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Effects of Season Variation on Water, Feed, Milk Yield and Reproductive Performance of Dairy Cows in Smallholder Farms in Eastern Africa

Ongadi Patrick Mudavadi[1,2*], Mpolya Abraham Emmanuel[1], Gachuiri Charles[3], Muyekho Francis Namasake[4] and Lukuyu Adubwa Bernard[5]

[1]Nelson Mandela African Institution of Science and Technology, P.O. Box 447, Arusha, Tanzania.
[2]Kenya Agricultural and Livestock Research Organization, P.O. Box 169-50100, Kakamega, Kenya.
[3]College of Agriculture and Veterinary Sciences, University of Nairobi, P.O. Box 29053-00625, Kangemi, Kenya.
[4]Masinde Muliro University of Science and Technology, P.O. Box 190-50100, Kakamega, Kenya.
[5]International Livestock Research Institute, P.O. Box 24384, Kampala, Uganda.

Authors' contributions

This study was carried out in collaboration among all authors. Authors OPM, LAB and MAE designed the study, wrote the protocol and interpreted the data. Authors OPM, LAB and MAE anchored the field study, gathered the initial data and performed preliminary data analysis. While authors OPM and MAE managed the literature searches and produced the initial draft. Authors GC and MFN reviewed and refined the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The smallholder dairy industry in Eastern Africa continues to be characterized by seasonality driven milk fluctuations and reproductive performance of dairy cows. In this review, we present important effects of changes in seasons on water, feed quantity and quality, milk yield and reproductive performance of dairy cows in smallholder dairy farms.

**Corresponding author: E-mail: pmudavadi@gmail.com;*

Methods: We considered peer-reviewed publications from 1990 to 2019, and extracted any information pertaining to the effects and intensity of changes in seasons and implications on water, feed quality and quantity, milk yield and reproductive performance.

Results: Seasonal variation in rainfall, characteristic of the East Africa region, is strongly reflected in cropping and feeding calendars. Hence, 305-days lactation milk production per cow in Eastern Africa ranges from 850-3150 kg/cow/year, which has not increased, partly because of lack of improvement in nutrition and management, but also due to slow genetic selection of breeds that matches available feed to milk yield and reproductive performance. High milk fluctuations arise mostly because of farmers' dependence on rainfall for feed production and rarely make provisions for preserving fodder for the dry season, as there isn't adequate forage (fodder and pasture) even during the wet season.

Conclusion: For the smallholder dairy farmers to remain competitive, it is important to increase the dairy value chain capability to manage implications of changes in seasons on milk yield and reproduction. Therefore, in order to overcome the current seasonal changes, we have discussed technological interventions in adoption of practical, sustainable farmer-led strategies for optimizing water and feed production, milk yield and reproductive performance in Eastern Africa. We have also identified knowledge gaps where research is needed to guide dairy value chain stakeholders on how to ameliorate current seasonal changes or that we expect will occur in the future.

Keywords: Dairy cattle; feeding; milk fluctuations; seasonal changes; sustainability.

1. INTRODUCTION

Seasonality in milk production is a crucial factor in smallholder dairy farms (SDFs) with livelihood strategies [1] revolving around seasonal patterns [2] of water and forage availability and corresponding agro-climatic variability [3]. 305-days lactation milk yield per cow from SDFs in Eastern Africa varies from 850-3150 kg/cow/year [4,5], which is low in comparison to milking cows in more intensive dairy farms in Europe and North America that produce, on average, 7800 kg/cow [6–8]. Studies in Eastern Africa have documented a decline in milk production during the dry season, following significant seasonal variation in rainfall and feed availability [9,10].

Therefore, annual average milk yield per cow per 305-days lactation obtainable was less than 2000 kg from pure dairy breeds, 1000 from cross breeds and 500 kg from indigenous cows in Eastern Africa [5,10–12]. Studies have also described high milk variability during the dry season among SDFs compared with their large scale counterparts [13], and suggested that in the smallholder dairy farming context, seasonally determined milk fluctuation is significantly determined by dairy cattle nutritional status [14]. High milk fluctuations in SDFs arise because most farmers, firstly, depend on rainfall for feed production and rarely make provisions for adequate green feed and fodder preservation for the dry season. Secondly, due to small land sizes [15]. Thirdly, in addition to seasonality of feed supply, the diets are largely made of low quality feed products such as crop residues between 30-35% and native pastures of poor nutritive value (56% - 90%). Hence, the potential of smallholder dairy cows for milk yield and reproductive performance are never attained [5].

