

Research Article

Effects of Brewery Byproducts on Dairy Cows in Northern Tanzania

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Abstract

An on-farm monitoring experiment was conducted to assess the effect of supplementing lactating dairy cows with wet spent grain by-products (WSGB) on milk production, methane emissions, and economic profitability in smallholder dairy systems in Northern Tanzania. Forty (40) lactating cross-bred dairy cows, with equal numbers selected from two locations: Arusha City Council (ARCC) and Hai District Council (HDC) were subjected to two dietary supplements, wet spent grain by-products (S1) and common concentrates (S2) in a 2x2 factorial arrangement. Data on feed intake, milk yield, milk composition and methane emissions were recorded for a period of 30 days, including 7 days of adaptation. An economic analysis was performed to evaluate the profitability of the two supplements in the study areas. Body weights (BW) were estimated using heart girth width measured using weighing bands. Near-Infrared spectroscopy (NIRS), lactoscope 300^{MT}, and laser methane detector (LMD) were employed to determine the chemical composition of the feedstuffs, milk quality and methane (CH₄) emissions from the cows, respectively. The results showed that the average values (%) of crude protein (CP) and neutral detergent fibre (NDF) of supplement S1(21.93 and 53.35, respectively) were higher ($P<0.05$) than those of S2(12.63 and 29.12, respectively). The mean values of intake (g/kg BW) of CP and supplement NDF were higher ($P<0.05$) in cows supplemented with S1(3.23 and 3.06, respectively) than those on S2(2.48 and 1.04, respectively). Similarly, cows supplemented with S1 had higher ($P<0.05$) average yields of milk (39.7 g/kgBW), milk fat (308 g/kg of milk) and milk protein (449 g/kg of milk) than those on S2(33.64, 201.96, and 358.25, respectively). The gross margin (TZSH, per litre of milk) was higher ($P<0.05$) for cows fed on supplement S1 (777.38) than those on S2(622.48). In terms of location, cows in ARCC had a greater gross margin (701.08) than those in the HDC (698.8). The amount of methane (g/litre of milk) emitted from the cows on S1(11.7) was lower ($P<0.05$) than their counterparts in S2 (17.2), and the intensity was more pronounced in ARCC (17.27) compared to HDC (11.54). It is concluded that wet spent grain byproduct is a valuable supplement for dairy cows, effectively enhancing milk yield, gross margin from milk sales and lowering methane emissions. Further investigation is recommended into the optimal level of combination of brewery by-products with common concentrates to optimize nutrition and production potential of the cows.

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Received: 2 January 2026; **Accepted:** 27 January 2026; **Published:** 11 February 2026



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Keywords

Wet Spent Grain By-products, Dairy Cows, Milk Production, Methane emission, Smallholder Dairy Farmers, Economic Profitability

1. Introduction

Small dairy farming plays a vital role in enhancing livelihoods and ensuring food security in Tanzania. However, smallholder dairy farmers are facing several challenges that hinder productivity and sustainability of their animals. One of the major limiting factors is poor accessibility to affordable and nutritious feeds. As a result, farmers struggle with low levels of milk production, reducing their income and ability to meet household needs through dairy sales [1]. Additionally, environmental concerns associated with livestock farming, particularly methane (CH₄) emissions from enteric fermentation in ruminants pose significant ecological risks [2]. Despite these obstacles, dairy farming remains an essential source of income and nutrition for many households. Thus, addressing the challenges is crucial for improving productivity and sustainability of the dairy sector.

In dairy farming, supplementation has emerged as a key strategy to enhance performance by improving nutrient balance and milk production. In addition, concentrate supplementation is known to lower CH₄ emission by 2.5 to 15 percent, improving both feed efficiency and overall milk production [3]. Nevertheless, utilizing some by-products generated from the agro-industrial sector as cattle feed could offer a viable solution to feed shortages [4, 5], essentially diluting the methane output relative to milk yield [6]. Previous research revealed that cows fed residual grains from beer brewing emit 13 percent less methane than those on conventional grain-based diets [7-9]. This reduction occurs because the brewing process alters the nutritional composition of the grains, making them easier for cattle to digest, hence, less fermentation gases, primarily methane are released during digestion. By optimizing feed composition, it is anticipated to balance between production and conservation, while ensuring dairy farming is both commercially viable and environmentally responsible.

The nutritional quality of brewing by-products, specifically wet spent grain, depends on the type of grain, additives and procedures used during beer making. Protein content ranges from 19.4 to 34 percent, while levels of neutral detergent fibre fall between 43 and 56 percent [7]. Correspondingly, the by-products are rich in nutrients, with 71 to 75 percent total digestible nutrients (TDN), making them a suitable supplement [10]. Brewing by-products have tendency of changing the rumen composition, which influence digestion efficiency, nutrients absorption and productivity of dairy cows [4]. Additionally, dairy cows supplemented with wet spent grain byproduct showed a

21.9 kg higher live body weight and produced 2.3 litres of milk more compared to those fed on conventional concentrates [11]. By incorporating brewery waste, as part of dairy nutrition could evolve to change both productivity and environmental sustainability, offering an economic solution, while contributing to methane mitigation efforts. Moreover, dairy cows, similar to other ruminants are known to generate methane in their normal digestion from microbial fermentation and methanogenesis leading to a loss of 2 to 12 percent of the animal energy intake. However, the amount of methane emission is influenced by the quality and amount of feed consumed by the animal [12]. Therefore, investigating alternative feed supplements to promote ecological protection from dairy farming by reducing methane emissions is imperative. Despite these benefits, scarce information is available on the usage of brewery by-products from the beer processing plants in the Northern Tanzania as feed supplement to dairy cows. The present study was planned to evaluate the effects of supplementing wet spent grain byproduct to lactating dairy cows on the feed intake, milk yield and quality and methane emissions from the cows in northern Tanzania.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in Arusha City and Hai districts in northern Tanzania. Arusha City is situated at a coordinate of 3°23'12.93" S and 36°40'58.78" E, with an elevation of 1,500 meters above sea level. It has average temperatures ranging from 21–24 °C and annual rainfall between 800–1,000mm [11]. Hai district is situated at coordinates of 3°24'30.24" S, 37°10'7.32" E, in the Kilimanjaro region [13]. It has an average temperature of 23.3 °C and experiences bimodal rainfall of an average of 521 mm, with long rains from March to June and short rains in November and December [5].

