Effects of dry season supplementation of *Calliandra calothyrsus* leaf-meal mixed with maize-bran on dairy cattle milk productivity in the West Usambara Highlands, Tanzania

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Abstract

The dry seasons decline in milk production due to insufficient feed supply to dairy cattle poses a great challenge to sustainability of smallholder dairy production systems in Tanzania. Locally produced leguminous fodder tree leaf meals combined with maize bran provide a great potential for overcoming the dry season protein-energy deficit in the basal roughage feeds. This study evaluated the effects of dry season *Calliandra calothyrsus* (Calliandra) leaf-meal: maize-bran based protein-energy homemade supplementary ration (HSR) on milk production of lactating cross-bred dairy cows in the Western Usambara Highlands (WUHs), Tanzania. Complete randomized design was employed whereby four groups of 4 lactating dairy cows were subjected to four levels of HSR rationed at 0, 2, 4 and 6 kg/cow/day. The lactating cows which were not subjected to HSR supplementation (0 kg/cow/day) were left under farmers' feeding practices as a control. HSR had significant effect on dry season milk yields ($P < 0.001$) whereby milk yields were 2.7, 4.5, 5.6 and 6.1 litres/cow/day for 0, 2, 4 and 6 kg HSR/cow/day, respectively. In addition, simulated year-round daily milk yields indicated that 4 and 6 kg HSR/cow/day would double the milk yields. Nevertheless, there was overall significant difference in the income to cost ratios ($P = 0.02$) whereby it was 0.50, 0.79, 1.06 and 1.09 for 0, 2, 4 and 6 kg HSR/cow/day, respectively. However, the income to cost ratios for 4 and 6 kg HSR/cow/day did not differ significantly ($P < 0.05$). In conclusion, if the dairy farmers in WUHs are to produce profitable milk amounts during the dry seasons the supplementation level of 4 kg HSR/cow/day to the basal diets is recommended.

Introduction

Dry season protein and energy deficiencies are common in the grasses and crop residues which are the major constituents of dairy cattle basal diets in the tropics (Leng, 1990; Mtengeti et al., 2008). Supplementation of poor roughages with balanced protein, energy and mineral rich concentrates is essential for meeting both maintenance and production nutrient demands of dairy cattle (Moran, 2005; Olafadehan and Adewumi, 2009). However, selection of appropriate supplementation strategies which can be easily adopted by the majority of smallholder dairy farmers within their local environments has remained a great challenge (Chakeredza et al., 2008; Makkar, 2016). Leguminous multipurpose fodder tree species including *Calliandra calothyrsus* have proven to be among the cheap sources of protein which can be easily produced under East African crop-livestock mixed farming systems (Wambugu et al., 2011; Franzel et al., 2014). In East Africa, fodder legumes and maize bran play an important role as alternatives for expensive commercial protein and energy concentrate feeds, respectively (Paterson et al., 1998). On the other hand, commercial dairy feed concentrates including dairy meals, oil seed cakes and molasses syrup are often locally unavailable and with unreliable quality in the most of rural dairy farming areas of Tanzania (Maleko et al., 2018b)

A number of studies have shown that the use of multipurpose leguminous tree leaves has potential for improving dairy cattle performance in East Africa. For example, Place et al. (2009) reported a daily addition of 1 kg of *C. calothyrsus* leaf meal to a Napier and lablab basal diet fed to dairy cattle culminated in milk yield increase by 0.7 litres per cow per day. Likewise, Franzel et al., (2014) reported that 1 kg of Calliandra leaf meal (24% crude protein) increased milk yield by roughly 0.6–0.8 kg/day under the smallholder dairying conditions in Kenya. However, the milk production response was variable, depending on extraneous factors such as health of the cow and the quantity and quality of the site-specific basal feeds.