In general, seasonal effects (factors) are not new to on-farm research and farming systems research, but needs to be further investigated [13]. SDFs have priorities for different types of feed-food crops according to their vulnerability to seasonality [16]. They allocate their land, labour and other inputs according to these priorities [17,18]. SDFs produce milk in diverse production environments [13], where productivity of dairy breeds is increasingly challenged directly and indirectly with the impacts of the ever changing climate [19]. Milk decline and fluctuation is as a result of seasonality related changes is usually linked to the 'milk deficit/gap' [5,8]. This usually occurs towards the end to early half of the year, linked to the dry season, the end of which is considered to be the most desperate period for SDFs. Main causes are decreased availability of good quality and quantity forages and water, hence reduction in milk production and increased work-loads [4]. In adopting to impacts of climatic changes, SDFs in Eastern Africa keep dairy cattle with generally low production potential [11], [20], since they rely on indigenous breeds [21,22], and associated poor reproductive management which reduces the productive and reproductive efficiency [23].

The development of the smallholder dairy industry in Eastern Africa must not only be viewed as a means of providing food for the increasing human population [24], but also as a livelihood in the existing SDF systems [2]. The potential for increasing production in SDFs is considerable. However, this can only be achieved in a secure and sustainable way through comprehensive studies of their current production methods and constraints that slow down improvement [8], [25]. During the recent past, considerable developments in improving the productivity of smallholder dairy cattle in Eastern Africa has been observed. However, there has also been an increasing recognition of the fact that the performance of dairy cattle on smallholder farms do not always mirror those of farmers in medium to large scale farms [23].

The purpose of this review was to assess the effects of seasonal changes in water and feed quality and quantity, with particular emphasis on their influences on milk yield and reproductive performance; and eventual influence on seasonal milk fluctuations. We reviewed the most common constraints imposed by locally available feed resources and feeding systems, with outline of conventional approaches to feeding dairy cattle and their usefulness for SDFs. We then sought to widen the discussion as to whether seasonal changes in feed and water quality and quantity are the main cause of milk fluctuations and low reproductive performance in SDFs. We finally drew conclusions on the issues considered and suggested recommendations on future work on this topic. Therefore, the main objectives of this review paper were, a) to determine the existing seasonal changes in water, feed quality and quantity and their effects on milk yield and reproductive performance of dairy cows in SDFs, and b) to determine the opportunities and problem oriented approaches/interventions for overcoming seasonal milk fluctuations and low reproductive performance of dairy cows in SDFs in Eastern Africa.

2. WATER AVAILABILITY AND QUALITY

Seasonal changes in water availability and quality has been observed in Eastern Africa, with SDFs experiencing challenges of meeting water requirements for dairy cattle. Comprising 50-80% of a cow's body, depending on age, and essential for all cellular functions as well as milk production [26], the transport of nutrients and excretion of waste products, water is the single most important dairy nutrient, as it is also vital to the regulation of body temperature. [27], investigated factors affecting amount of water offered to dairy cattle and their effects on productivity in central Kenya. He found that the amount of water seasonally offered per cow per day was 13.4 litres to 35.6 litres per 300 kg live weight (LW), with high variability ranging from 7 to 108 litres per 300 kg LW/day. This availability was way below the ratio of drinking water to milk production by lactating cows that is estimated at 2.00-5.00 litres of water per kg of milk [28], or at least 60 litres of water/cow/day, which may increase up to 100 litres or more depending upon breed (size), feed intake, weather conditions, milk production, and stage of lactation [26].

Water availability, and hence frequency of watering, per cow per day in Eastern Africa is highly seasonal, and affected by the type of water source (mainly rivers, dams, wells and bore holes), distance to water source, transportation means, storage facilities, watering frequency, volume of watering rack/trough [29,30,31]. These variables in turn influenced the daily maintenance energy [32], required by the dairy cow to have water and feed (includes superficial protein losses caused by the replacement of hair, hooves, dermal epithelial desquamation, and sebaceous glands); breed and body size (local zebu, exotic breeds and their crosses); dry matter and nutrient intake; and eventual milk yield. These observations were similarly reported in a study by [33] in Zimbabwe and [34] in Rwanda.

Dairy cows in SDFs [27], spent more time, in excess of 7.0 hours per day or up to 7.0 km or more, walking in search of drinking water (seasonal rivers and communal wells/bore holes), including feed, resulting into more maintenance energy wastage and poor performance (milk yield, growth and reproduction), due to decreased feed intake and negative energy balance. Feed and water were also ranked as the two main constraints and challenges of meeting requirements for dairy cattle in Ethiopia [30], with reduced water availability and of poor quality, as a major concern to SDFs within rural, peri-and-urban settlements. Poor water sources, hence quality (valley dams and rivers) were reported as a major cause of higher water borne disease and parasites' occurrences, for example helminth infestation (helminthiasis) in Rwanda [34] and Kenya [27].

