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Assessing Animal Disease Prevalence and Mortality in Smallholder Dairy Farms under Contrasting Management Practices and Stressful Environments in Tanzania

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Abstract

In dairy farming, deploying effective animal husbandry practices minimise disease infections and animal mortality. This improves animal health and welfare status, which is important in tropical smallholder dairy farming, where animals are persistently exposed to multiple environmental stresses. The hypothesis of this study was that animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality, whether under low- or high-stress environments. The study adopted a two-factor nested design with farms contrasting in the level of animal husbandry (positive deviants and typical farms) nested within environments contrasting in the level of environmental stresses (low- and high-stress). A total of 1,999 animals were observed over 42 month period in the coastal lowlands and highlands of Tanzania. The disease prevalence was lower ($p < 0.05$) in positive deviant farms than in typical farms under low-stress (10.13 vs. 33.61 per 100 animal-years at risk) and high-stress (9.56 vs. 57.30 per 100 animal-years at risk). Cumulative disease incidence rate was also lower ($p < 0.05$) in positive deviant farms than in typical farms under low-stress (2.74% vs. 8.44%) and high-stress (2.58% vs. 14.34%). The probability of death for a disease infected dairy cattle was relatively lower in positive deviant farms compared to typical farms under low-stress (0.57% vs. 8.33%) and high-stress (0.60% vs. 6.99%). Per 100 animal-years at risk, the mortality density of cattle was lower ($p < 0.05$) in positive deviant farms compared to typical farms, 15.10 lower in low-stress and 2.60 lower in high-stress. These results show that compared to typical farms, positive deviant farms consistently attained (p

< 0.05) lower animal disease infections and subsequent deaths, regardless of the level of environmental stress that the animals were exposed to. This implies that positive deviant farms deployed animal husbandry practices that more effectively minimised animal disease infections and deaths and therefore could maintain their animals in better health and welfare status.

Keywords

Dairy Cattle, Disease Infections, Case-Fatality Rate, Animal Mortality Density, Positive Deviants, Tropics

1. Introduction

Disease prevalence and mortality rates are metrics relevant in monitoring the animal health status in a dairy herd. In addition, these metrics have an influence on animal well-being and farm profitability [1] [2]. Disease infections and mortality in a dairy herd can account for significant economic loss from losses in financial, wealth, nutrition, improved genetic materials and investment. Disease exposure and infections contribute to reduced productivity levels attainable in smallholder dairy cattle farming. In chronic and severe incidences, disease exposure and infections lead to huge yield gaps [3] [4] and subsequent loss of livelihood benefits to households [5].

Involuntary loss of heifer calves before calving increases the need for externally sourced heifer replacements to offset the loss of potential replacements [1]. In young stock, disease infections can lead to suboptimal performance in later adult age, including older age at first calving [6], but also increased risk of exiting the herd before first calving [7]. Disease infections causing mortality are variable between management practices that farmers deploy, production systems and production environments [8]. In dairy cattle, up to 31.0% morbidity rate and 58.4% mortality rate have been reported [9] and variations occur between production environments, depending on the magnitude of stress to animals [10] [11] [12].

The magnitude of economic loss value experienced in smallholder dairy farming can be substantial, with adverse impacts on the livelihood benefits [13]. This necessitates estimating disease prevalence rates and associated animal mortality rates to inform animal health interventions. Good animal health status is a determinant of productivity and livelihood benefits in a dairy herd [14]. However, keeping a herd in good health status comes with increased investments in quality housing, feeds and animal health services as has been observed by Shija *et al.* [15] and Schumacher [16].

In studying distinguishable management practices between positive deviants and typical farms, Shija *et al.* [15] observed that positive deviant farms deployed management practices differently from typical farms. The authors also observed that cattle were exposed to higher levels of heat stress in a high-stress environment than in a low-stress environment (77.29 ± 0.39 vs. 68.20 ± 0.39 THI). These observations would imply that animal disease infections and mortalities are variable between farms with contrasting management practices and between contrasting stressful environments. The hypothesis was thus tested that animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality, whether under low- or high-stress environments. The study used sample smallholder dairy farms in two prominent milksheds found in the Northern highlands and Eastern coastal lowlands of Tanzania.