Effects on milk production resulted from supplementation of poor roughages with protein-energy rich concentrates are also documented. For example, Nkya and Swai (2000) reported that supplementation with 0.8 kg/cow/day of concentrate comprising of maize bran (70%), cottonseed cake (28%) and minerals (2%) during dry season improved cattle milk yields by 34%. Also, Mlay et al. (2005) reported that supplementation of cows with 4 kg/cow/day of concentrates constituting 68% maize bran, 31% sunflower meal and 1% mineral premix showed an average improvement in milk yield by 1.5 l/cow/day in the Eastern Tanzania.

Unfortunately, the data is sparse and invalid for constructing a milk response curve to show the effect of varying quantities of *C. calothyrsus* leaf meal mixed with maize bran based diets on milk production in West Usambara highlands (WUHs). This is augmented by the fact that variations in the constituents of the site-specific basal feeds mandate site-specific supplementary feeding trials. This is crucial for recommending a proper amount of supplements towards the optimization of local feeds in improving milk production, in particular, eliminating milk gaps during dry seasons.

In view of the above, on-farm feeding trial aiming at recommending proper supplementation level for optimizing on-farm grown feed resources was conducted. The dry season predominant basal feed at WUHs is dry maize stover in combination to unreliable natural pastures, Guatemala and Napier fodder grasses (Maleko et al., 2018a).

This work was based on the hypotheses that optimal feeding of on-farm feed resources has the potential to enhance dry season milk production and profitability. This information is envisaged to catalyze adoption of fodder legume growing and dairy cattle supplementation practices and technologies in Western Usambara Highlands and elsewhere with similar environments.

Material And Methods

Study site description

The study was conducted at Irente Biodiversity Farm located in Lushoto district, Tanga region, North Eastern Tanzania (4°47'36"S, 38°15'52"E) at 1413 m above sea level. Irente farm has an area of about 200 ha managed under multiple land use system which includes dairy farming, nature based ecotourism, aquaculture and apiculture. The farm has a herd of about 100 Friesian - zebu crossbred dairy cattle kept under stall feeding (cut and carry) with partial grazing in natural pastures within the farm. Also, the farm has an established stand of *C. calothyrsus* of about 5 ha managed under high frequency cutting for stall feeding.

Lushoto district lies in the Western Usambara highlands (WUHs) with an elevation range between 1200 and 1800 m a.s.l, and it is amongst the important milk sheds in the country. Rainfall at the WUHs is bimodal in nature averaging 1100 mm annually. Usually, long rainfalls begin in March and end in earlier June while the short rains occur between late October and December.

Basal feeds used in this study

The basal feeds were mainly crop residues and established pasture purchased from smallholder farms in the villages around Irente farm, whereby they were cut and carried for stall feeding. The availability of the basal feeds was in the order of dry maize stover > Guatemala grass > Napier grass > natural pastures > sugarcane tops. However, the availability of basal feeds was opportunistic in nature and with limited control of quality. The natural pastures mainly *Cynodon* and *Setaria* grass species often mixed with weeds and herbaceous legumes were gathered within the farm. Basal feed samples were collected and analyzed for nutrient compositions (Table 1) through Near-infrared spectroscopy (NIRS) techniques described by Corson et al., (1999).

Table 1 Nutrient composition of the most common basal feeds that were fed to the experimental animals

Basal feed type	n	CP	CF	Ash	ADF	NDF	IVDMD	ME(MJ/kg DM)
Dry maize stover	2	6.77±0.54	1.00±0.06	7.09±2.47	49.06±1.36	73.47±1.51	52.47±9.88	7.33±1.57
Napier grass	4	10.48±1.02	1.80±0.49	8.01±1.11	40.10±2.07	65.21±2.51	59.95±4.63	8.28±0.72
Guatemala grass	2	11.79±0.50	1.67±0.23	7.63±0.23	45.86±1.20	69.15±1.29	54.39±0.76	7.54±0.09
Natural pastures	7	8.78±4.69	1.66±0.33	7.03±1.93	34.06±4.52	56.77±5.68	56.09±2.88	6.82±0.46
Sugarcane tops	2	5.68±0.35	1.32±0.04	4.98±0.23	33.48±1.62	55.57±2.35	74.71±1.97	10.65±0.26

n= Number of samples; CP = Crude protein (%); CF= Crude fat (%); ADF = Acid detergent fibre (%); NDF = Neutral detergent fibre (%); IVDMD = In vitro dry matter digestibility; ME (MJ/kg DM)= Metabolizable energy (MJ/kg dry matter)