3. FEED SOURCES

Throughout Eastern Africa, forage feed resources available in SDFs for feeding dairy cattle consists of (1) dry roughage (straw, stover, sugar cane tops/bagasse and haulms from legume crops); (2) home grown fodder and green grass (non-cultivated indigenous grass, crop field weeds, road & embankment side grass, water-hyacinth, cultivated fodders, legumes, non-legume and perennial grasses from fallow lands and forests); (3) vegetables and fruit by-products (Jack fruit, pineapple, banana, mango, cabbage and other kitchen waste); (4) shrubs and fodder tree leaves; and (4) cereal grain and by-products (maize, wheat, rice, oats, barley). Among concentrate feed supplements, the commonly available feed resources are agro-industrial by products (rice bran, wheat bran, oil cakes, and molasses), marine and animal by products (fishmeal, shrimp waste, blood meal and bone meal) and homemade/commercial dairy ration [35,36].

However, practical feeding strategies for dairy cattle in SDFs across Eastern Africa are mainly based on natural pasture (green grasses), crop residues and by products of cereals, oil seeds and pulses [14,37,38]. Natural green grasses are available extensively during the rainfall season, while some cultivated fodder (i.e. Napier grass), forage legumes and fodder trees/shrubs are grown sporadically in some areas of Eastern Africa [14,39]. During dry season months of the year, availability of green grass and cultivated fodder is very limited and therefore dry crop residues (i.e. stovers, straws, hulls and haulms) alone contributes 60-87% of roughage portion of the dairy cattle feed [40]. These crop residues, though important sources of roughage, are highly seasonal with low nutritive values and therefore do not provide adequate nutrients required for dairy production [12,41].Consequently, animals fed on crop residue like maize stover would require supplements of higher nutritive value, since dry maize stover has low Crude Protein, CP (2.5% of dry matter) and is highly fibrous with neutral detergent fibres (NDFs) exceeding 70% of dry matter, DM [42]. Feed sources (quantity and quality) fluctuates between seasons (wet and dry), due to erratic and poor distribution of rainfall [9].

The Feed Assessment Tool (FEAST, www.ilri.org/feast) for assessing local feed sources and utilization in SDFs [14], was applied in this review to determine relative contributions of the different feed sources to year-round availability and utilization in Kenya and Tanzania (Fig. 1) in relation to rainfall variability (long term mean, LTM, monthly rainfall, mm). Year round feed sources, with the exception of concentrates supplements, in both Kenya and Tanzania varied seasonally between the wet season from March to June, September to November and the dry season from December to February, July to August. Therefore, as a lesson to reduce feed scarcity in SDFs, across Eastern Africa, there is need for proper planning (seasonal feeding calendars) and minimal dependence on rain-fed production. Feeding strategies for dairy cattle in response to seasonal availability and utilization of feedstuffs throughout the year can be based on optimizing the use of crop residues, total mixed rations and supplementation of legumes along with cereal by products or concentrate feed.

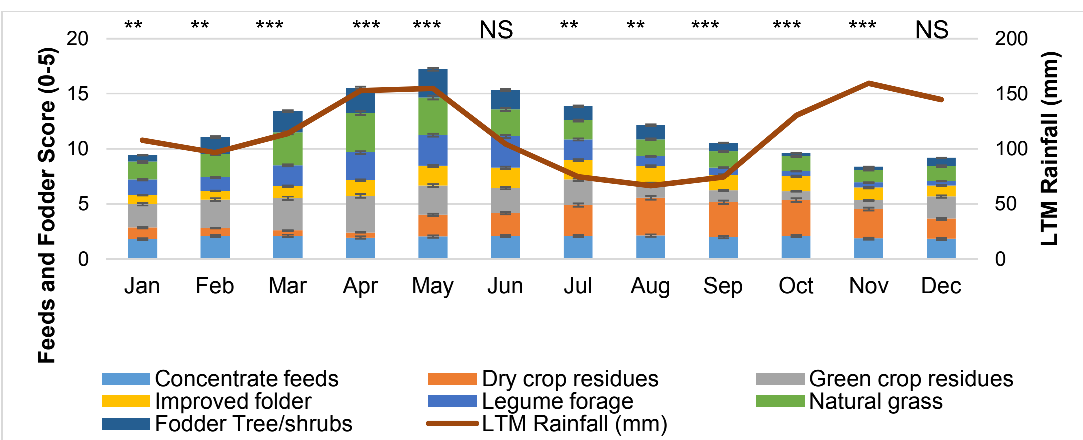

Fig. 1. Year round seasonal changes in feed sources with rainfall variability in Kenya and Tanzania in Eastern Africa

