], and [5] reported that feeding practices, which involve concentrate supplementation increase feed intake compared to those depending on forage alone. This effect is attributed to the ability of concentrate to enhance rumen microbial activity, hence increases microbial efficiency, leading into high digestion rate of both forages and concentrate. Another researcher [6] documented that feeding practices, which depend on forage alone receive low dry matter and nutrients, specifically in the dry season, when the availability and quality of forages are reduced. In Kilimanjaro region specifically Hai district, limited information is available on the effect of feeding practices on the feed and nutrients intake in relation to milk production.

Hai district is characterized by diverse agro-ecological zones namely, low and high-altitude zones, which vary in climatic condition, ecology, socio-economic characteristics of farmers and size of the land used in dairy production. These factors together affect feeding practices by enhancing the availability of feeds used in dairy production. For instance, in high altitude zones cooler climate and more rainfall could support availability of high quality natural and improved forages, however the small land size owned by the farmers in the study site as reported by [7], limit the availability, leading to high usage of conserved forages, such as crop residues. Conversely, the feeding practices in the lowland areas are affected by long days of drought leading to scarcity of feeds in most of the year. Furthermore, hot climatic condition affects the quality of feeds in terms of protein and fibre due to early lignification of plants [8] Therefore, animals in lowland zones are expected to receive less feeds with little nutrients resulting to low milk yield. Most of the documented studies such as [9, 3], explained the factors influenced production performance of dairy cows, in terms of milk yield and composition without considering the influence of altitude zones.

In parallel with the drive to enhance milk production, there is increasing global attention on the environmental impact of livestock, especially greenhouse gas (GHG) emissions. This is due to the fact that rumen microbial fermentation of feeds produces enteric methane which has high ability to trap long solar radiation resulting to global warming [10]. On the other hand, in ruminants, 2-12% of the gross energy intake is lost as methane (CH_4) during the rumination process, leading to reduced feed efficiency [11]. The amount of methane produced by dairy cows is influenced by many factors, including nutrition, genetics, and size of the animals. The aspects of nutrition include feed intake, diet composition, and rumen fermentation [12]. These factors influence quantity of methane production in different feeding practices and altitude zones as they determine the rate of feed digestibility and the condition favouring methanogen bacteria [13, 14]. For example, the feeding practices, which involve concentrate supplementation are expected to produce less methane compared with those depended on forage alone, when other factors such as animal size and breeds are not considered [15]. This is due to the fact that concentrate feeds favour production of propionate, which is the hydrogen sink a key substrate for methanogenesis. From such perspectives, assessment of factors affecting the nutrition of dairy animals is paramount to the development of strategic feeding for enhanced production and reduced CH_4 emission from dairy cows. Although feeding practices for dairy cows in different geographical zones are extensively documented [13, 16], research data linking the feeding practices in different altitude zones with level of methane production from the dairy cattle under smallholder production systems are scarce. The present study, therefore, assessed the influence of feeding practices and altitude zones on the production parameters and methane emission from the cows under smallholder dairy system in

Kilimanjaro region in Tanzania.

2. Material and Methods

This study was approved by the Research Ethical Com mittee (REC) of Sokoine University of Agriculture (Ref: SUA/DPRTC/R/186/25) on behalf of the Commission for Science and Technology of Tanzania (COSTECH).

2.1. Description of The Study Area

The study was carried out in Hai District, located in Kilimanjaro region of Tanzania. Geographically, the district lies between latitudes 2°50' and 3°29' South, and longitudes 30°30' and 37°10' East. Hai District is divided into two altitude zones. The lowland zone, situated at elevations above 1100 metres, while the highland zone is found below 1100 metres above sea level. The district experiences a bimodal rainfall pattern, with short rains occurring from November to December and long rains from March to June. The annual rainfall ranges from 500 to 900 mm in the lowland zone, and from 1000 to 1500 mm in the highland zone. The average annual temperatures vary accordingly, with the lowland zone experiencing hotter temperatures between 26°C and 31°C, while the highland zone has cooler conditions, averaging to 15°C.

2.2. Design and Nature of the Study

An on-farm monitoring of the dairy cows in the highland and lowland zones of Hai district was conducted in three different feeding practices. A total of 54 lactating dairy cows were monitored on-farm, using an unbalanced, partially nested design, across three different feeding practices in the highland and lowland zones. In the lowland zone, the cows were managed in three feeding practices, that were 16 cows under zero grazing (FP1), eight (8) cows under grazing with supplementation (FP2) and eight (8) cows under extensive grazing (FP3) practices, while in the highland zone, 22 cows were all managed under FP1. The monitoring period involved 28 days, from early March to early April 2024. The data collected included body weights of the cows, feed intake, milk yield and composition, methane emission and nutritional values of the feeds fed to the cows.