Supplementary feed used in this study

A supplementary homemade/on-farm ration (SHR) comprising of 56% maize bran (MB), 40% *C. calothyrsus* leaf meal (CLM), 2% mineral vitamin premix (MVP) and 2% molasses powder (MP) was formulated. The associated price of this supplementary ration was 620 Tsh./kg as fed and nutrient concentrations are shown in Table 2 (Analyzed by NIRS techniques). Maize bran a co-product of maize grain was selected based on the fact that maize cultivation and maize grain processing are common practices in Lushoto. Maize is among the staple food in Lushoto thus guaranteeing the availability of maize bran (Maleko et al., 2018a). *C. calothyrsus* leaf meal was incorporated as a protein concentrate (CP = 25.2%). *C. calothyrsus* was widely grown at Irente Biodiversity Farm and in nearby smallholder farms. The *C. calothyrsus* stand at Irente Biodiversity Farm was established in mid 1990s. The main trunks of the *C. calothyrsus* tree are maintained at a height of about 1.5m whereby new branches are regularly pruned for livestock feeding. Leaf meal was prepared through cutting and sun drying of small branches of *C. calothyrsus* during the dry season. Sun drying was done immediately after cutting for 2-3 days on plastic sheets placed on ground followed by sorting the sticks off dry leaves. At the time of this study in Tanga urban, leaf meal mainly of *Leucaena* species was being sold at a price of 0.27 USD/kg compared to 0.445 and 0.58 USD/kg for sunflower seedcake and cotton seedcake concentrates, respectively (Personal observation). Commercial MP and MVP were purchased from the accredited local dealers. MP was important for improving energy and palatability of the supplementary ration. MVP was essential for enhancing concentration of mineral elements and vitamins that are essential for milk production.

Table 2 Nutritive value of the Calliandra leaf-meal mixed with maize-bran homemade/on-farm supplementary feed ration for lactating dairy cattle

Variable	DM (%)	CP (%)	CF (%)	Ash (%)	ADF (%)	NDF (%)	IVDMD (%)	ME (MJ/kg DM)	Ca (%)	P (%)	Mg (%)	K (%)
Proportion	89.20	22.30	4.70	9.10	22.40	32.74	73.34	10.73	1.24	0.29	0.34	0.77

Milk sample collection and analysis

The cows were hand milked before milking the teats and udder were washed with clean water and then a milk salve teat lubricant was smeared. The cows were milked twice daily at 0700 and 1600 hours with individual cattle milk yields recorded at each milking. Milk was sampled once per week and immediately assessed for milk protein, fat, lactose and solids non-fat components using a portable Ultrasonic Milk Analyzer Model Master LM2 (Milkotester, Bulgaria).

Experimental design, treatments and animal care

Completely randomized design was employed in which a total of 16 lactating crossbred Zebu-Friesian dairy cows were used in this study. Four (4) groups each consisting of 4 lactating crossbred dairy cows making a total of 16 cows were subjected to four levels of HSR rationed at 0, 2, 4 and 6 kg/cow/day. Those 4 lactating cows which were not subjected to HSR supplementation (0 kg/cow/day) were left under farmers’ feeding practices as a control which is supplementing a 1 kg/cow/day maize bran (Maleko et al., 2018a). These were tested to determine the optimal feeding strategy in terms of milk production and economic returns under the WUHs farming conditions.