2.2. Nature and Design of the Study

The study was a monitoring experiment conducted on-farm for 30 days, including 7 days of adaptation and 23 days of data collection. Forty (40) lactating dairy cows were split into two equal groups and allocated into a 2 × 2 factorial arrangement to determine the effects of two dietary supplements and two locations on feed intake, milk yield and composition, methane

emission and economic analysis of milk production from the cows. The dietary supplements constituted of wet spent grain brewery by-products (S1) and common concentrates (S2), while the locations included Arusha City Council (ARCC) and Hai district council (HDC).

2.3. Source and Selection of Experimental Animals

The forty (40) crossbred dairy cows were selected from farmers who were participants of the Enviro-cow project, operated in northern Tanzania. The Enviro-Cow project was addressing concerns on climate change in African cattle production systems. The criteria used in selecting the cows were being 65-85 percent exotic breed, with an average parity of 3.5, calved within two months at the start of the experiment. Others include the type of supplement used, either wet spent grain byproduct or common concentrates, producing a minimum of 6 litres of milk per day and being in good health condition. The cows were purposefully selected from a total of 16 farms or households in two locations of ARCC and HDC, as illustrated in Table 1.

Table 1. Distribution of the experimental cows within the farms, dietary treatments and locations during the experiment.

Location	ARCC		HDC	
Supplement	S1	S2	S1	S2
Number of farms	5	5	3	3
Number of cows	10	10	10	10

In this and subsequent tables: ARCC-Arusha City council, HDC-Hai district council, S1-Wet spent grain byproduct, S2-Common concentrates.

2.4. Management and Feeding of Experimental Cows

Prior initiation of the experiment, the body weight of each cow was estimated using a measuring band to determine the heart girth, following the method described by [14, 17]. The experimental cows were housed in well-ventilated buildings, some in individual pens, while others were in shared pens with neck-tied on poles with ropes. The feeding of basal and supplement feed to cows by the farmers were based on routine and consistency. The source of basal feed for all cows was mainly crop residues and cut and curry forages. Crop residues were purchased from nearest farms and others were obtained from their own farms, stored in forage stores. The cut and curry fodders were harvested from river sides, farm boundaries and roadside. The compounded concentrates were purchased from the local markets, in addition with some

sourced from the farms. The brewery by-products were purchased either directly from the beer processing industry or from the local distributors, who procured in large volumes from the industry. Brewery byproduct, wet spent grain in particular, was normally stored in storage pits. The normal farm management and feeding practices were followed, whereby the feeds were supplied and feeding of the experimental cows was performed by the farmers. In feeding the dairy cows, farmers alternated between stored crop residues and fresh cut-and-carry fodder, ensuring nutritional balance for the cows. The forage was chopped into 3-4 cm pieces, a process achieved using either manual or automated grass choppers. The amounts of chopped forage mixture from crop residues and cut and curry forage were measured separately. During each feeding session, forage materials were packed into sacks or bundles tied with rope for weighing using a digital scale. Forage materials were offered ad libitum to exploit sufficient nutrients from forages. The leftover of forage from each feeding trough was collected and measured each morning before the next feeding. Concentrate supplements were carefully split into four allowances for each cow and offered before and after each milking session. The common concentrate and wet spent grain by-products were poured into a bucket suspended on a hanging digital scale to determine their weights. The amount of concentrate feeds offered to dairy cows was restricted based on the cost of the feeds and production level of the cow. The farmers measured the amounts of feed offered and recorded the amounts of refused feed. The farmers were facilitated with digital weighing scales for weighing feeds. To ensure precise data recording, research farmers were trained on the various research procedures, including the use of the weighing scales. The experimental cows had free access to clean drinking water, occasionally mixed with concentrates to encourage water intake.

Milking of the cows was done by hand, from 0500 to 0700h and from 1600 to 1800h. The milk from each cow in each milking session was poured into a graduated measuring jug to record the volume. The amounts of milk obtained during morning and evening were recorded in the farm production books and added together to obtain the total daily milk yield per cow. All these activities were performed by the farmers with some assistance from the researcher and the project research agent (PRA).

The concentration of methane emitted from each cow was measured twice per cow at the start and the end of the monitoring period. The measurements were conducted during the daytime, after the morning milking and before evening milking, at around 0800 h and 1500h. A handheld Laser Methane Detector (LMD, Tokyo, Japan Engineering Co., Ltd) was employed to measure methane concentration from the nostrils of the cow according to the procedures described by [18]. Before taking the measurements of an individual cow, the ambient levels of CH₄ around the shed were recorded for 5 minutes. The concentration of CH₄ was recorded at a

distance of 2.5 meters from the cow, targeting the nostrils, while adjusting the distance based on the activity of the cow to ensure a minimum distance of 3.5 meters between animals.

2.5. Feed and Milk Sampling and Laboratory Analyses

Samples of different types of forages offered to the cows were collected from the 16 farms, twice a week during the monitoring period. To ensure a comprehensive representation of the feed offered, samples were taken from both the farm feed stores and freshly cut bundles. The feed was collected after identifying the types of feed offered to cows from the feeding troughs and explanations from the cow attendants. The fresh forage samples were initially weighed at 500 grams and placed in paper bags for immediate spread on a clean drying tarp sheet in a well-ventilated room for air drying. After drying for two weeks, the samples were reweighed and then the air-dried samples were prepared for laboratory analysis. Samples of commonly used concentrates were collected from the feed stores of each farm. A total of 64 samples of common concentrates were collected. Samples of wet spent grain by-products were collected from each farm storage pit twice per week in a plastic zip bag and kept under a cold chain (4 °C) to preserve their original state. Sampling of milk was performed at the start and end of the experimental period. Milk samples were collected directly from the teats of each cow into 50 ml sterilized vials. Before sampling, the teats were cleaned with warm water and wiped with a white towel to remove dirt and contaminants. Immediately after collection, the milk samples were instantly refrigerated at 4 °C for subsequent laboratory analysis.

The dry matter (DM) content of the wet spent grain byproduct was estimated by freeze-drying, according to the procedures of AOAC [19], while the DM of the air-dried forage samples and common concentrates were estimated using the Near-infrared spectroscopy (NIRS) technique as described by [20]. The feed samples were analysed for crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) using the Near-infrared spectroscopy (NIRS) techniques explained by [20]. The metabolizable energy contents of the feed samples were predicted using their chemical components as detailed in [21]. Milk samples were analysed to determine the fat, protein, lactose, total solids, and solids-non-fat contents in the milk using a Lactoscope 300^{MT} machine, following laboratory protocols described by [22]. The chilled milk samples were thawed to 39–40 °C homogenised using a Vortex mixer and then analysed to display results automatically.