2.3. Selection and Management of the Experimental Animals

The 54 dairy cows were purposively selected from 20 dairy farms, which were among the farms intervened by the project on the Framework of Enviro-Cow. The overall goal of this project was to increase feed efficiency, reduce feed costs and greenhouse gas emissions (GHGs) from the dairy cattle under smallholder production system in Sub-Saharan Africa. The selection of the farms was based on the conditions that the farm should have at least one lactating dairy cow within 2 and 5 parities and in between the first and second stages of lactation. In addition, the farm should possess a housing structure that allows space for individual cow feeding. The farms, where the cows shared feeding stalls were selected provided the housing structures allowed some modifications to enable individual feeding of the cow. Local and low-cost materials, such as poles and woods were used to install pens, which enabled to house the cows separately during feeding. Among the selected farms, eight (8) were in the highland and twelve (12) in the lowland zone. The cows were housed in the buildings roofed with corrugated iron sheets, with slated floors ranged from earthern to concrete floors. The feeding troughs were either complete wooden, partially woodern or concrete. The cows were supplied with drinking water through buckets or built in structures as drinkers. The management of the experimental cows followed their usual routine management of the farm, in addition with the research measurements. Cows in the FP1 were managed indoor, while those in FP2 and FP3 the management of cows varied across households: some were housed in constructed stalls, others were tethered in open areas within the homestead, while a few were kept in traditional, simple enclosures locally referred to as bomas.

Milking was done by hands twice a day, between 0400 and 0630 h for morning and 1800 and 1930 h for evening sessions. The daily milk yield from each selected cow was measured using aluminium or stainless-steel milk litre cup and recorded in the record books, owned by the farmers. The cows were weighed fortnightly, between 0600-0800 h after milking, before feeding or going for grazing. The cows were weighed using a weighing band, through measuring the circumference of the heart girth (HG) behind the shoulder at the fourth rib and rear side of the fore legs. The measurements in centimetres (cm) were fitted in the equation developed by [17] to estimate body weight (BW) in kilogram (kg) as follows (Equation (1)):

$$BW\ (kg) = 4.277hG - 393.13 \tag{1}$$

The initial body weight was taken on the first two days, while the final weight was on the last two days of the monitoring period.

2.4. Source of Feeds and Feeding of the Experimental Animals

The forage resources used for feeding dairy animals consisted of either single types or mixtures of natural pastures and legumes, crop residues, weeds from crop fields and banana residues, particularly in the highland zone. The types of concentrate feeds used by the farms included individual or combined use of maize bran, homemade mixtures, commercial dairy meal, brewery waste and in a few cases, pellet feeds. The forages were obtained from uncultivated plots, reserved forests, road sides, river banks and established farm plots. Crop residues were either harvested or brought from crop fields after harvesting. The concentrates were bought from milling machines, oil refinery plants and agrovets. Cows in FP1 were fed with cut and carry for both forages and concentrate. For each meal, the forages offered to dairy cows, whether chopped or non-chopped, were packed into sacks and weighed using a 50 kg portable electronic weighing scale (Model WH A08, Mumbai, India). The frequency of forage feeding was twice to three times per day around 0600-0800 h, 1300-1400 h and 1800-1900 h. Concentrate feeds were offered separate from forages, normally during milking time at 0400-0630 h and 1800-1930 h and some farms provided concentrate after milking. The concentrate was measured using the same weighing scale and apportioned accordingly, between the meals. The refusals, in most cases forages were collected in the next day before new feed was provided and weighed. Cows under both FP2 and FP3 were grazed in the field for eight hours daily, from 0600 to 1200 h and 1600 to 1800 h. In FP2, cows were additionally supplemented with concentrate feeds in the shade during milking, while those in FP3 relied solely on extensive grazing. The daily amount of concentrate offered to the cows under FP1 and FP2 ranged from 2 to 5 kg. However, for the farms that supplemented cows with brewery waste, at least 10 kg of the fresh waste was provided to each cow daily. Drinking water for the cows was supplied *ad libitum* in the farms with built-in-drinkers. Other farms supplied drinking water using buckets at around 1300-1500 h. Grazing dairy cows were supplied with drinking water after return from grazing.

2.5. Parameters Derived

2.5.1. Body Weight Gain

The average body weight gain of each cow was estimated by calculating the difference between the final and initial weight divided by number of days in the experimental period.

2.5.2. Feed and Nutrients Intake

Different methods were employed to estimate feed intake by the cows in the three feeding practices. The feed intake by the cows under zero grazing (FP1) was obtained by subtracting the refusals from the quantity of feed offered. Forage moisture losses during feeding were expected to increase dry matter (DM) of the refusal by 2 percent [18]. Therefore, the absolute dry matter of refusal was added 2 percent before subtracted to DM of forage offered. Forage dry matter intake from the grazing cows in the FP2 and FP3 was estimated by a prediction equation adapted from [19], which used the percent neutral detergent fibre (NDF) content of the forage consumed by the animal (Equation (2)).

$$\text{Dry matter intake (kg) (DMI,\% of body weight)} = 120/\%\ \text{NDF} \quad (2)$$

To obtain the total dry matter intake (TDMI) for the cows in FP2, the dry matter intake of the concentrate was added to DMI of forage obtained from the equation. The nutrients intake by the cows were estimated by multiplying the DMI of the feed with specific nutrient contents of the feed.