The selected lactating cows were at their 3nd and 4th calving and with mean live weight of 359.38 ± 38.10 kg and average daily milk yield of 3.06 ± 0.91 litres/cow/day. The experimental period was 55 days which was the peak of dry season during September and October 2018. The first Ten (10) days were counted for acclimatization of the experimental diets/protocol and 45 days for data collection. Health care including proper prophylaxis e.g. vaccination and health management were provided by a veterinary expert contracted by the farm. Prior to actual feeding, the experimental cows were dewormed using Ivermectin injection and sprayed with acaricides weekly. The body weights of the experimental animals were estimated using a weigh band and their body condition score (BCS 1-5) assessed one day prior to commencing the study and thereafter biweekly. Animals were supplemented twice a day during milking (0700 and 1600 hours). Animals had access to adequate amount of drinking water and basal feeds in troughs, mineral lick blocks were provided *ad libitum*. Partial grazing was practiced during mid-days and during night times animals were housed in a well-constructed cowshed. The cowshed had stone walls, concrete floor and corrugated iron roof. The cowshed was cleaned daily to ensure animal comfort and hygienic conditions adherence.

Simulation of lactational milk yields, income and production costs

The Dairy Simulation Model under the Livestock Feeding Strategies Simulation models (LIFE-SIM) Version 8.1 was used to simulate the effects of different supplementation strategies (scenarios) on crossbred dairy cattle performance at WUHs. In which, effects of supplementation strategies on milk yields, incomes and costs were evaluated. The LIFE-SIM model has six (6) data inputs including 1). Animal (age, body weight and condition, lactation numbers, milk protein, fat and solid not fats composition) 2). Pasture and forage (dry matter availability, digestibility and protein contents) 3). Supplement feed (nutrient composition and amount offered to animal) 4) Weather conditions (Temperature, humidity and wind) 5). Feeding strategy (scenarios) and 6). Economic information (feed costs and milk farm-gate price). The model is described in detail in León Velarde et al. (2006).

Statistical analysis: The general linear model (GLM) under MINITAB® 18 computer based statistical program was used to assess the effects of supplementary ration, lactation phase and experimental week on milk quantity and quality (Lesik, 2018). The following model was used: Yijk = μ + Si + Lj + Wk + (SL)ij + (SW)ik +(LW)jk + (SLW)ijk + Eijk. Where: Yijk is milk yield /nutrient composition of the i^{th} supplementary ration, in j^{th} lactation phase fed i^{th} ration on the k^{th} experimental week. μ = overall mean, Si = effects of the i^{th} supplementary ration, Lj = effects of the j^{th} lactation phase, Wk effects of k^{th} experimental week, (SL)ij = effects of the interaction between i^{th} supplementary ration and j^{th} lactation phase, (SW)ik = effects of the interaction between i^{th} supplementary ration and the k^{th} experimental week, (LW)jk = j^{th} lactation phase and the k^{th} experimental week and (SLW)ijk = effects of the interaction between i^{th} supplementary ration, j^{th} lactation phase and the k^{th} experimental week and Eijk = error term.

Moreover, One Way ANOVA was used to test the effect of supplementary rations on simulated milk yields, income, production costs, methane emission and manure excretion. Tukey’s Post Hoc test was used to perform all the pairwise comparisons to test the effects among the supplementary rations at P = 0.05.

Results

Animal conditions, milk yields and milk quality

The body weight and BCS was not affected by any of the analyzed variables (P > 0.05) (Table 3). The level of CLM-MB-MVP-MP supplementation was found to have an effect on milk yields (P < 0.001). In which, increase in amount of supplement offered to cows was resulting to increased milk yields (MY) as indicated in Table 3 and Figure 1. The un-supplemented cows yielded consistently low milk compared to the supplemented ones (Figure 1). Moreover, interactions between S and L, and between L and W had significant effects on MY (P < 0.001 and P = 0.02, respectively). Milk fat, protein, lactose and SNF composition were affected by SL (P < 0.05) (Table 3). Nonetheless, L and interactions between S and L had effects on milk protein content (P = 0.003 and P = 0.02, respectively) (Table 3).

ble 3 Effects of graded protein-energy rich supplementary feed on milk yield and composition, and interactions th the lactation stage and feeding week of lactating Friesian crossbred cows during the dry season in Western ambara highlands, Tanzania, 2018.