2. Materials and Methods

2.1. The Data Source

Data were from 794 sample smallholder farms registered with the African Dairy Genetic Gain (ADGG) Project that delivers to farmers' superior heifers and bulls for dairy cattle upgrading [17]. Farms sampled were from the northern and eastern milksheds, which respectively are Kilimanjaro and Tanga regions. In this study, the northern milkshed is classified as a low-stress dairy production environment for a combination of some characteristic features. One, the temperate/highland ecosystem that has developed around Mount Kilimanjaro is a result of the mountain's high altitude reducing the typically high tropical temperatures. The temperature-humidity index (THI) estimated by Shija *et al.* [18] is within the heat stress threshold (68 to 71) category as defined by Zimbelman *et al.* [19]. Rainfall is of a bimodal pattern, favoring high year-round fodder biomass growth for a mixed rain-fed production system. The disease incidences are considered relatively lower for animals here which are predominantly stall-housed and zero-grazed [15].

The eastern milkshed in this study is classified as a high-stress dairy production environment. The characteristic features underlying this classification are a combination of high humidity, low altitude and high temperatures with THI within the category of mild to moderate heat stress (72 to 79) levels for dairy cattle [18]. The ecosystem is considered high in incidences and prevalence of tick-borne diseases - East Coast Fever, Babesiosis and Anaplasmosis, and internal parasitic worm infestations. Production system is mixed rain-fed crop-livestock. Feeding system is a mixture of stall feeding and pasture grazing with a supplemental offer of fodder, crop residues and agro-industrial by-products-based concentrates offered at strategic times.

In both low- and high-stress environments, dominant dairy cattle breeds are Holstein-Friesian and Ayrshire, with a variable proportion of crossbreeds between these dominant breeds, Jersey and zebu cattle in a herd often less than ten heads. Dairy crossbreds are prominent in the herd because farmers practice upgrading to higher levels of Holstein-Friesian or Ayrshire blood as observed by Shija *et al.* [15]. Mating is both by a bull and artificial insemination while milking is done twice a day by hand. The milk yield was estimated recently at an average of 8.55 L/d [18], translating to a 305-d lactation milk production of 2600 liters.

2.2. Research Design

The study used a two-factor nested research design. In this design, environment is a fixed factor while farm (positive deviants and typical) nested with the environment (low- and high-stress) is a random factor. The experimental units are the individual farms. This design was used to investigate the observed differences between positive deviants and typical farms in animal disease prevalence, cumulative disease incidence, case-fatality rate and animal mortality density under low- and high-stress environments.

The study builds on positive deviant farms earlier objectively identified in a large sample of farms using Pareto-Optimality ranking technique [18]. The positive deviant farms were isolated on criteria of consistently outperforming ($p < 0.05$) typical farms in five production performance indicators. Specifically, these were total energy balance to indicate the extent that cattle were experiencing feed scarcity, disease incidence density to indicate the extent that animals were exposed to disease infections while daily milk yield, age at first calving and calving interval indicated the extent of expression of production and functional traits.

Shija *et al.* [18] have detailed a stepwise process implemented to identify positive deviant farms based on those five production performance indicators. A brief outline is presented in this paper. First was to obtain the average of each performance indicator for each of the 794 individual farms, which had been observed for a period of 42 months. Next step was to obtain overall sample averages for each of the performance indicator, to use in setting the population threshold points (population mean). Energy balance was set to ≥0.35 Mcal NE_L/d (1.46 MJ NE_L/day) while milk yield was to ≥6.32 L/cow/day. Age at first calving and calving interval were respectively set to ≤1153.28 days and ≤633.68 days while disease incidence density was set to ≤12.75 per 100 animal-years at risk.