2.5.3. Milk Yield

The measurement of milk yield in litres was converted into kilogram (kg) milk by the factor proposed by [20] which is 1 litre of milk is equivalent to 1.03 kg milk.

2.6. Collection and Preparation of Feed and Milk Samples

Forage samples offered to dairy cows from each farm were collected twice per week, in which the farms practiced FP1, the forage samples were obtained from the feeding troughs/stalls. The quartering method was used to obtain samples from the fields for farms practiced FP2 and FP3. Forages were harvested using a sickle from various grazing sites, including uncultivated plots, roadsides, riversides, and reserved forests. The collected forages were then hand-chopped into pieces measuring 2 to 3 inches using garden scissors. The chopped samples were thoroughly mixed and divided into four equal portions, from which two opposite quarters were taken as representative samples. Samples of concentrate feeds were collected once per week from the batches prepared for feeding cows. Similar samples from different farms following the same feeding practice were pooled and then sub-sampled. Forage and concentrate samples were weighed fresh on the site using a 50 kg portable electronic weighing scale (Model Wh A08, Mumbai, India). Each sample was placed into a separate envelope, labelled, transported to National Artificial Insemination Centre (NAIC) in Arusha where they were dried under shade in a room prepared for curing feed samples. Dried samples were re-weighed to obtain air-dried sample weights. The dried samples were transported to the Tanzania Veterinary Laboratory Agency (TVLA) in Dar es Salaam for analysis of their nutritive values. Samples of wet brewery waste were sealed in waterproof zip-top plastic bags and stored frozen at the Tanzania Veterinary Laboratory Agency (TVLA) in Arusha and later to the Nutrition Laboratory at Sokoine University of Agriculture (SUA) in Morogoro. A total of 160 samples of forage mixtures were collected as illustrated in Table 1.

Milk samples were drawn directly from the teats of cows after milking using 50 ml sterilized plastic containers. The sampling was done once in two weeks interval and a total of 108 samples were collected as illustrated in Table 1. The samples were stored into cool boxes at 4°C to maintain cold temperatures before being transported to the National Artificial Insemination Center (NAIC) laboratory, where the facilities for storage and analysis were available. At laboratory, the milk samples were frozen at temperature -10°C and analysed within a week.

Table 1. Breakdown of the Samples of Feed and Milk Collected From the Different Feeding Practices and Altitude Zones.

Variables	Highland	Lowland			Total
Feeding practices	FP1	FP1	FP2	FP3	
Dairy farms	8	4	4	4	20
Dairy cows	22	16	8	8	54
Forage samples	64	32	32	32	160
Concentrate samples	32	16	16	n/a	64
Milk samples	44	32	16	16	108

2.7. Chemical Analyses of Feed and Milk Samples

Feed samples were analysed at the Tanzania Veterinary Laboratory Agency (TVLA) for their chemical composition, including dry matter (DM), crude protein (CP), crude fat (CF), ash, neutral detergent fibre (NDF) and acid detergent fibre (ADF), using Near-Infrared Reflectance Spectroscopy (NIRS). The DM of air-dried samples was corrected by the dry matter from NIRS and wet chemistry to obtain the DM content of the samples. A subset of samples was further analysed for in vitro dry matter digestibility (IVDMD) and in vitro organic matter digestibility (IVOMD) at the Nutrition Laboratory of SUA, Morogoro, following the procedure outlined by [21]. The metabolisable energy (MJ ME /kg DM) contents for both forages and concentrate were estimated using prediction equations developed for ruminants by [22].

The milk samples were analysed at the NAIC, in Arusha using LactoScope 300 (LS 300) (PerkinElmer Inc., version 3003000-03 of 2022 Thane-Maharashtra, India). The frozen milk samples were thawed by placing the containers under tape water until the milk melted. Thereafter, the samples were placed in water bath and incubated at a temperature of 35-38°C. Then, the containers were placed into LactoScope 300 (LS 300) where milk was scanned for fat, protein, lactose, total solids and solids-non-fat (SNF).

2.8. Quantification of Methane Emitted by the Experimental Cows

Methane measurements for individual experimental cows were performed twice during the period of monitoring, using a Laser methane detector (Laser methane mini™ (LMm)" model, Tokyo Gas Engineering Co., Ltd., Tokyo, Japan), a device that utilizes laser technology to detect and measure methane emitted to the environment. The procedures, protocols and processing of methane data from the laser methane detector (LMD) were adopted from Chagunda, (2009). The measurements from the cows on indoor feeding practice were performed between 0800 to 1500 h, while those on grazing were taken before grazing, between 0600 and 0800 h or after grazing between1300-1600 h. The procedure was first to record the ambient methane for 5 minutes followed by taking the actual measurement on the animal. The LMD gadget was located at a distance of 2-3 m far from the cow by directing the laser beam directly on its nostrils. The LMD records every 0.5s over a period of 60s for five minutes. The values of methane were read in parts per million metres (ppm*m), which were later converted to methane in grams (g) per day using the equation developed by [23] and [24] as follows:

$$CH_4\ (g/day) = CH4\ peak \times 1440 \tag{3}$$

Where; CH_4 peak, was the average of the peak value of emission in ppm*m divided by the distance from the animal. The standard deviation method adopted from [23] was used to automatically separate the eructation values from the respiration values in which an easily calculated threshold is one standard deviation (SD) above the mean of all values in a CH_4 profile. In obtaining methane emission intensity in gram per kilogram of milk (g/kg milk), the daily amount of CH4 obtained from the cow was divided by the mean daily milk yield in kg.