2.6. Parameters Derived

Forage intake was calculated by subtracting the weight of the refused forage from the weight of the forage offered. The total feed consumed was determined by adding the quantities of forage and concentrate ingested by the cows. Daily dry matter intake per cow was estimated following the established

methods [14], which considered both the total feed consumed and its dry matter content from the laboratory. To calculate the nutrients intake relative to body size, the total dry matter intake (DMI) was multiplied by the nutrient concentration in the feed, followed by dividing by the body weight (BW) of the cow. The total daily milk yield per cow was calculated by summing the production from both milking sessions throughout the experimental period. The milk yield in litres was converted to mass by multiplying the volume by the density of milk, which was taken as 1030 g per litre [15]. This conversion facilitated the expression of milk production in mass units, which was subsequently divided by the body weight of the cow to estimate yield in grams per kilogram BW. Parameters of milk quality, such as fat or protein percentage, were similarly converted to absolute values by multiplying the percentage based quality metric by the total milk yield in grams [16]. This allowed for a direct comparison of daily milk components in grams.

The data collected on methane emissions were processed following the procedure described by [23]. The CH₄ emissions were quantified using processed measurements converted from parts per million-meter (ppm*m) to grams per day, following the calibration methodology described by [24]. To contextualize emissions relative to the size of the cow, the daily methane output was divided by the average body weight of the animal, yielding CH₄ production per kilogram of BW. Additionally, CH₄ per unit of feed intake was calculated by dividing daily CH₄ production by the daily dry matter intake by the cow (TDMI), forage intake (FDMI) and supplement intake (SDMI), while CH₄ per litre of milk was derived by dividing total daily emissions by the density of milk produced.

The quantitative approach was used to determine the gross margins (GM) in assessing the economies of supplementation from the cows supplemented with different types of concentrates, mainly wet spent grain by-products (S1) and common concentrates (S2). The total variable cost was calculated per cow per day, including the costs of forages and concentrates based on the market price. The price of S1 was TSH 120/= and 160/= per kg for ARCC and HDC, respectively, while the prices of forage and S2 were TSH 291/= and 750/= per kg, respectively, in both locations. The other management costs, such as water, labour and medication, remained constant for both locations. The total revenue (TR) was estimated based on the average milk yield multiplied by the market price of milk, which was TSH 1200 per litre. The gross margin of the cow per day was calculated by subtracting the value of total revenue and the total variable cost as detailed in [25]. The gross margin per litre of milk was calculated by dividing the gross margin obtained per day by the amount of milk produced per day.

2.7. Statistical Analysis

The data were subjected to a general linear model procedure of JMP[®] Pro 18 version 2024 of statistical analysis of science

[26] to examine the effects of the supplements, locations and their interactions on the parameters of performance, methane emissions and economic analysis of using the supplements. In the model, the initial body weights of the cows were included as a covariate during the analyses. The student t-tests were used to compare the difference between means due to supplements and locations, while Turkey's HSD post-hoc test was employed to compare means between interaction effects of supplements and locations.

3. Results

3.1. Nutritional Values of the Feedstuffs

The Lsmeans of the nutritional values of supplements and forage mixtures offered to the experimental cows in the two locations during the experiment are presented in Table 2. The mean values of dry matter (DM) and metabolizable energy (ME) contents of supplement 1 (S1) were lower ($P<0.05$), while the mean values of crude protein (CP), neutral detergent

fibre (NDF) and acid detergent fibre (ADF) were higher ($P<0.05$) than those of supplement 2 (S2). The composition of the supplements varied ($P<0.05$) between locations, whereby the mean values of DM contents of both supplements (S1 and S2) were lower ($P<0.05$) in Location 1 (ARCC) than those in Location 2 (HDC). The Lsmeans of the CP, NDF and ADF contents of S1 were higher ($P<0.05$) for samples collected in ARCC than those in HDC. On the other hand, the mean value of ME content of the samples of S1 collected in HDC was greater ($P<0.05$) than those collected in ARCC. Conversely, the mean value of ADF content of samples of S2 collected in ARCC was higher ($P<0.05$) than those collected from HDC. The mean value of ME content of supplement S2 in ARCC was similar ($P>0.05$) to that of HDC. The Lsmean of DM content of the samples of forages collected in ARCC was significantly higher ($P<0.05$) than those from HDC. The mean CP content of the forages was higher ($P<0.05$) in samples collected in HDC compared to those of ARCC. The Lsmeans of NDF and ADF contents of forages were higher ($P<0.05$) in samples collected in ARCC, whereas the mean value of ME content was lower ($P<0.05$) than those from HDC.

Table 2. Lsmeans $\pm$ SEM of the effect of location on the nutritional values of the supplements and forage mixtures given to the experimental cows.

Feed type	Supplement/ Location	No of observations	Components (% DM)				
			DM	CP	NDF	ADF	ME (MJ/KgDM)
Supplements	S1	64	29.98 ^b	21.93 ^a	53.35 ^a	28.02 ^a	10.59 ^b
	S2	64	85.6 ^a	12.63 ^b	29.17 ^b	15.84 ^b	11.03 ^a
	SEM		0.67	0.28	0.49	0.61	0.11
	P-value		<0.0001	<0.0001	<0.0001	<0.0001	0.005
Supplement 1 (S1)	ARCC	40	25.86 ^b	23.23 ^a	54.55 ^a	30.92 ^a	10.43 ^b
	HDC	24	34.11 ^a	20.64 ^b	52.15 ^b	25.12 ^b	10.77 ^a
	SEM		0.32	0.21	0.75	0.54	0.08
	P-value		0.0001	0.0001	0.032	0.0001	0.004
Supplement 2 (S2)	ARCC	40	83.7 ^b	12.58	28.14	17.19 ^a	11.23
	HDC	24	87.5 ^a	12.68	27.93	14.49 ^b	11.02
	SEM		0.45	0.4	0.56	0.67	0.19
	P-value		0.0001	0.861	0.95	0.008	0.891
Forage mixture	ARCC	80	56.96 ^a	3.46 ^b	62.23 ^a	38.39 ^a	6.27 ^b
	HDC	48	44.81 ^b	5.32 ^a	54.62 ^b	34.65 ^b	7.06 ^a
	SEM		2.8	0.22	1.04	1.01	0.14
	P-value		0.007	0.0001	0.0001	0.011	0.001