	Supplementary level (kg/cow/day)					P value						
riable	0	2	4	6	S.E.M	S	L	W	S x L	S x W	L x W	S x L x W
/(kg)	366^{a}	346^{a}	368^{a}	357^{a}	4.22	0.36	0.07	0.95	0.36	0.99	0.99	0.99
S	3.15^{a}	3.33^{a}	3.45^{a}	3.30^{a}	0.05	0.08	0.58	0.47	0.11	0.61	0.34	0.68
' (litre)	2.73^{d}	4.48^{c}	5.59^{b}	6.13^{a}	0.08	<0.001	0.18	0.22	<0.001	0.20	0.02	0.08
t (%)	3.77^{c}	3.88^{c}	4.24^{b}	4.98^{a}	0.09	0.001	0.09	0.55	0.08	0.78	0.43	0.73
otein (%)	2.91^{b}	3.15^{a}	2.96^{ab}	3.17^{a}	0.04	0.002	0.003	0.73	0.02	0.15	0.14	0.31
ctose (%)	3.86^{a}	3.94^{a}	3.59^{b}	3.81^{a}	0.03	0.01	0.09	0.11	0.27	0.49	0.16	0.47
IF (%)	6.99^{a}	7.25^{a}	6.55^{b}	6.95^{a}	0.06	0.001	0.53	0.45	0.17	0.80	0.91	0.88

riable means that do not share a similar superscript letter within the same row are significantly different. *P* values in italics licate statistical significance (P < 0.05). *SEM* stands for the overall standard error of the mean, *BW* body weight, *BCS* body ndition score, *MY* milk yield, *S* supplementation level, *L* lactation phase, *W* experimental week, *S x L, S x W, L x W, S x L x W* – eractions between the independent variables

Simulated impacts on milk yields, income and production costs

Supplementation was found to improve milk production significantly both in terms of per lactation and per day milk yields (P = 0.02 for the two variables) (Table 4). Similarly, supplementation level was found to have an effect on potential milk production (litre/lactation) (P = 0.017). However, simulated milk productions and associated milk yield per cow per day for both supplementation of 4 and 6 kg/cow/day did not differ significantly (P > 0.05) (Table 4). Furthermore, the lactation curves revealed that the simulated milk yields were below the theoretical production potential (15 – 20 litres/cow/day) of the Friesian – Zebu crossbred cows (Figure 2). Supplementation was found to increase both gross income and total production costs per lactation substantially (P = 0.018 and P = 0.042, respectively) (Table 4). Production cost per litre of milk which was highly influenced by milk yields differed significantly across all the supplementation levels (P < 0.001). Whereby, the production cost per litre of milk was highest for un-supplemented followed by supplemented cows in the in order of 2 kg/cow/day >6 kg/cow/day >4 kg/cow/day. Consequently, the income to cost ratios were affected and were in the order of 6 kg/cow/day >4 kg/cow/day > 2 kg/cow/day > 0 kg/cow/day (P = 0.019) (Table 4).

Table 4 Simulated bio-economic effects of graded supplementary concentrate feed on lactating crossbred Zebu-Friesian cows fed fed maize stover, napier grass, guatemala grass and natural pasture in wuhs, Tanzania

Variable	0 kg/cow/day	2 kg/cow/day	4 kg/cow/day	6 kg/cow/day	SEM	P Value
Simulated milk production (litre/lactation)	$1,342.50^{c}$	$2,193.50^{b}$	$2,936.75^{a}$	$3,000.75^{a}$	234.42	0.02
Milk yield per cow per day (litre)	4.10^{c}	6.57^{b}	8.80^{a}	9.06^{a}	0.70	0.019
Gross income (USD/cow/lactation)	596.79^{b}	975.20^{b}	1305.47^{a}	1344.56^{a}	104.30	0.018
Total cost (USD/cow/lactation)	1102.91^{b}	1231.87^{a}	1231.81^{a}	1232.02^{a}	1.61	0.042
Gross margin (USD/cow/lactation)	-506.12^{d}	-256.67^{c}	73.66^{b}	112.54^{a}	12.58	0.021
Price of milk (USD/litre of milk)	0.44	0.44	0.44	0.44	NA	NA
Production cost per litre of milk (USD)	0.89^{b}	0.57^{a}	0.43^{a}	0.45^{a}	0.06	<0.001
Income to cost ratio	0.54^{b}	0.79^{ab}	1.06^{a}	1.09^{a}	0.21	0.019