2.9. Statistical Analysis

A linear mixed-effects model was employed to analyse the parameters of dry matter and nutrients intake, body weight, milk yield and composition as well as methane emitted from the cows under different feeding practices using R software version 4.4.1 of 2024 [25]. The model accounted for the partially nested design, where three feeding practices were practiced in the lowland zone and one feeding practice in the highland zone. Zone was included as a fixed effect, feeding practice nested within zone was treated as a random effect. The initial body weight was included in the model as a covariate to adjust for body weight gain, feed intake, milk yield and methane emission. The emmeans was used to separate means and was considered significant at $P<0.05$. An independent t-test was used to compare the means of parameters obtained from the cows under FP1 in the highland and lowland zones.

3. Results

3.1. Nutritive Values of Diets Offered to Dairy cows in Different Feeding Practices

The nutritive values of diets used during the experiment as influeced by feeding practices are presented in Table 2. The average CP content of forage mixtures fed to the cows in all feeding practices were similar (P>0.05). The mean values of crude fat contents of forage mixtures fed to the cows under zero grazing (FP1) and grazing with supplementation (FP2) were similar (P>0.05), however, higher (P<0.05) than in forages fed to cows under extensive grazing (FP3). Forages used by cows under FP3 and FP2 contained higher (P<0.05) mean ash content than those used under FP1. The mean values of neutral detergent fibre (NDF), acid detergent fibre (ADF), in vitro dry matter (IVNDMD) and organic matter (INVOMD) digestibility and the average values of metabolisable energy (ME) of the forages were similar in all the feeding practices. The nutritional values of concentrate mixtures were similar (P>0.05) across feeding practices.

Table 2. Lsmeans ±SEM of the nutritive values of diets offered to the experimental cows under different feeding practices.

	Forage mixtures					Concentrate mixtures			
Variable (%)	FP1	FP2	FP3	SEM	P-value	FP1	FP2	SEM	P-value
N	32	32	32			16	16		
DM	28.59	25.16	28.18	2.17	0.395	89.25	88.68	0.42	0.377
CP	9.36	9.66	9.78	0.91	0.939	12.38	10.98	0.43	0.075
C. Fat	1.95[a]	1.72[ab]	1.42[b]	0.13	0.029	6.94	7.54	0.79	0.613
Ash	6.29[b]	7.65[a]	7.88[a]	0.38	0.005	8.21	7.58	0.77	0.592
NDF	54.09	53.89	53.97	0.79	0.980	28.32	27.37	2.59	0.806
ADF	31.09	31.20	30.88	0.73	0.961	14.60	12.10	1.35	0.222
IVNDMD	46.66	44.57	44.86	4.67	0.947	81.69	83.11	4.05	0.810
I IVNOMD	43.01	41.53	42.21	4.73	0.977	80.08	83.27	4.97	0.660
ME MJ/kg DM	6.88	6.64	6.75	0.75	0.976	12.01	12.49	0.54	0.660

In this and subsequent tables: DM= dry matter, CP= crude protein, C.fat= crude fat, NDF= neutral detergent fibre, ADF= acid detergent fibre, INVDMD= in vitro dry matter digestibility, INVOMD= in vitro organic matter digestibility, ME_MJ/kgDM metabolisable energy in mega joules per kilogram dry matter

a-c Means with different superscript within a row differ significantly (P<0.05). SEM= standard error of the mean

3.2. Nutritive Values of Diets Offered to Dairy Cows in Different Altitude Zones

Table 3 highlight the nutritive values of diets used by the experimental cows in different altitude zones. The mean value of the CP content of forages used by the cows under zero grazing practice was similar (P>0.05) in both zones. The mean value of the fat content of the forages used by the cows in the lowland zone was higher (P<0.05) than that in the highland zone. There was no significant difference (P>0.05) in the mean value of ash content of forages used by the cows in the highland and lowland zones. The mean values of both NDF and ADF were higher (P<0.05) in the forages used by the cows in the highland than those in the lowland zone. The mean values of the IVNDMD and INVOMD of the forages were similar (P>0.05) among the altitude zones.

The mean values of the CP and ash contents of the concentrate mixtures supplemented to lactating cows on the zero grazing practice were higher (P<0.05) in the highland than in the lowland zone. Higher (P<0.05) mean value of crude fat was observed in the concentrate mixtures used in the lowland than highland zone. Higher (P<0.05) mean value of NDF was observed in the concentrate mixtures used in the lowland than highland zones. The mean values of the in vitro digestibility and ME of the concentrate mixtures were not different (P>0.05) between zones.

Table 3. Lsmeans ± SEM of the nutritive values of diets used by the experimental cows in different altitude zones.