With the population threshold points set, z-scores were computed through z-transformation of each of the farm performance indicator obtained in step one. These performance scores for each of the 794 individual farms were then subjected to Pareto-Optimality ranking algorithm in which total energy balance and daily milk yield were maximized while minimising age at first calving, calving interval and disease incidence density. This maximization and minimization reflected the management goals to increase productivity and livelihood benefits in dairy farming. As executed, the Pareto-Optimality ranking assigned rank 1 to Pareto-Optimal solutions for farms not dominated by other farms. The ranking produced the farms that outperformed other farms with equivalent characteristics in at least one dimension without being outperformed in any other dimension. Next, the farms in rank 1 were removed from the set and the procedure was repeated by identifying the next set of non-dominated farms, which were assigned to rank 2. This ranking procedure was repeated until the entire sample farms were all ranked. The resulting farms were the Pareto-Optimal or non-dominated solutions.

In this study, a comparison was made between the individual farm performance obtained in step one and the population threshold points set in step two to identify the truly positive deviant farms. Finally, a comparison of each farm's performance was made against a threshold value to identify which farms truly deviate from the average or beyond expected performance on each indicator variable. From a set of Pareto-Optimal farms, sorting of multiple indicator variables was applied to select farms that had all indicator variables above the threshold points for milk yield and energy balance and below threshold points for disease incidence density, age at first calving and calving interval. The selection process involved sorting multiple indicator variables to complement the Pareto-Optimality ranking in order to isolate only truly positive deviant farms that consistently outperformed each of the indicator variables simultaneously. In a sample of 794 farms, those qualifying as positive deviant farms were 3.4% (27 farms).

2.3. Data Collection and Processing

Information about disease and treatment events was captured during monthly farm visits. The ADGG engaged farmers in collecting routine animal performance data recording services offered by trained para-professional veterinary assistants (PPVAs) who visit the individual farms once or twice monthly. The PPVAs record animal performance in an Open Data Kit tool installed on Android Tablets. In this study, the disease events occurred between 1st of January 2017 and 31st of July 2020. A dynamic cohort approach was adopted to account for additional animals recruited provided that they were either born after initial recruitment or acquired (purchase or gift). Clinical signs and treatments were recorded for each case.

Treatment events that were recorded simultaneously with vaccination or routine animal health management records were excluded as it was not possible to determine if the record was associated with disease treatment or prevention. A disease was considered unique and was recorded as a new event for a given animal if it occurred 14 days or more from the termination of a previous similar disease episode. This timeframe was determined based on recommended on-farm protocols designed to identify new cases of disease as opposed to retreatment of the same disease episode [20]. In this context, disease diagnosis was based on differential clinical signs consistent with the type of disease observed in a susceptible animal.

The major diagnostic features included weight loss, diarrhea, dullness, thriftlessness, loss of appetite, labored breathing, ocular discharges, nasal discharges, paleness of ocular and buccal membranes, enlarged superficial lymph node (parotid or pre-scapular or pre-crural), constipation and pyrexia (elevated body temperature > 40˚C). The presence of these clinical features is directly indicative of seroconversion to most common disease infections in dairy cattle [21].

After all edits, 794 farms had a total of 1999 cattle with a total of 1912 health treatment events on 849 diseased cattle available for analysis. In addition, a total of 69 dairy cattle ($\geq$18 months of age) died during the study period. **Table 1**

Table 1. Distribution of numbers of farms, animals, diseased animals, deaths and total animal-years at risk in the database used for the analyses.

Factor	Level of stress	Number of farms	Number of animals	Number of diseased animals	Number of deceased animals	Number of animal-years at risk
Production environment	Low-stress	386	930	348	31	3044.7
	High-stress	408	1069	501	38	3430.6
	Total	794	1999	849	69	6475.3
Farm (environment)	Low-stress					
	Positive deviants	15	39	4	2	182.2
	Typical farms	371	891	344	29	2862.5
	Total	386	930	348	31	3044.7
	High-stress					
	Positive deviants	12	31	5	3	114.3
	Typical farms	396	1038	496	35	3316.3
	Total	408	1069	501	38	3430.6
Farm	Overall					
	Positive deviants	27	70	9	5	296.5
	Typical farms	767	1929	840	64	6178.8
	Total	794	1999	849	69	6475.3

provides a summary of the number of dairy farms, animals, diseased animals and deaths that occurred during the study period in positive deviants and typical farms by the environments. In this study, animal disease prevalence, cumulative disease incidence, case-fatality rate and animal mortality density were used to assess health status of dairy cattle managed in positive deviants and typical farms under low- and high-stress environments.