1 USD ≈ 2250 Tanzania shillings at the time of this study. SEM stands for standard error of the meanwhile NA stands for not applicable. Means that do not share a similar superscript letter within the same row are significantly different

Discussion

Observed animal conditions, milk yields and milk quality

The observed lack of significant influence of HSR supplementation on body condition and weight changes is attributed to short duration of this experiment. Roche et al., (2009) argued that the body condition of a lactating cow apart from feed is determined by interplay of other factors including hormones, lactation stage, gestation period, diseases and physical activity. However, effects of feeding on milk response can be observed within few hours or days upon altering either feed quantity or quality. The observation that increase in supplementation level was concurrent to milk yield increase was in agreement to our prior assumptions.

However, lack of significant difference between 4 and 6 kg HSR/cow/day could be attributed to the poor genetic potential of the cows. This is owing to the fact that there were no records on genotypes and breeding of the crossbred dairy cows at the study site. At Irente farm and nearby villages, estrous cows received bull services from crossbred Friesian bulls of untraceable origin while artificial insemination was not practiced. Thus, indigenous cattle genotype (*Bos indicus*) might have dominated that of temperate dairy cattle (*Bos taurus*) hence reducing milk production potential. This is also supported by Chagunda et al. (2016) who reported milk yields of 7.3 and 11.9 litres/cow/day for cattle with genotypes of 1/2 Friesian x 1/2 Malawi Zebu and 3/4 Friesian x 1/4 Zebu Malawi, respectively.

Nonetheless, the observed significant effect of HSR on milk quality improvement in particular milk fat is in agreement with Paterson et al., (1999). These authors reported that Calliandra based diet increased milk butterfat by 10% under the smallholder farming conditions in the Kenyan highlands. Therefore, implying that adoption of HSR feeding strategies has potential for improving both milk yields and quality in the WUHs.

Simulated impacts on milk yields, income and production costs

Similarly to observed milk yields the simulated milk yields had positive responses to HSR increments. Subsequently, income was also positively influenced by HSR supplementation as income was calculated based on milk sale using existing farm gate price. The finding that feed quality improvement improved both milk production and profitability is consistent with Shikuku et al. (2017). These authors projected that milk yields and incomes would increase by 42 and 48% respectively, if households in WUHs would improve dairy cattle diets in terms of energy and protein concentrations.

Nonetheless, low milk yields on un-supplemented or limited HSR supplemented cows were reflected on their higher production costs per litre of milk. This was possibly due to fixed costs including labour, animal health (vaccination and internal and external parasites control) and water which must be incurred regardless of the animal production level. Low farm gate milk prices was observed to be a major bottleneck at the study site whereby income to cost ratios (ICR) indicated that if milk price would increase by even a marginal percent will make dairying more competitive in WHUs. Comparably, Zvinorova et al., (2017) reported as low as an ICR of 0.6 and affirmed that incomes did not cover costs in smallholder dairying of Zimbabwe. Previous studies in WUHs (Maleko et al., 2018a; Shikuku et al., 2017), also emphasized on the importance of improving milk prices so that to incentivize farmers to adopt feeding and breeding technologies.