In this and subsequent tables: DM - dry matter, CP-crude protein, NDF-neutral detergent fibre, ADF-Acid detergent fibre, ME-Metabolizable energy, SEM-standard error of the mean, ARCC-Arusha City, HDC-Hai district council, a, b -mean values with different superscript letters within the column are significantly different at $P \leq 0.05$

3.2. Body weight and Nutrients Intake

The Lsmeans of the influence of the supplements and locations on the body weight, dry matter and nutrients intake by the cows during the monitoring period are given in Table 3. The mean body weights of the cows on the different supplements and locations were similar ($P>0.05$) except the mean difference between the initial and final body weights was higher in ARCC than HDC. The mean differences in dry matter intake (kg DMI) between the cows on the different supplements and locations were not significant ($P>0.05$). The average intake (kg DM) of crude protein (CPI), neutral detergent fibre (NDFI) and acid detergent fibre (ADFI) by the cows on S1 was greater than those on S2, however, the intake (DM) due to supplement was higher on S2 than those on S1. On the other hand, the lsmean of the intake of neutral detergent fibre from the supplements (NDFS) by the cows on the S1 was higher ($P<0.05$) than those on the S2. In terms of location, the mean differences in the intake of NDF, DMS, NDFS and NDFE were higher ($P<0.05$) by the cows from ARCC than those of the HDC. There were significant interaction effects between supplement and location on the

intake of DM and NDF from the supplements as illustrated in Figure 1. The differences in the mean dry matter intake (g DMI/kg BW) by the cows were neither significantly different between supplements nor locations. The Lsmeans for the intake (g/kg BW) of crude protein (CPI), neutral detergent fibre (NDFI) and acid detergent fibre (ADFI) by the cows on S1 were higher ($P<0.05$) than those on S2. In addition, while the mean intake of supplements (DMS) by the cows been higher on S2 than S1, the intake of supplement NDF (NDFS) was higher on S1 than S2. The mean values of intake of NDF, DMS, NDFS and NDF from forages (NDFE) were higher ($P<0.05$) by the cows from ARCC than those of HDC. There were significant ($P<0.05$) interaction effects between supplement and location on the intake of DM and NDF from the supplements. The supplement DM intake (g/kg BW) by the cows in ARCC was higher on S2 than on S1, while in HDC, the intake by the cows was higher in S1 than in S2. Furthermore, the mean differences of TDM intake by the cows in kg DM were insignificant ($P>0.05$) for both supplements and locations; however, the level of intake by cows in g/kg BW was higher in ARCC than in HDC.

Table 3. Ls means $\pm$ SEM on the effects of the type of supplements and locations on the body weight(kg), dry matter intake (kg DM) and nutrient intake (g/kg DM and g/kg BW) by the cows during the experiment.

Parameter	Supplement				Location				S*L
	S1	S2	SEM	P-value	ARCC	HDC	SEM	P-value	P-value
N	20	20			20	20			
Body weight(kg)									
Initial BW	376.22	348.71	10.07	0.61	372.66	352.28	10.09	0.061	0.09
Final BW	420.03	392.54	10.55	0.07	414.41	398.16	10.57	0.28	0.15
BW change	44.92	43.82	8.78	0.99	62.13 ^a	25.5 ^b	8.79	0.005	0.81
Nutrients intake (kg DM/d)									
TDM	11.16	10.4	0.38	0.17	11.53	10.45	0.315	0.051	0.46
CP	1.17 ^a	0.98 ^b	0.05	0.02	1.13	1.01	0.053	0.092	0.797
NDF	6.61 ^a	5.49 ^b	0.27	0.004	6.64 ^a	5.46 ^b	0.264	0.002	0.062
ADF	3.84 ^a	2.79 ^b	0.143	0.009	3.27	3.06	0.148	0.277	0.071
DMS	2.89 ^b	4.11 ^a	0.168	0.0001	3.77 ^a	3.23 ^b	0.17	0.028	0.0001
NDFS	1.57 ^a	1.21 ^b	0.06	0.0001	1.57 ^a	1.43 ^b	0.045	0.035	0.0001
DMF	8.03	6.98	0.586	0.957	7.18	6.83	0.583	0.673	0.957
NDFE	5.12	4.39	0.134	0.076	5.3 ^a	4.09 ^b	0.187	0.004	0.051
Nutrients intake (g/kg body weight)									
DM	29.24	28.78	1.01	0.74	30.54 ^a	27.47 ^b	1.011	0.034	0.061
CP	3.23 ^a	2.48 ^b	0.16	0.002	2.99	2.72	0.164	0.26	0.08

Parameter	Supplement				Location				S*L
	S1	S2	SEM	P-value	ARCC	HDC	SEM	P-value	P-value
NDF	17.95 ^a	14.53 ^b	0.77	0.0002	17.2 ^a	15.26 ^b	0.774	0.0009	0.569
ADF	9.59 ^a	8.01 ^b	0.51	0.031	9.39	8.21	0.52	0.105	0.85
DMS	9.46 ^b	11.39 ^a	0.45	0.0001	10.99 ^a	9.46 ^b	0.45	<0.0001	0.0001
NDFS	3.06 ^a	1.04 ^b	0.17	0.0001	2.17 ^a	1.77 ^b	0.212	0.0001	0.0003
DMF	19.94	16.91	1.37	0.126	19.56	18.29	1.372	0.37	0.102
NDFF	14.95	13.57	0.69	0.56	15.03	14.49	0.66	0.681	0.059

In this and subsequent tables, TDMI- Total dry matter intake, DMIS- Supplement dry matter intake, NDFS-Supplement neutral detergent fibre intake, DMF-Forage dry matter intake, NDFF-Forage neutral detergent fibre intake.