*NB: NS=Not Significant; *Significance level (P≤0.05); ** Significance level (P≤0.001); ** Significance level (P≤0.01); LTM, Long term mean rainfall (mm); Score, 0-5, where: 0=none, 1=moderately low, 2=low, 3=moderately high, 4=high and 5=very high availability)*

4. FEED RESOURCE AVAILABILITY

Seasonality determined feed availability (quantity) has significant influence on dairy cattle nutritional status in Eastern Africa. In this region, feed availability can vary the productivity of dairy from boosting milk production in times of plenty (wet season) to mere survival in times of scarcity (dry season), as similarly reported by [23,43–45,40], sought to investigate the availability and utilization of feed resources in Kenya, and found that roughages from a variety of sources were the main feeds, especially during the dry season. Other feeds available, were herbages such as leguminous feeds that had the lowest potential dry matter degradability (DMD) and weeds harvested from cropland and roadsides, which had the highest DMD.

[46], investigated the effect of seasonality on availability of feed resources on dairy cattle productivity in coastal lowlands of Kenya, and reported that productivity was low. This was attributed to low genetic potential of the dairy cows and inadequate forage due to seasonality of availability. Forages available in SDFs were mostly of moderate quality, especially during the dry season, with average high rumen degradability, ranging from 30 to 65% [40]. There was also an acute deficit in dry matter (DM) availability during the dry season, and majority (>70%) of SDFs did not provide any feed supplement during dry season or conserve excess pasture produced in the wet (rainfall) season [30], [47].

As a result of season variation, cultivated fodder, like Napier grass contains moderate crude protein (CP) content (6-12%) during the wet season, but declines to less than 5% during the dry season [48]. Therefore, availability and quality of feed crops and forage may be affected more by extended dry season conditions due to variations in concentrations of water-soluble carbohydrates and nitrogen [49–52]. Furthermore, temperature increases may increase lignin and cell wall components in forages, which reducedigestibility and degradation rates, leading to a decrease in nutrient availability for dairy cattle [12,53].

In Eastern Africa, feeding dairy cattle during the dry season period is a regular challenge for SDFs. Similarly, during the wet (rainfall) season, feeding dairy cattle may be restricted in cultivated regions, when food crops are being cultivated, hence “starvation in the green”. These seasonality determined changes in feed and forage availability, quality and usage during wet and dry seasons, affects the year round feeding calendars, options/strategies and patterns, which in turn results into seasonal fluctuations in milk yield, growth and reproductive performance.

5. ROUGHAGE QUALITY AND QUANTITY

In Eastern Africa, variation in the quality (and availability/quantity) of roughage during different seasons (wet and dry), significantly affects milk yield (and its quality) and reproductive performance of dairy cows in SDFs [50]. Seasonality (rainfall and temperature) affects roughage quality (and quantity) in terms of both energy intake [12,54], and that which is available for milk yield and performance (growth and reproduction). This also directly affects the utilization of other feed nutrients (proteins, minerals and vitamins) because in many cases nutrient requirement is a function of available energy [55]. According to [26], roughages tend to be more highly digested during the dry season (or warm conditions) than when the same diet is fed to dairy cattle during the wet season (or exposed to cold temperatures). However, the quality of roughages seems to be better during the wet season, but preserving carried over plant biomass for use as standing hay during the dry season reduces production [42].

Energy and protein intakes from roughages fed to dairy cows in Eastern Africa during the dry season is insufficient to meet the requirements due to the high levels of fibre concentration (ADF-acid detergent fibre and NDF-neutral detergent fibre), lignin, and in some instances, anti-nutritive factors. Hence, for SDFs, it’s important to emphasize the need to consider available energy from roughage feed, in the light of seasonality and to adjust rations to enhance efficient utilization of all feed nutrients. [46], found a high variability in roughage quality among farm types in Kenya, due to different site conditions (agro-ecology), seasonality and varying forage management that resulted into significant differences in milk yield.

The wet season period in Eastern Africa is characterized by forage biomass, which is higher in quality and quantity, with crude protein up to 9% in most of the natural (native) grasses [41]. Natural grasses and legumes are rich and highly digestible at this period. As the dry season sets in, the protein level drops and the fibre increases [41]. There is an increase in lignin and voluntary intake decreases which makes it a poor feed, resulting in weight loss and decreased fertility and milk yield for about 4 to 5 months of the year. The severity and duration of low-quality feed differs in Eastern Africa. Further, also during the wet season period the nutrient content of natural grasses on average is about 25% dry matter; 10% crude protein; 6% ash and a fibre content of 35% crude fibre or 43% acid detergent fibre (ADF) [41]. As the dry season advances and conditions become severe, their nutritional quality declines to the extent that crude protein could fall to as low as 2% [56]. Ash values also decline to about 3 to 4% as a result of translocation to the root system, while fibre content increases in response to the process of lignification, and sometimes the crude fibre could be as high as 50 or 60% ADF [57,58].