In this study, morbidity events were estimated in terms of crude disease prevalence in a stepwise process. First, disease incidence density which is the number of new cases that occurred in a population over a period of time was quantified at the individual herd level monitored over a period of 42 months. This is an indicator measuring the rapidity with which new cases of the disease develop overtime to derive disease prevalence [22] [23]. Disease incidence density (ID) was computed according to Thrusfield [18] [22]:

$$\text{ID} = \frac{\text{number of events occurred during observation period}}{\text{sum of animal years at risk of developing disease}} \quad (1)$$

The resulting disease incidence density expressed per animal-years at risk was used to derive the disease prevalence rate. Disease prevalence is defined as the number of instances of disease or related attributes (e.g., infection) in the study population, at a designated time or over a specified time period (period prevalence) without distinction between old and new cases. Since disease prevalence depends on the duration and disease incidence [22], therefore, disease prevalence was computed from the relationship:

$$\text{Disease prevalence} \propto \text{Disaese incidence} \times \text{Duration} \tag{2}$$

For clarity, the disease prevalence is presented as per 100 animal-years at risk (multiplying by 100). The periods at risk, or animal days at risk, are the total number of days the study animals were present during the observation period. The contribution of each animal to the total animal days was the difference between its date of exit or end of the study and its date of entry (or the start of the study).

In addition, cumulative disease incidence which is used to predict an individual's change in health status was estimated. This indicator shows the probability of an individual becoming ill over a specified period of time. Therefore, cumulative disease incidence was estimated from disease incidence density obtained in Equation (1) using the following function:

$$\text{Cumulative incidence} = 1 - \mathrm{e}^{-(\text{Incidence density})} \tag{3}$$

Further, case-fatality rates were calculated based on the number of deceased cases to the total number of diseased animals in the population [13] [22]. This is defined as the number of deaths that occurred during the study period to the total number of diseased animals in the population.

Mortality density measures are analogous to incidence measures where the relevant outcome is death rather than new cases of a specific disease. This is computed in a similar way as incidence density (λ: number of deaths in a population per unit of animal-time during a given period). The numerator comprise the number of deaths. For this study, mortality was defined as any observed death, irrespective of the cause. Confirmation of mortalities was made by PPVAs or by examining the farmers' disease event records during the subsequent farm visits. Following confirmation, mortality density (λ) was computed at the herd level for the entire period of study. Thus, crude λ was estimated by applying the following equation:

$$\lambda = \frac{\text{number of deceased animals that occurred during observation period}}{\text{sum of animal years at risk of dying}} \tag{4}$$

The resulting λ represented the rate per animal-years at risk in a predefined period and was translated into a rate per period at risk per defined time period (*i.e.*, year). Thus, the λ for predefined period was presented as per 100 animal-years at risk (multiplying by 100).

2.4. Data Analysis

Statistical analysis was to test the hypothesis that in smallholder dairy farming, animal disease infections and mortality significantly differ between positive deviant and typical farms whether under low- or high-stress environments. All statistical analyses were performed in SAS software [24], fitting the linear mixed model to account for variables that were correlated or with non-constant variability. Means separation was achieved with the Least Significant Difference for direct pairwise comparisons between means. The fitted statistical model was in the form:

$$Y_{ijk} = \mu + PE_i + FT\left(PE\right)_{ij} + e_{ijk} \tag{6}$$

where, Y_{ijk} is either estimated disease prevalence, cumulative incidence and mortality density rates; μ is the overall mean, PE_i is the fixed effect of environment, $FT\left(PE\right)_{ij}$ is the random effect of farm (positive deviants and typical) nested within the environment (low- and high-stress) and e_{ijk} is the random error.