Nevertheless, lack of significance difference between 4 and 6 HSR kg/cow/day the ICRs implied that 4 HSR kg/cow/day is optimal if dairying is to be profitable in the WUHs. A sensitivity analysis was done by increasing the HSR to 8 kg/cow/day, milk yield increased to 9.65 lt/cow/day but the ICR was only 1.16 which is comparable to that of 4 kg/cow/day. Henceforth, this implies that most smallholder dairy farmers in WUHs do not break even due to low milk prices. The low farm gate milk prices are disincentive for farmers to supplement lactating dairy cows to their optimal milk production potentials due to the associated low or unprofitable gross margins

Furthermore, these findings suggest that for economic viability farmers should give more attention to high producing cows in their least cost supplementation programmes. Also, it indicates that the farmers' motive for keeping crossbred dairy cattle might be over-emphasized by other associated benefits of dairy cattle keeping. These benefits include milk for home consumption, manure for crops fertilization, fuel or sale, and cattle as a household asset.

Declarations

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Author contribution DM and GM conceived and designed research. DM and GM conducted experiments and analyzed the data. DM and KM wrote the manuscript. GM revised the final manuscript. All authors read and approved the manuscript.

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Data and material availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval The sampling protocols were granted ethical approval from the NM-AIST. The standard operating

Procedures for handling, feeding, milking and weighing of cattle were followed.

Consent to participate Authors agreed upon the roles and responsibilities taken towards one another throughout the study.

Consent for publication Authors grant the publisher the sole and exclusive license of the full copyright.

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

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Figures

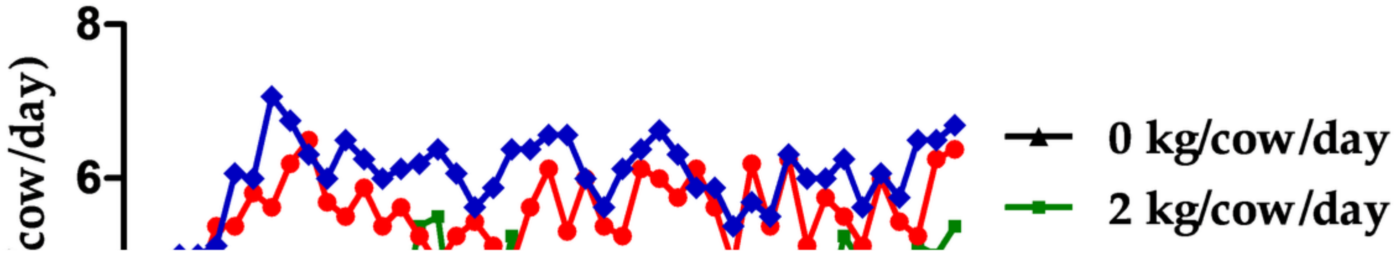

Figure 1

Effects of graded CLM-MB-MVP-MP supplementary concentrate feed on dry season milk production trends of lactating crossbred Friesian cows fed maize stover, Napier grass, Guatemala grass and natural pasture as basal feeds in September to October 2018, WUHs, Tanzania.

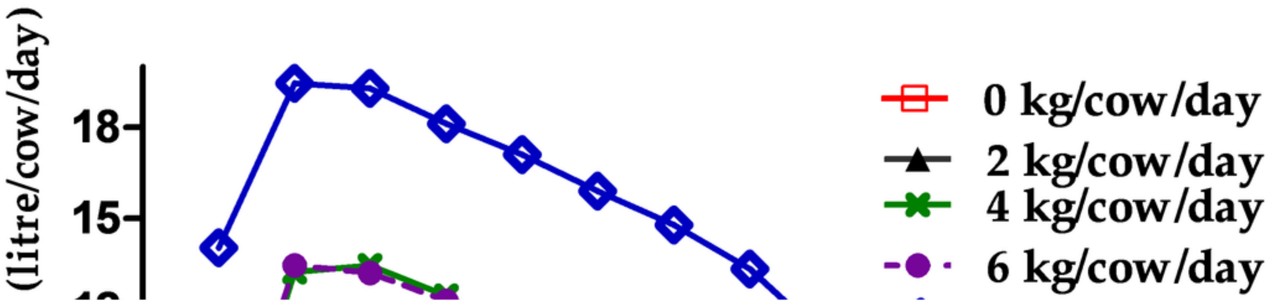

Figure 2

Simulated milk yields and potential milk production of lactating crossbred Friesian cows at the study site