The ability of rumen microorganisms to digest cell polysaccharides in roughages, consisting mainly of cellulose and hemicellulose is limited by lignin. Since fibre is often used as a negative index of nutritive value in predicting the total digestible nutrient (TDN) and net energy, the available energy from roughages during the dry season is likely to be low in relation to roughage yield [26]. The consequences for dairy animals are low feed intake (about 1.2 kg DM/100 kg live weight) and low performance [26,57]. Therefore, roughages, being more fibrous in nature during the dry season require that their quality be upgraded through supplementation for effective utilization by dairy cattle.

[56], demonstrated that dairy cows fed with urea-treated wheat/rice straw had similar milk yield to that of cows feed with fresh grass. However, milk of the cows fed urea treated wheat/rice straw had a higher milk fat content and net income as compared with the milk produced by cows fed un-treated straw or fresh grass. The seasonal effects on roughage (forage) quality in the highlands and lowlands areas of Kenya in Eastern Africa were systematically reviewed (Table 1). The quality of roughage was better in the wet season, compared to the dry season. Hence, feed quality fractions, namely dry matter (DM), crude protein (CP), ash, organic matter (OM), acid detergent fibre (ADF) and metabolizable energy were slightly higher during the wet season, compared to the dry season period. Across Eastern Africa, the feeding value of roughage forage, reduces in the dry season, as during this period roughage comprises mainly crop residues (by products and wastes) and low quality pastures (straws and standing hays).

6. FEEDING FREQUENCY AND FEED INTAKE

The dry season in Eastern Africa is associated with low or no rainfall, and feed for smallholder dairy cattle advances in maturity and declines in quantity and quality, compromising feeding systems [11], [54,60,61]. These are the conditions under which the ability of the animal to derive nutrients from the diet are restricted, not only by the highly refractory nature of plant fibre to microbial attack, but also by the decline of protein and minerals to inadequate levels for both the fermentative microbes and the tissues of the animal [62]. As a consequence, all aspects of dairy cattle production are dominated by climate-regulated supply of feed between wet and dry seasons, as the feed available changes in quality from supra-maintenance to maintenance and finally sub-maintenance [26].

Therefore, the potential undesirable impacts of seasonal influence on feeding frequency and intake of smallholder dairy cows can be intensified more during the dry season period (unlike the wet season period), when cows do not have good access to quantity and quality feed. During the dry season period in SDFs, feeding frequency is low (due to limited feed and water availability), limiting the ability of smallholder dairy cows to access feed (in right quantity and quality) at times when feeding motivation is high [26]. The low feeding frequency, reduces the feeding rate, at which cows feed throughout the day. This results into cows having fewer meals per day, and shift in their feeding behavior and intake patterns, which tend to be larger and longer as the dry season progresses.

These seasonal effects on feeding frequency, hence intakes, and the potential reduction in dry matter intake (DMI), may be greatest for transition dairy cows in both the highlands and lowlands of Eastern Africa. The seasonal effects on feed and nutrients intake by smallholder dairy cows in highlands and lowlands areas in Eastern Africa were systematically reviewed (Table 2). Daily DM, OM, ash, ADF and ME in feed and hence intake by smallholder dairy cows in dry season were slightly lower, compared to the wet season. Similarly, the CP, rumen degradable protein (RDP) and rumen un-degradable protein (RUDP) intake by smallholder dairy cows were higher in wet season compared to the dry season, due to shortage of quality and quantity of roughage feeds.

Table 1. Seasonal effects on roughage (forage) quality in highlands and lowlands areas of Kenya in Eastern Africa

Feed Parameters	Mean Value		Reference
	Wet Season	Dry Season	
DM, kgDM	8.53	5.40	[46] [59] [48]
CP, g/kgDM	839	386	
Ash, g/kgDM	0.94	0.75	
OM, g/kgDM	7.62	4.63	
ADF, g/kgDM	2.92	1.25	
ME, MJ/kgDM	8.24	7.27	

*Level of significance: **P < 0.01; [1]LSD = least significant difference; DM=Dry matter; CP=Crude protein; OM=Organic matter; and ADF=Acid detergent fibre; ME=Metabolizable energy*

Table 2. Seasonal effects on feed and nutrients intake by smallholder dairy cows in highlands and lowlands areas of Kenya in Eastern Africa