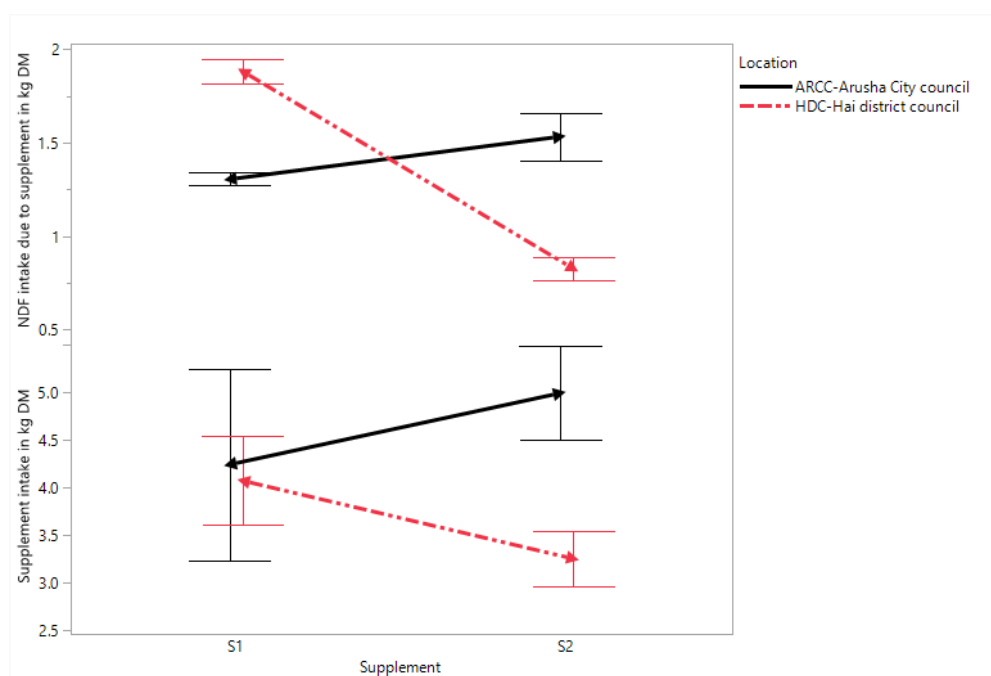


Figure 1. The trends of supplement intake in kg DM and NDF intake due to supplement in kg DM by the cows, as influenced by supplements in their locations.

3.3. Milk yield and Quality Attributes

Table 4 presents the Lsmeans on the effect of supplements and locations on the quantity and quality of milk from the experimental cows. The Lsmean on the quantities of milk produced by the cows on S1 was higher ($P < 0.05$) compared to that from S2. The mean value of the milk produced by cows in HDC was slightly higher ($P > 0.05$) than that produced by

cows in ARCC. The average yield of milk fat from the cows fed on S1 was higher ($P < 0.05$) than that from S2. The yield of milk protein shown by cows supplemented with S1 was higher ($P < 0.05$) than that presented by cows supplemented with S2. Furthermore, milk yield of solids was higher ($P < 0.05$) in cows supplemented with S1 compared to those on S2. There were minimal differences ($P > 0.05$) on the milk quality attributes observed between ARCC and HDC.

Table 4. *Lsmeans ± SEM on the effects of supplements and locations on the yield and quality of milk produced from the experimental cows.*

Parameter	Supplement				Location				S*L
	S1	S2	SEM	P-value	ARCC	HDC	SEM	P-value	P-value
n	20	20			20	20			
Milk yield (kg/d)	15.78 ^a	13.06 ^b	0.586	0.007	13.97	14.8	0.485	0.25	0.981
Milk yield (g/kg BW)	39.68 ^a	33.64 ^b	1.163	0.0004	36.937	36.385	1.163	0.73	0.891
Milk composition (g/kg of milk)									
Number of samples	40	40			40	40			
Fat	308.2 ^a	201.96 ^b	20.19	0.0004	240.88	269.28	20.189	0.323	0.066
Protein	448.94 ^a	358.25 ^b	27.89	0.023	433.15	374.17	27.88	0.948	0.915
Lactose	630.37	565.78	31.45	0.301	605.52	590.62	31.45	0.738	0.301
Solids	1543.1 ^a	1122.9 ^b	67.01	0.0001	1377.6	1288.4	67.014	0.35	0.184
Solid not fat	1153.13	1008.63	56.12	0.0721	1081.1	1080.6	56.119	0.99	0.573

3.4. Methane Emissions

Table 5 shows the Lsmeans of the effects of supplements and locations on the levels of methane (CH₄) emissions from the experimental cows during the monitoring period. The mean values of CH₄ emissions from the cows supplemented with S1 was slightly higher ($P>0.05$) than those from cows on S2, regardless of the mode of expression, except the Lsmean values of CH₄ in grams per kg of milk. The Lsmean of CH₄ emission per unit of milk was lower ($P<0.05$) in cows supplemented with S1 compared to their counterpart in S2. The levels of CH₄ tended to be affected by the locations, whereby cows in ARCC showed higher ($P<0.05$) amounts of CH₄ compared with those in HDC, except when the amount

of CH₄ emission was expressed per kilogram of forage dry matter intake, where similar ($P>0.05$) mean values were observed. Furthermore, there were significant ($P<0.05$) interaction effects between supplements and locations on the mean values of CH₄ emissions, when expressed as grams per day, and per intake of DM and supplement dry matter (g/SDMI) as illustrated in Figure 2. The common trend was that the differences in the levels of methane emissions between the cows in ARCC and those in HDC were much wider when the cows were offered supplement S1 than S2. While the levels of CH₄ emissions from the cows in ARCC decreased drastically when offered supplement S2, the levels from cows in HDC were increasing slightly, bringing a convergent point.

Table 5. *Ls means ± SEM on the effects of supplements and locations on the amount of methane emissions from the cows used in the study.*

Parameter (g)	Supplement				Location				S*L
	S1	S2	SEM	P-Value	ARCC	HDC	SEM	P-Value	P-Value
Methane emission									
Per day	261.97	205.65	24.503	0.11	308.10 ^a	159.52 ^b	24.51	0.0001	0.029
Per kg body weight	0.621	0.601	0.049	0.708	0.73 ^a	0.49 ^b	0.049	0.001	0.756
Per DM intake									
DM	24.19	19.28	2.62	0.19	28.06 ^a	15.41 ^b	2.62	0.0013	0.037
Forage	58.05	32.59	20.81	0.155	66.54	34.09	20.81	0.392	0.344
Supplement	84.39	56.09	11.43	0.086	92.11 ^a	48.37 ^b	11.43	0.009	0.009

Parameter (g)	Supplement				Location				S*L
	S1	S2	SEM	P-Value	ARCC	HDC	SEM	P-Value	P-Value
Per kg of milk	11.68 ^b	17.2 ^a	2.026	0.005	17.27 ^a	11.54 ^b	2.026	0.0003	0.689