3. Results

Table 2 shows the estimated means for crude disease prevalence and cumulative disease incidence rates in positive deviant and typical farms under low- and

Table 2. Least squares mean (mean ± SE) of crude disease prevalence per 100 animal-years at risk and cumulative disease incidence rate (%) in dairy cattle raised in positive deviant and typical farms under low- and high-stress environments.

Factor	Level	Crude disease prevalence per 100 animal years at risk	Cumulative disease incidence rate (%)
Production environment	Low-stress (n = 386)	21.87 ± 5.95	5.59 ± 1.46
	High-stress (n = 408)	33.43 ± 6.62	8.46 ± 1.63
	Mean difference	11.56	2.88
	p-value	0.1945	0.1899
Farm (environment)	Low-stress		
	Positive deviants (n = 15)	10.13 ± 11.67	2.74 ± 2.87
	Typical (n = 371)	33.61 ± 2.35	8.44 ± 0.58
	Mean difference	23.48	5.70
	p-value	0.0489	0.0522
	High-stress		
	Positive deviants (n = 12)	9.56 ± 13.05	2.58 ± 3.21
	Typical (n = 396)	57.30 ± 2.27	14.34 ± 0.56
	Mean difference	47.74	11.76
	p-value	0.0003	0.0003
Farm	Positive deviants (n = 27)	9.85 ± 8.75	2.66 ± 2.15
	Typical (n = 767)	45.46 ± 1.63	11.39 ± 0.40
	Mean difference	35.61	8.73
	p-value	<0.0001	<0.0001

***$p < 0.001$; *$p < 0.05$; $^{NS}p > 0.05$.

high-stress environments. Results reveal that positive deviant farms realized lower crude disease prevalence and cumulative disease incidence rates ($p < 0.001$) in both low- and high-stress environments. The disease prevalence was lower in positive deviant farms than in typical farms in both low-stress environments (10.13 vs. 33.61 per 100 animal-years at risk) and high-stress environments (9.56 vs. 57.30 per 100 animal-years at risk). Also, cumulative disease incidence rate was lower in positive deviant farms than in typical farms in both low-stress environment (2.74% vs. 8.44%) and high-stress environment (2.58% vs. 14.34%).

Average case-fatality rates (%) for animals in positive deviants and typical farms in both high and low stressful environments are reported in **Figure 1**. The case-fatality rate measures the probability of death in diseased animals. The results reveal a lower probability of death for dairy cattle in positive deviant farms compared to those in typical farms, in both low-stress environment (0.57% vs. 8.33%) and high-stress environment (0.6% vs. 6.99%). Further, results reveal a lower probability of death for animal under low-stress environment relative to high-stress environment (3.65% vs. 4.48%). This indicated that disease infected animals had a higher survival rate in positive deviant farms regardless of the level of environmental stress.

Mean differences in animal mortality density (per 100 animal-years at risk) and risk rate by farm and environment is illustrated in **Figure 2**. A positive value for low-stress environment indicated higher mortality density in low-stress environment than was in high-stress environment, while a positive value for positive deviants indicated a higher mortality density in positive deviant farms than was in typical farms. A negative value indicated the opposite. Per 100 animal-years at risk, mortality density was lower in positive deviant farms compared to typical farms in both low- and high-stress environments. Positive deviant farms recorded a lower animal mortality density, 15.10 lower in low-stress and 2.6 lower in high-stress environments (**Figure 2**). Further, animal mortality