Feed Parameters	Mean Value		Reference
	Wet Season	Dry Season	
DM, kg/DM	7.00	6.93	[46] [59] [48]
M/D, g/kgDM	70.23	40.20	
CP, g/kgDM	664	561	
RDP, g/kgDM	358.5	296.0	[68]
RUDP, g/kgDM	305.6	265.4	[69]
Ash, g/kgDM	0.76	0.93	[70]
OM, g/kgDM	6.27	5.98	
ADF, g/kgDM	2.60	1.57	
ME, MJ/kgDM	7.90	7.61	
Roughage: concentrate	1.61:1	2.64:1	[26]
ME, MJ/kgDM (req.)	68.9	66.1	[63]
Protein deficit, g/kgDM	-197.2	-237.3	
RDP, g/d (req.)	538.0	515.0	

NS = not significant, *P < 0.05, **P < 0.01; req.=requirement; [1]LSD = least significant difference. Source: *The values of rumen degradable protein (RDP) and rumen un-degradable protein (RUDP); Energy values*

The ratio of roughage to concentrate was higher during the dry season, compared to the wet season, as slightly more concentrates (mainly cereal grains by products and molasses), are utilized during this period to supplement the poor quality and quantity forages. However, in both the wet and dry seasons, the daily protein, rumen degradable protein (RDP) and ME intake as per live body weight gain and milk yield were below the requirements [26,63]. In smallholder dairy cattle production systems, the feeding frequency can greatly influence feeding behavior patterns, and this also affects cow health and productivity [64].

Therefore, providing feed two times daily or more often has been demonstrated to contribute to more consistent nutrient intakes over the course of the day, as compared to feeding once daily. Such desirable feeding patterns are conducive to more consistent rumen pH [65], which likely contributes to improved milk fat and fibre digestibility [66]. Further production efficiency [67], observed is higher when cows are fed more frequently than once daily.

7. FEEDING STRATEGIES AND COST

Feeding strategies are an important indicator of the intensity of dairy production [5], where the quantity of feed that can be consumed by a dairy cow depends on the interactions among live body weight, level of intake, rumen fill, passage rate, specific gravity (buoyancy), neutral detergent fibre (NDF) content, particle size, particle fragility/tensile strength and digestion rates of potentially digestible NDF versus indigestible NDF fractions [26]. Clear seasonal differences have been observed in SDFs between feeding strategies in the rainfall (wet) and the dry season, with an abundance of green forage in the rainfall season and a lack of forages in the dry season, when farmers resort mainly to low quality crop residues, straws and hays [5].

[40] and [46]; [9] and [71]; and [72], assessed the production, economics and estimated methane emissions from traditional (existing) and optimized feeding strategies (alternative and intermediate feeding) in small scale dairy farms in highlands and lowlands of Kenya, Uganda and Tanzania, during both dry and rainfall (wet) seasons. Basal feeding during the wet and dry seasons was based on grazing pastures and green or dry crop residues (mainly weeds, cereal crop thinning's or by products such as maize stover) in the traditional strategy. Basal feeding consisted of mainly cultivated fodder and pasture (mainly Napier grass) supplemented with some dry, green crop residues or maize silage in the alternative feeding strategy. Basal feeding finally consisted of some cultivated fodder or maize silage with mostly crop residues (maize stover and cereal straws) in the intermediate feeding strategy [73].

Concentrates offered varied seasonally between 1-5 kg per cow per day in the wet season and 3-9 kg per cow per day in the dry season, depending also on the specific feeding strategies adopted by the farmers, feed availability and cost [74]. The alternative feeding strategy produced higher milk yields than the intermediate and traditional feeding strategies in the dry season. Similarly, in the rainfall season, milk yields with the alternative feeding strategy were higher than the other two strategies. It is was also beneficial to increase the inclusion of quality forages like cultivated fodder and pastures and maize silages during the dry season and to avoid the inclusion of mostly straws. Overall, as similarly reported by [33] in Zimbabwe, these optimized (alternative) feeding strategies in SDFs increase milk yields, reduce feeding costs, increase incomes, and reduce enteric methane (CH_4) emission per kg of milk.

Therefore, parallel to increased milk yields and lower feeding costs, which result in improved profit margins by implementing high quality feeds or optimized feeding strategies, there may be an enhanced sustainability not only in the economic scale, but also in the social scale from better incomes, and in the environmental scale from lower greenhouse gas (GHG) emissions. [60], sought to determine factors affecting milk production cost in SDFs using a multiple regression model. and reported that some factors such as the time spent in dairy cattle farm, farmers' dairy farming experience, farmers' educational level, farmers' feed procurement and conservation, livestock pests and diseases, farm-made roughage and maize silage production in the farm had significant effects on milk production costs. Hence, paying attention to these factors were explained to have important impacts on decreasing farmers' milk production costs.