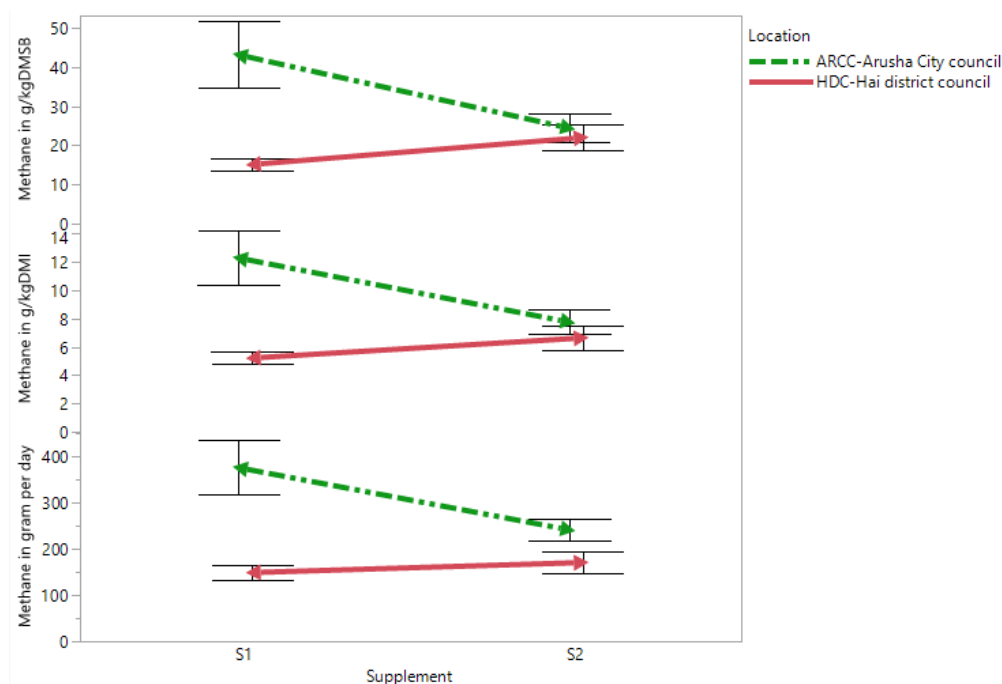


Figure 2. Trends on the levels of methane emissions from the experimental cows as influenced by the supplements and locations.

3.5. Total Variable Cost, Revenue and Gross Margin

Table 6 presents the influence of the type of supplements and locations on the economic analysis of the experimental cows. Cows supplemented with S1 had lower ($P < 0.05$) total variable costs than those on S2. The mean total revenue per day was higher ($P < 0.05$) for cows on S1 compared to those on S2, while the revenue per litre of milk was similar ($P > 0.05$) for both groups of cows. Cows on S1 had higher ($P < 0.05$) mean value of gross margin than those on S2. Location had less ($P > 0.05$) influence on all the economic parameters assessed in the study. The effects of the interaction between

the supplements and locations were significant ($P < 0.05$) for the total variable costs (TVC), total revenue (TR) and gross margin (GM) as illustrated in Fig.3. The mean total variable cost per litre of milk (TVC/L) for cows in ARCC was lower compared with those of HDC when supplemented with S1, however the opposite trend was observed when supplied with supplement S2, where the average cost was much higher in ARCC than HDC. Similarly, the average total revenue per cow per day (TR/day) for cows in ARCC was lower than their counterparts in HDC when supplemented with S1, but higher than that in HDC when given S2. The gross margin per litre of milk (GM/L) for cows in ARCC was higher than those in HDC when supplemented with S1, and the opposite trend was observed with S2.

Table 6. Lsmeans $\pm$ SEM of the effects of types of supplement and locations on the economic analysis of supplementing cows in the experiment.

Parameter (TZSH)	Supplement				Location				L*S
	S1	S2	SEM	P-Value	ARCC	HDC	SEM	P-Value	P-Value
TVC/d	6202.8 ^b	7274.3 ^a	209.81	0.0006	6776.5	6701	207.91	0.797	0.0001
TVC/L	425.63 ^b	609.82 ^a	25.83	0.0001	533.81	501.6	25.59	0.378	0.008

Parameter (TZSH)	Supplement				Location				L*S
	S1	S2	SEM	P-Value	ARCC	HDC	SEM	P-Value	P-Value
TR/d	18178 ^a	15447 ^b	490.74	0.0002	16730	16895	486.31	0.81	0.0009
TR/L	1203	1232.3	15.81	0.199	1200.4	1235	15.68	0.127	0.125
GM/d	11975 ^a	8173 ^b	543.3	0.0001	9953	10195	538.4	0.752	0.0023
GM/L	777.38 ^a	622.48 ^b	26.15	0.0001	701.08	698.8	25.92	0.95	0.005

TZSH – Tanzanian shillings, TVC/d-Total variable cost per day, TVC/L-Total variable costs per litre of milk, TR/d- Total revenue per day, TR/L-Total revenue per litre of milk, GM/d- Gross margin per day, GM/L-Gross margin per litre of milk