	Forage				Concentrate			
Variable (%)	Highland	Lowland	SEM	P-value	Highland	Lowland	SEM	P-value
N	64	32			32	16		
DM	30.65	28.59	1.41	0.317	87.78 [b]	89.25[a]	0.27	0.002
CP	8.71	9.36	0.69	0.513	14.06[a]	12.38[b]	0.35	0.002
C. Fat	1.58[b]	1.95[a]	0.07	0.001	4.87[b]	6.94[a]	0.46	0.001
Ash	6.67	6.29	0.29	0.349	9.96[a]	8.21[b]	0.49	0.021
NDF	57.40[a]	54.08[b]	0.65	0.001	23.26[b]	28.32[a]	1.57	0.023
ADF	34.32[a]	31.09[b]	0.56	0.001	19.01	14.60	2.88	0.528
INVDMD	45.81	46.66	2.74	0.892	85.83	81.69	3.55	0.203
INVOMD	42.94	43.01	2.70	0.847	85.39	80.80	4.35	0.252
ME MJ/kg DM	6.75	6.88	0.43	0.818	12.81	12.01	0.65	0.252

3.3. Nutrients Intake by the Cows in Different Feeding Practices

The nutrients intake by the experimental cows under different feeding practices are presented in Table 4. The average values of forage dry matter intake (FDMI) were similar in cows under FP1 and FP2, however, they were lower (P<0.05) than that of cows under FP3 practice. The mean of concentrate dry matter intake (CDMI) was higher (P<0.05) by the cows under FP1 compared to those on FP2. The cows under FP3 were not supplemented with concentrate. The mean total dry matter intake (TDMI) was higher (P<0.05) for the cows under FP1 followed by those under FP2 and least in those on FP3. The mean forage crude protein intake (FCPI) was higher (P<0.05) for cows under FP3, followed by FP1 and lowest in those under FP2. The average values of concentrate crude protein intake (CCPI) were higher (P<0.05) for cows in FP1 than those in FP2. The higher (P<0.05) mean value of total crude protein intake (TCPI) was observed on cows under FP1, followed by those on FP2 and was lowest for cows under FP3. The mean values of forage metabolisable energy intake (FMEI) were higher (P<0.05) for cows under FP3 compared to FP1 and FP2. The mean of concentrate metabolisable energy intake (CMEI) was higher for cows under FP1 than those on FP2. The average total metabolisable energy intake (TMEI) was higher for cows under FP1 followed by those on FP2 and least in those on FP3.

Table 4. Lsmeans ± SEM of the nutrients intake by the experimental cows in different feeding practices.

Variables	FP1	FP2	FP3	SEM	P-value
n	16	8	8		
Dry matter intake (DM, g/d)					
Forage	7116[b]	7231[b]	7461[a]	66.24	0.003
Concentrate	3974[a]	2586[b]	NA	25.44	0.001
Total	11090[a]	9817 [b]	7461 [c]	67.83	0.001
Protein intake (CP, g/d)					
Forage	536[b]	508[c]	539[a]	4.45	0.001
Concentrate	645[a]	427[b]	NA	5.54	0.001
Total	1181[a]	935[b]	539[c]	6.84	0.001

Variables	FP1	FP2	FP3	SEM	P-value
Metabolisable energy intake (ME, MJ/d)					
Forage	44.3[b]	42.0[c]	45.34[a]	0.39	0.001
Concentrate	72.9[a]	48.1[b]	NA	0.56	0.001
Total	117.1[a]	90.0[b]	45.34[c]	0.71	0.001

In this and subsequent tables NA = not applicable

3.4. Nutrients Intake by the Cows in Different Altitude Zones

Nutrients intake by the experimental cows in different altitude zones are presented in Table 5. The cows in the highland zone had higher (P<0.05) mean values of intake of all nutrients than those in the lowland zone, except slight variations (P<0.05) between zones were observed on the mean FCPI and FMEI.

Table 5*. Lsmeans ± SEM of the nutrients intake by the experimental cows as influenced by altitude zones.*

Variables	Highland	Lowland	SEM	P-value
n	22	16		
Dry matter intake (g/d)				
Forage	7509 [a]	7116 [b]	61.34	0.001
Concentrate	4177[a]	3974[b]	30.01	0.001
Total	11686[a]	11090[b]	66.61	0.001
Protein intake (CP,g/d)				
Forage	550[a]	536[ab]	4.59	0.041
Concentrate	702[a]	645[b]	9.51	0.001
Total	1251[a]	1181[b]	10.48	0.001
Metabolisable energy intake (ME, MJ/d)				
Forage	44.7	44.3	0.42	0.490
Concentrate	77.2[a]	72.9[b]	0.66	0.001
Total	121.9[a]	117.1[b]	0.78	0.001