[75], on SDFs in Mexico, sought to evaluate the effects of ration cost and ingredient composition on milk yield and income over feed cost, and suggested that optimal ration formulation rather than least cost strategies may be key to increasing milk yield and income over feed cost, and that profit margin may be affected more by quality of the feed rather than the cost. [46], carried out a one-year investigation aimed at evaluating all incomes and costs with a specific focus on the impact of seasonality on feeding in 32 smallholder dairy farms in coastal lowlands in Kenya.

On-fam feeding strategies varied between farms, seasons and agro-ecology, depending on the cost of on-farm produced feeds; price of purchased feeds and the price of milk. In which case, feed was the largest farm expense making 68% of total farm costs. Therefore, constraints for improving feeding strategies in SDFs are varied but mainly relate to inappropriate feeding and management practice applied at dairy farms, and include: low to moderate milk yield compared to genetic potential of dairy cattle breeds, low quality of on-farm produced roughages, high costs of arable land rent, high costs of inputs necessary to feed production, using of relatively high level of expensive concentrate feed for low to moderate milk yield level and unbalanced feeding of cows during different lactation stages. To improve performance of SDFs-owned dairy animals, there is a need to develop feeding strategies that will enhance the quality, quantity and sustained availability of feed resources produced on-farm.

8. MILK YIELD AND REPRODUCTIVE PERFORMANCE

Milk yield and reproductive performance of dairy cattle in Eastern Africa is best at temperatures between 10^0C to 30^0C [76]. However, temperatures frequently rise above this thermal comfort zone in most dairy production environments, due to seasonal changes in climate [50]. Seasonal fluctuations in milk yield and reproductive performance in SDFs are, therefore, often seen to be most marked during the dry season period, characterized also by low or no rainfall [50,77,78]. SDFs face feed resources constraints during the dry season period, which also worsens with frequent droughts and flooding associated with the changing climate, witnessed recently throughout Eastern Africa [11,18,20]. This is mainly associated with reduction in herbage growth rate, quality, species composition and DM yield [78]. Further, it leads to reduced nutrients available to the animals and ultimately leading to seasonal milk fluctuations and a reduction in overall performance.

[79] reports that for smallholder dairy cows, heat and nutritional stresses due to climatic variability, reduces herd productivity and profitability through increased mortality, reduced growth rates (body weight and condition scores), low milk yields, low calving rates, late age at first calving and long calving intervals, which can be of substantial economic loss to SDFs utilizing less adaptable breeds. [47], further reports that in their choice of dairy breeds, SDFs hardly pay attention to breed tolerance and adaptability to the climate related stresses. They utilize European/exotic breeds (Holstein-Friesian, Friesian, Ayrshire, Guernsey or Jersey) in production environments already classified as hotspots of climate change variability, which include highlands, semi-arid rangelands, coastal and great-lakes ecosystems in Eastern Africa, where [78], projects an increased severity of seasonal climate variability and change.

According to [80], in a study in Tanzania, season and location differences in quality, quantity and composition of milk are due to a combination of factors including breed differences, age of the cow, lactation stage, season of the year, climate, and feeding practices. Further, [7] points out that across SDFs in Kenya, dairy cattle breeds seasonally differ in average milk composition and between individual cows within breeds, there is even greater variation, such that groups of paternal half-sisters differ significantly in mean values of milk fat, solids non-fat, and protein content.

Therefore, in Eastern Africa, attaining sustainable dairy production (milk yield and reproductive performance) requires utilizing breeds that are highly adaptable to the seasonally variable and changing climate including feed and water quality and quantity. This is crucial in order to overcome the state of insecurities in feeds, nutrition, incomes and health of SDFs and their dairy animals. When adaptable dairy breeds and feed resources (climate smart feeds and forages) are identified, they can be promoted in appropriate environments. Coupled with appropriate management interventions that effectively reduce animal stresses, SDFs could mitigate and adapt to effects of seasonality driven changes to maintain and sustain milk yield and reproductive performance.

9. SEASONALITY: IMPLICATIONS FOR RESEARCH

Seasonal differences in temperature and rainfall, characteristic of the East Africa region are strongly reflected in cropping and feeding calendars [11,18]. For example, inter-annual fluctuations in rainfall can also affect crop residue yield, which may in turn affect the ratio between edible and non-edible fractions within residues [19]. SDFs cultivate a variety of feed-forage associations (pasture, fodder, legumes) and crops (maize, potatoes, beans, peas) in order to increase their returns and simultaneously reduce risks and impacts of seasonality [20]. This crop diversity on small cultivated areas leads to difficulties in providing a constant feeding diet to their dairy cattle in a green forage-based system. Therefore, dairy feeding decisions for SDFs are highly variable considering the complexity of animal characteristics, management effects, available feed resources and agro-climatic variability.