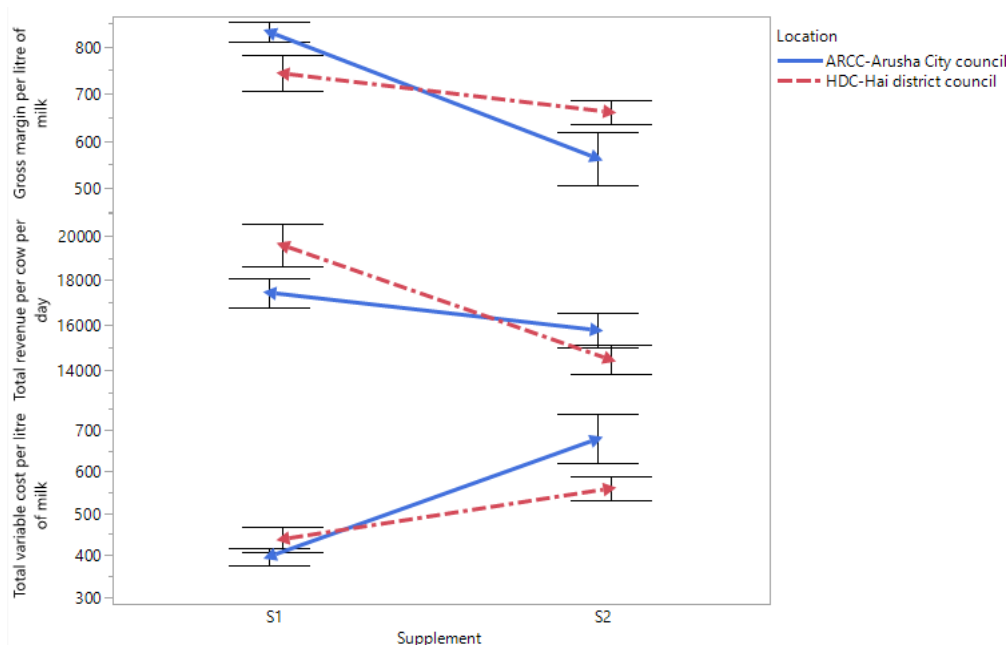


Figure 3. The trends in Tanzanian Shillings of the variable costs, revenue and gross margins from the experimental cows as influenced by supplements and locations.

4. Discussion

The current study aimed at examining the effect of supplementing lactating cows with wet spent grain by-products (WSGB) on milk production, methane emission and their economic profitability on lactating dairy cows managed by smallholder farmers in northern Tanzania. The observed higher average crude protein (CP) content in supplement 1 (S1) than that in supplement S2 could be due to the higher nutritional value of the raw materials used in beer making, such as yeast and other additives for enhancing the fermentation process during beer making. These materials could have improved the protein level of the WSGB relative to the concentrate feeds commonly used in the study areas. In contrast, supplement S2 with common concentrate feeds is normally formulated using minimal protein ingredients, such

as sunflower and cottonseed cake, which contain relatively low protein content. The result aligns with those of [3, 11, 27] who reported the range of CP content of brewery by-products as 19 to 30%, while that of common concentrate feeds as 11 to 16%. The reported result for supplement S1 supplemented to cows on supplement S1 is above the recommended CP level for lactating dairy cows demonstrated by [33], which could result in higher performance of cows on milk yield than expected compared to their counterparts fed on supplement S2. The observed higher neutral detergent fibre (NDF) in the S1 than that in the S2 was caused by the composition and types of raw materials, such as barley and sorghum husk remains as by-products after the processing of beer during brewing. The NDF content of S1 observed in the present study accords with the values of 51 and 54% reported by [11, 27]. The observed higher mean value of metabolizable energy (ME MJ/kg DM) in S2 than S1 was attributed to the type of ingredients used in compounding the common concentrates, which are dense in

energy sources, such as hominy feed and wheat feed. The result on the mean ME content of the common concentrates (S2) was higher compared to the value of 10.5 MJ/kg DM reported by [28] for the common concentrates fed to crossbred dairy cows in East Africa, however the Lsmean of ME of supplement S2 from this study was in range with the recommended ME for lactating dairy cows with 11.2 to 12 MJ/Kg DM reported by [33] from supplement. The significant differences in the nutritional value of supplement S1 between ARCC and HDC could be attributed to the differences in the raw materials used in making the specific type of beer manufactured during the time of collection of the WSGB. The present findings accord with those reported by [11], that each type of beer has specific requirements of materials, which may result in by-products of different quality. Similarly, the observed variation between ARCC and HDC on the nutritional values of common concentrates could be due to the types of ingredients available in their area for compounding the concentrates. For instance, the higher mean acid detergent fibre (ADF) content in the S2 in ARCC indicates that there is a higher level of indigestible components in the concentrates than in those in HDC. In HDC, some farmers purchase and feed commercial dairy meal to the cows, which could explain the lower ADF contents in S2 compared with those of ARCC.

The observed higher values of DM and NDF contents of forage mixtures fed to the cows in ARCC than those in the HDC were attributed to the feeding practices. In ARCC, farmers were highly dependent on the crop residues, which were stored in the feed stores for a long time before they were fed to the cows. The result was similar to that reported by [29], that the lower quality of forage materials in urban areas was contributed by the dependence on crop residues, which are mature, with high lignin content. Additionally, in ARCC, forage materials were sourced from natural pasture, along the roadside and river areas, whereas in the HDC, most forage materials were obtained from the established pasture plots and along the farm boundaries, only a few farmers were sourced forages from the river sides. The results on the nutritional values of forages were within the ranges of 2.9- 5.9% CP, 65-73% NDF and 5.9 to 6.7 MJ/kg DM, reported by [29] for a basal diet made up with crop residues and fed to dairy cows in Mvumero district. The nutritional values of forage materials from this study were beyond the recommended level with 8% CP, 35 to 45% NDF and 7.56 to 8.368 MJ/Kg DM for lactating dairy cows proposed by [31].

The observed total dry matter intake (TDMI) was lower for the cows in both supplements and locations compared with the recommended feed intake level of 17.3 to 13.8 kg DMI during the early stage of lactation and 15.9 to 12.7 kg DMI for the mid-stage of lactation for the feeds containing 8 and 10 MJ/kg DM [30]. Similarly, the concentration of critical CP intake of forage materials for the ruminant diet was also lower than the recommended value of 8% DM required for proper rumen function [33]. In addition, the supplement DM intake for cows on supplement S2 was higher than those on S1 with lower DM

content. This could be attributed to the dense nutrients used in compounding S2 with low moisture content. The observed higher body weight change and milk yield for the cows on supplement S1 compared with the cows given common concentrates on supplement S2 could be attributed to the higher CP content on S1 than S2, which is known to enhance feed intake, body tissue deposition and milk synthesis in cows. This observation is in agreement with the results by [29] who reported a body weight of 387 kg for crossbred cows fed on silage made from a 50% inclusion level of wet spent byproduct. This could be attributed to the level of CP and ME supplemented to cows, which provided protein and energy for body tissue metabolism for growth, although the ME content of S1 was lower compared to that of S2. This could be attributed to the higher digestible energy in the pre-fermented wet spent grain byproduct contained in S1.