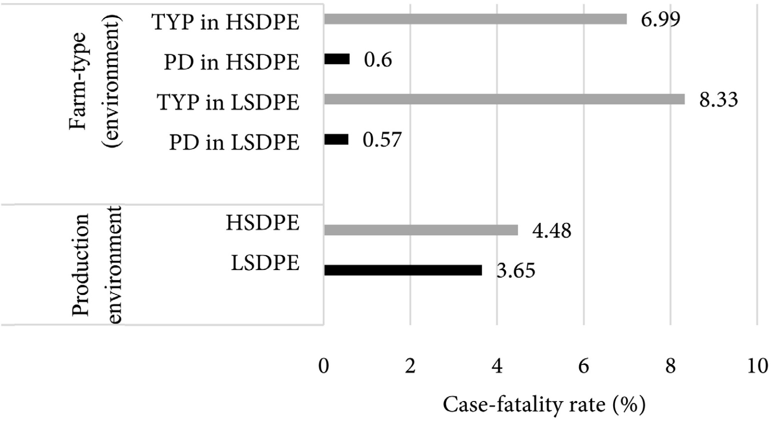

Figure 1. Estimated case-fatality rates (%) of dairy cattle managed in positive deviants (PD) and typical (TYP) farms under low-stress (LSDPE) and high-stress (HSDPE) production environments.

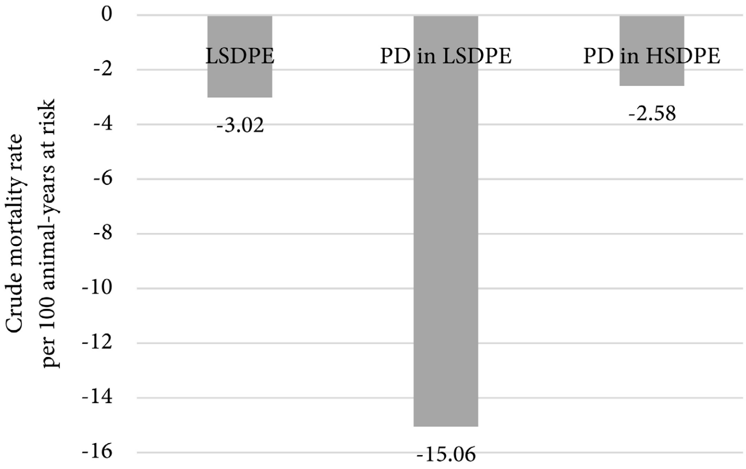

Figure 2. Means difference in mortality density of dairy cattle raised in positive deviants (PD) and typical farms under low-stress (LSDPE) and high-stress (HSDPE) production environments.

density was a marginal 3.02 per 100 animal-years at risk lower in low-stress environment compared to those in high-stress environment.

4. Discussion

After the animal disease prevalence, cumulative disease incidence, case-fatality and mortality density estimated in this study is to indicate the deployment of animal husbandry practices that improve animal health and welfare status. The differences observed between positive deviant and typical smallholder dairy farms reveal the extent to which animal husbandry practices deployed have been effective in minimising disease infections and animal mortality. In smallholder farming, where dairy cattle are persistently exposed to multiple environmental stresses, the level of animal husbandry practices has an influence on the animal health and welfare status that can be attained. A previous study by Shija *et al.* [15] with the same sample farms revealed that positive deviant farms do deploy management practices differently from typical farms. Distinguishing positive deviant farms from typical farms were consistent outperformance in five production performance indicators. These were set at ≥0.35 Mcal NE_L/d (1.46 MJ NE_L/day) energy balance, ≥6.32 L/cow/day milk yield, ≤1153.28 days age at first calving, ≤633.68 days calving interval and disease incidence density ≤ 12.75 per 100 animal-years at risk. With this knowledge, this study assessed whether animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality under similar environmental stress. A study design suited to testing this hypothesis was identified and implemented. This was a two-factor nested design with contrasting levels of environmental stresses (low- and high-stress) as fixed effect and farms contrasting in the level of animal husbandry (positive deviants and typical farms) nested within the environment.