3.5. Production Performance of the Cows Under Different Feeding Practices

Table 6 presents the production performance of the experimental cows in different feeding practices. There was no significant difference (P>0.05) in the mean initial body weight of cows across the feeding practices. The Lsmeans of final body weight and body weight gain were higher (P<0.05) for cows in the FP1, followed by cows in the FP2 and were lowest for cows in the FP3. Cows under FP1 had significantly higher (P<0.05) mean value of daily milk yield followed by those on FP2 and least from cows on FP3. There was no significant (P>0.05) difference in mean percent fat and protein in the milk produced by the cows from the different feeding practices. The Lsmeans of the percent lactose was significantly lower (P<0.05) in the milk from cows under FP3 than other feeding practices. However, the Lsmeans of milk lactose from the cows under FP1 and FP2 were similar (P>0.05). The Lsmeans percent of total solids did not differ (P>0.05) between the feeding practices. The mean percent of solids-non-fat (SNF) was higher (P<0.05) in the milk from cows under FP1 compared with other practices, moreover, cows under FP2 and FP3 had similar SNF contents.

Table 6. Lsmeans ± SEM of the production performance of the experimental cows under different feeding practices.

Variables	FP1	FP2	FP3	SEM	P-value
Initial body weight (kg)	329.89	323.87	299.80	8.39	0.057
Final body weight (kg)	339.79^{a}	329.71^{b}	302.79^{c}	8.63	0.017
Average body weight gain (kg/d)	0.35^{a}	0.21^{b}	0.11^{c}	0.008	0.001
Milk yield (kg/d)	9.02^{a}	6.75^{b}	4.76^{c}	0.70	0.001
Milk composition (%)					
Fat	4.04	4.92	4.16	0.49	0.359
Protein	3.58	3.11	2.89	0.25	0.110
Lactose	4.44^{a}	4.33^{a}	3.93^{b}	0.12	0.022
Total Solids	11.97	12.44	10.92	0.62	0.362
Solids-non-fat	8.51^{a}	7.99^{b}	7.29^{b}	0.29	0.018

3.6. Production Performance of the Cows in Different Altitude Zones

Table 7 presents the production performance of the cows in highland and lowland zones. The Lsmeans of the initial body weight, final body weight and body weight gain of the cows in the highland zone were higher ($P<0.05$) than those in lowland zone. The cows in the highland zone had higher ($P<0.05$) mean daily milk yield compared to those in the lowland zone. Milk from the cows in the lowland zone had higher ($P<0.05$) mean contents of fat and protein than those in the highland zone. The difference in mean percent lactose in the milk between the altitude zones was not significant. The Lsmeans of the total solids and solids-non-fat contents in the milk from cows in the lowland were higher compared to those in the highland zone.

Table 7. Lsmeans ± SEM of the production performance of the cows in different altitude zones.

Variables	highland	Lowland	SEM	P-value
Initial body weight	352.92^{a}	329.89^{b}	4.37	0.001
Final body weight (kg)	365.93^{a}	339.79^{b}	4.57	0.001
Average body weight gain (kg/d)	0.46^{a}	0.35^{b}	0.006	0.001
Milk yield (kg/d)	11.16^{a}	9.02^{b}	0.51	0.004
Milk composition (%)				
Fat	2.14^{b}	4.04^{a}	0.18	0.001
Protein	2.91^{b}	3.58^{a}	0.11	0.001
Lactose	4.45	4.44	0.07	0.929
Total Solids	9.78^{b}	11.97^{a}	0.29	0.001
Solids-non-fat	7.75^{b}	8.51^{a}	0.15	0.001

3.7. Methane Emission from the Experimental Cows in Different Feeding Practices and Altitude Zones

Table 8 presents the Lsmeans of the methane (CH_4) emitted from the experimental cows from different feeding practices and altitude zones during the monitoring period. The Lsmeans of the intensity of CH_4 emitted from the experimental cows were similar (P>0.05) in all the feeding practices. Regarding altitude zones, the average gross CH_4 was significantly higher (P<0.05) in cows from the highland than those in lowland zone. The mean CH_4 intensity was similar (P>0.05) for both zones. The average CH4 respiration intensity was higher (P<0.05) for the cows in the highland zone, whereas the mean CH_4 eructation intensity was similar (P>0.05) between zones.

Table 8. Lsmeans ± SEM of the CH4 emission from the experimental cows in different feeding practices and altitude zones.

Parameters	n	Gross methane (g/d)	Methane intensity	Methane Respiration intensity	Methane Eructation intensity
Feeding practices					
FP1	16	149.98	16.89	9.13	41.44
FP2	8	166.87	24.31	15.05	59.35
FP3	8	118.90	20.46	12.80	50.17
SEM		18.24	3.71	2.49	9.23
P-value		0.308	0.254	0.133	0.274
Altitude zones					
highland	22	265.21^{a}	22.05	12.83^{a}	46.20
Lowland	16	149.98^{b}	16.89	9.14^{b}	41.44
SEM		18.08	1.82	1.20	4.29
P-value		0.001	0.051	0.035	0.442

a-c Means with different superscript within a column differ significantly (P<0.05). SEM= standard error of the mean