The observed higher mean milk yield in the cows on supplement S1 than S2 was attributed to the greater CP content in wet spent grain byproduct for milk metabolism. The present observation aligns with those of [34, 35], who showed that brewery wastes provide superior nutritional value, supplying the cows with essential amino acids and energy necessary for efficient milk production. On the other hand, the observed higher milk fat content (g/kg of milk) in the cows fed on S1 than in those on S2 could be due to the higher milk production from the cows on S1 associated with higher DM and CP intake of supplement S1 than that contained in S2, which was projected to promote greater milk fat yield [29]. The result of this study was lower compared to those reported by [29], who reported a higher milk fat yield with 321.6 g/kg milk yield in crossbred dairy cows fed with silage containing 33.3% of brewery-spent grain by-products. Although the amount of milk fat yield in this study was lower to the recommended level of 395 g/kg of milk yield per day [32]. The observed higher yield of milk protein from dairy cows on supplement S1 might be due to the higher protein content, which enhances the utilization of amino acids and increases the efficiency of protein production in dairy cows. The result of milk protein from this study was greater than the recommended level of 335 g/kg of milk yield per day for lactating dairy cows in warm climate regions [32]. Similar findings were reported by [36], highlighting the significant influence of feed materials with higher protein content synthesized into milk production in dairy cows. These results highlight the importance of balanced feed formulations in optimizing microbial activity and dairy cow performance.

The observed increasing trends in the amounts of CH₄ emissions (g CH₄/day and CH₄ g/kg DMI) from the cows supplemented on S1 could be attributed to the higher NDF content and lower ME possessed by the S1 with wet spent grain byproduct compared to those on S2 with common concentrates. The values of CH₄ obtained in the present study were higher than those reported by [37], who noted 190.1 gCH₄/cow/day and 21.35 g CH₄/kg DMI from young Nollere bulls supplemented with a diet consisting of 100% level of

corn-dried distiller's grains in Brazil. However, the amount of methane production in this study was lower than the average values of 340 to 390 g of CH₄ per day per cow and within the range of methane yield of 18 to 26.4 g per kg DMI from lactating dairy cows in the global methane estimate [35]. The possible reason for the observed greater deviation from the result of this study might be attributed to the lower dry matter intake of the above authors and the gas tracer methodology used to measure the methane gas in cows. According to [12], diets containing a lower level of NDF and higher ME, as expected in S2, are highly digestible; the diet produce energy in favour of propionate production, which acts as a hydrogen (H₂) sink and reduces methane production by increasing the passage rate of feed materials in cows. Similarly, with location, the observed greater amount of methane emission in g/day and per DMI from cows in the ARCC was due to the higher NDF content and lower ME by both supplement and forage materials fed to cows than those consumed by cows in the HDC.

The observed trends of lower levels of nutrient intake in kg DM fed to cows on S1 with wet spent grain brewery byproduct in the HDC might be the reasons for the lower methane emission when expressed per CH₄ g/day and DMI g/kg with interaction result. The amount of methane from this study was lower compared to those reported by [38], with 357 and 390 gCH₄/day, 19.4 and 20.5 gCH₄/Kg DMI for a dairy diet with higher and lower NDFI in Holstein Friesian using the sulphur hexafluoride tracer technique and the Greenfeed monitoring system. The lower NDF content of supplement S1 with wet spent grain byproduct in the HDC fed to cows could have the advantage of altering rumen microbes, which increases the microbial activity that significantly raises the fermentation pathways that yield less methane. In addition, the lower methane intensity (g/kg of milk yield) in cows supplemented on S1 likely stems from the higher nutritional value of the supplement S1 with wet spent grain byproduct and improved efficiency, which boosted milk yield. Similarly, [39, 40] demonstrated that increased milk production reduces emission intensity by distributing greenhouse gases. The emission values from this study were lower than those reported by [41], who recorded 35.7 g CH₄/kg milk with 4 kg concentrates and 33.8 g CH₄/kg milk with 8 kg concentrates using SF₆ tracer techniques.

The current study showed that dairy cows supplemented on S1 with wet spent grain byproduct had the potential to generate over 3800 TZS more gross margin per day and 154 TZS gross margin per litre of milk compared to their counterparts supplemented with S2, with common concentrates. However, the higher trend of gross margin per litre of milk was observed from cows on S1 in the ARCC than from cows on S2 in the ARCC and S1 and S2 in the HDC. This may be attributed to the lower purchasing price of supplement S1 materials and its greater impact on milk yield in dairy cows, resulting in a higher gross margin from the economic analysis in dairy cows supplemented with

supplement S1 with wet spent grain byproduct. A similar result was reported by [29], who documented higher milk production efficiency in crossbred dairy cows using the least expensive feed materials from silage made with wet spent grain by-products. Similarly, [12] reported that high digestibility of NDF in brewery by-products leads to improved nutrient utilization and metabolism into milk production in dairy cows, associated with less increase in methane intensity in cows supplemented with S1 than those on the S2. Generally, the study results revealed that supplementing wet spent grain byproduct in dairy cows from both locations has a positive increase in the nutrient intake, milk yield, and a higher gross margin for farmers in the study area.

5. Conclusions and Recommendations

It is concluded that supplementing wet spent grain byproduct to lactating cows in the study area significantly improved milk yield, fat and protein contents in the milk produced from the cow relative to the conventional concentrate supplements. In addition, the wet spent grain byproduct was found to improve the gross margins through lowering the total variable costs and reducing methane emissions per unit of milk produced in both locations. These findings highlight the dual economic and ecological benefits of utilizing brewery by-products in dairy nutrition, recommending further investigation into optimized feed formulations for dairy cows by incorporating brewing by-products.

Abbreviations

WSGB	Wet Spent Grain Byproduct
ARCC	Arusha City Council
HDC	Hai District Council
S1	Wet Spent Grain Byproduct
S2	Common Concentrate
BW	Body Weight
NIRS	Near-infrared Spectroscopy
LMD	Laser Methane Detector
CP	Crude Protein
NDF	Neutral Detergent Fibre
ADF	Acid Detergent Fibre
PRA	Project Research Agent
DMI	Dry Matter Intake
TDMI	Total Dry Matter Intake
FDMI	Forage Dry Matter Intake
DMIS	Supplement Dry Matter Intake
NDFS	Supplement Neutral Detergent Fibre Intake
NDFI	Forage neutral Detergent Fibre Intake
GM	Gross Margin
TR	Total Revenue
ME	Metabolizable Energy
TVC	Total Variable Cost

Acknowledgments

The study was successful because of the support of the International Livestock Research Institute through the "Enviro-cow Research Program" implemented by the Tanzania Livestock Research Institute (TALIRI).

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Daniel Komwihangilo: Investigation, Methodology, Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors state that there are no competing interests influencing this work.

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