The data from which estimates were made of the disease prevalence rate and mortality density was reasonably of high reliability level, suited to testing the hypothesis. The data was from sufficiently large sample of 794 farms, 1,999 animals observed over 42 months longitudinal period in which 1,912 health treatment cases were recorded on 849 diseased animals. The farms, especially the positive deviants, frequently sourced professional veterinary services that accorded closer monitoring of sick cases and animal health practices [15]. Also, a dynamic cohort approach was adopted in which clinical signs and treatments were recorded for each case longitudinally and additional animals were recruited after verifying their origin (birth after initial recruitment, purchase or gift). The estimated disease prevalence and cumulative disease incidence rate are indicative of the extent to which animal husbandry practices deployed effectively minimised disease infections. The average case-fatality as a probability of death for a disease infected animal and mortality density is indicative of the extent to which animal husbandry practices deployed effectively minimised animal mortality.

The animal disease prevalence and cumulative disease incidence rates obtained in positive deviant farms were consistently lower than those in typical farms in both low-stress and high-stress environment. In positive deviant farms, the disease prevalence was 3.3 times lower (10.13 vs. 33.61 per 100 animal-years at risk) in low-stress environment and 6.0 times lower (9.56 vs. 57.30 per 100 animal-years at risk) in high-stress environment when compared to typical farms. Cumulative disease incidence rates in positive deviant farms were 3.1 times lower (2.7 vs. 8.4) in low-stress environment and 5.5 times lower (2.58% vs. 14.34%) in high-stress environment when compared to typical farms. This is a strong evidence that disease infections were more minimised in the positive deviant farms, whether in low- or high-stress environments. It is argued that positive deviant farms deployed animal husbandry practices that more effectively minimised disease infections than were the husbandry practices deployed in the typical farms.

Higher rates of disease prevalence and cumulative incidences in typical farms can be associated with the reliance on fellow farmers for provision of veterinary services unlike the positive deviant farms who frequently sourced professional animal health service providers [15]. This observation corroborates those by Singh *et al.* [25] in India where smallholder farmers had reliance on untrained fellow farmers for provision of veterinary services. Rarely are fellow farmers adequately trained in veterinary service delivery, so such a practice potentially can lead to misuse of drugs or misdiagnosis of diseases. There are disadvantageous when fellow farms source unqualified veterinary services because of associated poor management outcomes [26]. For instance, a previous study reported unqualified farmers to incorrectly dilute and apply highly poisonous acaricides to control ticks at shorter intervals of 1 - 2 weeks [27]. With such practice, the efficacy of acaricides becomes compromised when under dosing because this encourages the strongest and most resistant parasites to survive and acquire resistance [28].

The challenges associated with accessing unqualified veterinary services can be addressed by strengthening farmer cooperative movement. This collective approach to delivering veterinary practices offers affordable access to professional veterinary services [10] [29] [30] [31]. In Tanzania presently, some smallholder dairy cooperatives like Tanga Dairies Cooperative Union in the high-stress environment and Nronga Women Dairy Cooperative Society Limited in the low-stress environment operate several milk collections centres (MCCs). These milk collections centres can be focal hubs for input and veterinary service delivery to farmers. That will require organizational innovations by the cooperatives. Success with such hubs has been recorded in Kenya that can inform replication in Tanzania set up [32]. Setting dairy hub service centres is highly relevant in the high-stress environment where disease prevalence and incidences are high.

The estimated case-fatality and mortality density in positive deviant farms were consistently lower than those estimated in typical farms in both low-stress and high-stress environments. The average case-fatality rate in positive deviant farms was 14.6 times lower (0.57% vs. 8.33%) in low-stress environment and 11.7 times lower (0.60% vs. 6.99%) in high-stress environment than was observed in typical farms. The case-fatality rate estimates being indicative of the probability of death in diseased animals, shows that animals managed in positive deviant farms had a lower probability of death whenever were disease infected compared to those animals managed in typical farms, in both low-and high-stress environments.

The per 100 animal-years at risk mortality density in positive deviants when compared to typical farms was 15.06% lower under low-stress and 2.58% lower under high-stress environments. Lower animal mortality rate in positive deviant farms in both low-stress and high-stress environments provides good evidence that the risk of death from disease related causes were more minimised in the positive deviant farms, whether in low- or high-stress environments. This is indicative evidence that positive deviant farms deployed animal husbandry practices that more effectively minimised the risk of death to their animals, even in the event of disease infections [33]. This was realized in positive deviant farms with closer monitoring of sick animals as they had frequent access to high-quality professional veterinary services [15].