4. Discussion

The present study was planned to evaluate the influence of different feeding practices and altitude zones on the production performance and methane emission of dairy cows within the smallholder system. The observed metabolisable energy (ME) values of the forages used by the cows in all the feeding practices were in agreement to the ME values reported for most tropical forages, ranging between 5-9 MJ ME/kg DM [26]. However, the values are below that (12 MJ ME/kg DM) recommended by [27] for a high milk producing cows. Thus, for sustainable production of milk in the study site, supplementation of high energy and rich protein concentrate feeds is invertible. The observed higher contents of neutral detergent fibre (NDF) and acid detergent fibre (ADF) of forages used by the cows under zero grazing (FP1) in the highland zone than lowland zone could be attributed by the use of conserved crop residues rather than pastures as reported by [7]. The observed higher total dry matter intake (DMI) by the cows in FP1 could be contributed by the higher DMI from the concentrate compared to other feeding practices. This trend could as well contribute to the higher total protein intake (TCPI) and energy intake (TMEI) by the cows in FP1 and those in the highland zone. The higher dry matter and nutrient intake by the supplemented versus none supplemented cows was similarly reported by [28] and [5].

During the study period, which coincided with the growing season, dairy cows were recovering from body weight losses incurred during the preceding dry season, when feed availability and intake were significantly reduced. The higher body weight gain observed in cows under (FP1), compared to other feeding practices, was largely attributed to concentrate supplementation, which provided readily available energy and protein. Furthermore, cows under FP1 in the highland zone exhibited greater body weight gain, likely due to the combined effect of improved forage quality and strategic concentrate feeding, enhancing nutrients intake and utilization. Following milk production parameters, the observed higher milk yield (10.5 kg per cow per day) from the cows under FP1 relative to other practices was contributed by the higher concentrate dry matter (CDMI) and hence nutrients intake by these cows compared to those on the other practices. Concentrate supplementation, specifically rich in energy provide fermentable carbohydrates, which balance energy deficient from the feeding of forage alone [29]. Furthermore, the higher milk yield from cows in the highland than those from the lowland zone could be associated to the observed higher CP content and protein intake from the concentrate offered to these cows. This signifies that the animals are provided with protein and mineral rich concentrate, which are essentials in rumen function for high milk yield. The higher milk yield and nutrient intake by the cows supplemented with concentrates compared with none supplemented was also reported by [30]; [5]. The lower milk yield from the cows under extensive grazing (FP3) than other practices was the result of lower CP (FCPI) and ME (FMEI) intakes from grazing forages alone. It is important to note that the potential for milk production of the cows under study is 15-20 litres per day [31], which require at least at energy of 135 MJ ME and protein of 1978 g CP per day [27]. Thus, from the present results, it is revealed that the cows in all the feeding practices and altitude zones are underfed in both energy and protein. The observed lower milk yield below the production potential for all the feeding practices and altitude zones was attributed by lower levels of ME and CP intake by the cows. High milk production in the study area can be achieved by improving the intake of quality feeds, which ultimately enhances protein and energy intake. This can be attained by harvesting excess forages during the growing season at the blooming stage and preserving them as silage or hay for use during periods of feed scarcity. Crop residues should also be utilized more efficiently by minimizing wastage through chopping and improving their digestibility by treating with urea or applying molasses. In addition, farmers should provide appropriate supplementation using high energy and protein concentrate, based on the nutritional requirements of their dairy cows. Farms with plots for forage production are encouraged to intercrop grasses with legumes, which enhances forage quality and soil fertility. Moreover, planting multipurpose trees such as *Leucaena leucocephala*, *Gliricidia sepium*, and *Calliandra calothyrsus* is recommended, as they provide valuable green fodder particularly during the dry season to support rumen microbial activity.

Milk composition is also a function of nutrient received by an animal which ultimately affect the types of volatile fatty acids produced in the rumen. In the present study, the observed higher percent of lactose in milk produced by cows from FP1 and solids-non-fat from FP2 could be due to the effect of concentrate supplementation, which provided starch and sugars for rumen metabolism. Rumen microbes convert starch and sugar into volatile fatty acids (VFAs) specifically propionate, which is transformed into glucose, the building block of lactose synthesis in the mammary gland and hence into the milk [32]. It was expected that milk with higher percent of fat, protein, total solids and solids-non-fat could be produced by cows from the highland zone due to higher nutrients intake compared to that of lowland zone. However, the observed lower values of these parameters in milk from cows in the highland than lowland zone could be due to dilution factor from the relatively high milk yield in this zone as also noted by [33].