The full expression of an animal's genetic potential in terms of milk production and reproductive performance depends on the provision of adequate nutrition [22]. Genetic potential, however, is not the guiding principle for farm optimization by SDFs, who have limited access to additional feed resources [15,81]. Therefore, for these SDFs and development agents alike, the fundamental challenge is to develop a combination of animals and feeds that assures satisfactory levels of growth, reproduction and lactation. This must be based on large part on the optimal use locally available feed resources like crop residues and by-products.

Milk production is greater from systems growing a wide range of forages, including high energy forages, but the cost of the increase in complexity of such systems is not likely to be offset by the increase in income [26]. Therefore, most SDFs generally have feeding systems adapted for smallholder lower-yielding dairy cows, where locally farm produced (and occasionally purchased) roughage represents the major source of feed utilized [5,43]. However, low productivity in dairy cattle on roughage (forages) results from inefficient utilization (low digestibility) of the feed because of deficiencies of critical nutrients in the diet [82]. The amounts of nutrients that an animal acquires each day depend on the quantity of feed consumed and the nutrients released per unit of feed as it passes through the digestive tract [26]. Therefore, utilization of good quality grazing or cultivated pastures in SDFs is a good feeding strategy that results in higher milk yields to the traditional cut and carry strategy using Napier grass, as it reduces feeding costs up to 25% and increases margins over feeding to 15% [5]. This enhances the sustainability of the smallholder dairy feeding systems by improving the economic scale.

There is lack of nitrogen supply to rumen microbes and the animal itself depresses feed intake, hence restricted intake and digestibility of roughages will remain a constraint in SDFs [83], even when the protein supply deficiencies have been overcome [12]. However, further research is needed to verify these observations and to examine the use of low protein supplements to reduce nitrogen excretion of dairy cows grazing or fed crop residues during the dry season. Introduction of improved feeding practices based on strategic supplementation of locally available feed resources is required not only to enhance milk production but also to introduce sustainable farming practices that will ensure a continuous supply of milk and milk products at lower production costs in SDFS for sustainability and competitive advantage.

Supplementary feeding of smallholder dairy cattle must then be seen as a least-cost system which is integrated into the management of an enterprise with low stocking rates [62], [84]. The end result is tolerating some annual weight loss and expecting a relatively low reproduction rate and annual weight gain [19], [85]. Within such a management system, provision must be made to feed only those animals with the greatest need and to ensure the safe and uniform distribution of supply to the target animals. Finally, care must be taken that supplementary feeding does not lead to the overgrazing or overutilization of part or all of the locally available feed resources with irreversible damage to what is generally a fragile ecosystem.

Smallholder dairy cattle feeding systems permits the expenditure of only minimal amounts of money on supplements and hence the aim is to maximize the intake and digestibility of roughage by supplying limiting nutrients [26], [62] These usually comprise minerals and sources of ammonia such as urea for rumen microbes. If the animal continues to lose weight at a rate faster than desired, protein to supply amino acids to the tissues is then added to the supplement and if that is not adequate, additional sources of energy must be provided [26], [62]. However energy supplied as grain or molasses is generally expensive and has the further disadvantage of acting partly as a substitute rather than as a supplement for roughage.

10. CONCLUSION

In order to reduce seasonal and inter-year fluctuations in feed supply, smallholder dairy production systems have to be integrated and holistic. Many technical interventions increase variability and risk, especially when they depend on poorly functioning markets. Reducing the risk of adverse seasonal effects requires diversification, wider choice of feed-food crops, livestock and income-earning activity, marketing infrastructure and support, and for SDFs multiple sources of food-feed and income. This selective agenda of policy and research needs show that seasonality matters especially for SDFs, and that policies and projects can have components which reduce seasonal adversity. It is especially - though not only - in those parts of Eastern Africa which are remote, semi-arid, or arid and with uncertain rainfall that seasonality has become and must remain a prominent dimension of policy and research. For SDFs to remain competitive, it is important to increase industry capability to manage the implications of seasonality to milk yield and reproductive performance of dairy cattle. There is every expectation these seasonal changes will be further accentuated and sustainable farmer-led feeding decisions must be adopted in the future.

ETHICAL APPROVAL

All procedures performed in study involving human and animal participants were in accordance with the ethical standards of the researcher institutional (KALRO and NM-AIST) and/or national agricultural research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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