Interestingly, there was no significant difference between the feeding practices on the methane (CH_4) emission from the experimental cows. Since dry matter intake (DMI) is a major driver of methane production in dairy cows [34], it was expected that cows in FP1 and FP2 having higher DMI would emit more methane than those in FP3. However, this was not the case. The higher DMI in FP1 and FP2 was largely the result of concentrate supplementation, which reduced the proportion of forage in the diet compared to FP3. Principally Enteric CH_4 production is associated primarily with production of acetic acid and butyric acid and, in general, the fermentation of predominantly forage diets results in a higher molar proportion of acetic acid than occurs with concentrate based diets [35]. Conversely, concentrate based diets normally contain greater proportions of more readily fermentable components that favour propionate production during rumen fermentation, with a consequent reduction in CH_4 production per unit of fermentable organic matter in the rumen [36]. Although concentrate feeding increased intake and would typically raise methane emission in FP1 and FP2, it simultaneously improved diet quality by supplying more crude protein (CP) and metabolisable energy (ME). This better nutrient balance offset the expected increase in methane, leading to no significant differences in daily methane output among the feeding practice. On the other hand, the forage diets consumed by the dairy cows in all feeding practices during case study 2 were of good quality, with average values of neutral (NDF= 54%) and acid (ADF = 34%) detergent fibre contents, with reasonable in vitro digestibility values (INVDMD= 45%) which probably attributed to reasonable methane emission, particularly in cows under FP3 that relied solely on forage. In line with these results, [37] similarly observed insignificant difference between feeding practices on CH_4 production from dairy cows. The observed higher gross methane (CH_4 g/d) from dairy cows in highland zone compared to lowland zone could be due to the relatively high mean dry matter intake (DMI) and body weight of the cows in the highland zone. The present findings are in agreement with those reported by several authors [13], [38-40], who noted that DMI is the driver of enteric methane from dairy cows. This is due to the fact that dairy cows are large they consume more feed to reach their genetic potential for milk production, which leads to high methane emission. Also, it was observed that dairy cows in the highland zone received forage diets with high fibrous compared to those from the lowland zone, which may probably influenced the observed higher methane emission in this zone. [41] reported that methane intensity (CH_4 g/kg milk) decline with concentrate supplementation. Accordingly, cows receiving concentrate in FP1 and FP2 and those in FP1 across both highland and lowland zones, would be expected to have lower methane intensity. However, the absence of significant differences in methane intensity across feeding practices and altitude zones may be explained by a dilution effect, whereby the higher milk yields in FP1 and FP2 reduced methane intensity to levels comparable with cows in FP3 that produced less milk.

However, FP1 will remain more sustainable practice as it produces relatively high milk yield with the same level of methane emission to other feeding practices, which has less milk yield. The obtained daily mean CH_4 intensity (18-24 g/kg milk) in the present study was higher compared to the value (4-5 g/kg milk) observed by [42], in a study where rotationally grazing and supplementation with a commercial concentrate was practiced. In addition, [43] reported the CH_4 production of 14.5 g/kg milk, when fed dairy cows a total mixed ration, made from variety of high-quality forages. Therefore, feeding strategies that promote the use of high-quality forages and appropriate concentrate supplementation should be encouraged among smallholder dairy farms. These practices enhance feed efficiency and contribute to the reduction of methane emission per kilogram of milk produced.

5. Conclusions and Recommendations

It was concluded that dairy cows managed under FP1 in both highland and lowland zones exhibited higher production performance in terms of milk production and body weight gain. Additionally, cows under FP1 had higher milk yield with methane intensity similar to FP2 and FP3 which produced less milk than it. Therefore, to achieve sustainable dairy production in the study area, efforts should focus on promoting and enhancing FP1 practices with feeding strategies that will enhance production while reducing methane emission. Further research is recommended to assess the effects of supplementing dairy cows with different types and levels of concentrate feeds on production performance and methane emission.

Abbreviations

AADGG	African Asian Dairy Genetics Gain
ADF	Acid Detergent Fibre
ANOVA	Analysis of Variance
CCPI	Concentrate Crude Protein Intake
CH_4	Methane Gas
CDMI	Concentrate Dry Matter Intake
CMEI	Concentrate Metabolisable Energy Intake
COSTECH	Commission for Science and Technology of Tanzania
CP	Crude Protein
CPI	Crude Protein Intake
DAARS	Department of Animal, Aquaculture and Range Sciences
DM	Dry Matter
DMI	Dry Matter Intake
FCPI	Forage Crude Protein Intake
FDMI	Forage Dry Matter Intake
FMEI	Forage Metabolisable Energy Intake
FP1	Zero Grazing Practice
FP2	Grazing with Supplementation Practice
FP3	Extensive Grazing Practice
HEET	Higher Education for Economic Transformation
HG	Heart Girth
ILRI	International Livestock Research Institute
INVDMD	In vitro Dry Matter Digestibility
INVOMD	In vitro Organic Matter Digestibility
LMD	Laser Methane Detector
ME	Metabolisable Energy
MEI	Metabolisable Energy Intake
MJ	Mega Jouls
NA	Not applicable
NAIC	Artificial Insemination Centre
NDF	Neutral Detergent Fibre
NIRS	Near-Infrared Reflectance Spectrophotometer
REC	Research Ethical Committee
SEM	Standard Error of the Mean
SRUC	Scotland's Rural College
SUA	Sokoine University of Agriculture
TALIRI	Tanzania Livestock Research Institute
TMA	Tanzania Meteorological Agency
TCPI	Total Crude Protein Intake
TDMI	Total Dry Matter Intake
TMEI	Total Metabolisable Energy Intake
TVLA	Tanzania Veterinary Laboratory Agency

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Conflicts of Interest

Authors declare no conflict of interest**.**

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