Frequently accessing quality veterinary services can be argued to empowered positive deviant farmers with the capacity to more effectively implement disease preventive health practices and corrective measures in more timely and effective manner. However, frequent access to professional veterinary services comes at cost, implying that positive deviant farms minimised disease infections, case-fatalities and mortalities at greater investment relative to typical farms. This suggests resource endowment is a distinguishing attribute between positive deviants and typical farms when it is necessary to improve animal health and welfare status [2] [34]. This has implications on pro-poor animal health service delivery system. The low resource endowed farms could be vulnerable to disease infections and loss of livestock assets when mortality occurs. This necessitates public investments in infrastructure that is supportive of efficient veterinary service delivery [35] [36].

Minimising the risk of death for animals from disease related causes attained in positive deviant farms shows that animals had higher survival rates, which reduce the need to rear replacement heifers. The survival rates obtained are consistent with the previous studies under the same high-stress dairy production environment (Tanga coastal lowlands zone) that estimated a mean morbidity of 8.3% and mortality of 12.0 per 100 animal-years at risk [10]. High animal survival rates attained in positive deviant farms demonstrates better animal health performance outcomes, even under high-stress environment, where heat load, disease infections and feed scarcity are prevalent [10] [29] [30] [31]. The high-stress in Tanga coastal lowlands zone is associated with a combination of lower altitude, high humidity and high temperature reaching 72 to 79 THI units. These are conditions that are favourable to thriving of tick-borne and non-tick borne disease infections [37] [38] [39].

Ticks are important both as direct blood-feeding parasites and also as vectors of a range of production limiting pathogens with economic and welfare impacts on dairy production, relating to animal mortality and reduced production and reproduction [40] [41]. In this case, improvement in dairy cattle productivity would be achieved through well-structured crossbreeding programmes to attain resilient animals, implementing appropriate animal health management practices and designing conducive cowsheds allowing adequate floor spacing for cow comfort. These husbandry practices can minimise disease infections associated with tick-borne and non-tick-borne diseases, improve tolerance to heat load stresses, and subsequently improve reproduction and milk production in dairy herds [39]. The provision of inadequate floor spacing per animal has been associated with increased disease prevalence in animals [42]. In these sample farms, the provision of better-quality housing and allowing for adequate larger floor spacing per animal in the zero-grazing stall units had been observed in positive deviant farms [15]. It can thus be argued that with effective animal health management, positive deviant farms attained better animal health status [33] [43] [44].

5. Conclusion

This study estimated animal disease prevalence, cumulative disease incidence, case-fatality rate and mortality density in positive deviants and typical farms in two prominent milksheds in Tanzania. The two milksheds were representative of low- and high-stress dairy-production environments. Results of the study show that compared to typical farms, positive deviant farms consistently attained ($p < 0.05$) lower animal disease infections and subsequent deaths, regardless of the level of environmental stress that the animals were exposed to. The implication is that positive deviant farms deployed animal husbandry practices that more effectively minimised animal disease infections and deaths, and therefore could maintain animals in better health and welfare status.

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Author's Contribution

Conceptualization; DSS, BOB: methodology; DSS, BOB: software; DSS: validation; DSS, BOB, OAM, PKM: formal analysis; DSS: investigation; DSS: resources; DSS, OAM, NJK: data curation; DSS: writing—original draft preparation; DSS: writing—review and editing; DSS, BOB, OAM: visualization; DSS, BOB, PKM: supervision; DSS, BOB, OAM, PKM, NJK: project administration; DSS, BOB, OAM, PKM, NJK: funding acquisition; DSS, OAM, NJK. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The animal study protocol was approved as provided for by the Tanzania Livestock Research Institute Regulations (2020) and the Research Clearance issued by the Tanzania Livestock Research Institute on behalf of the Tanzania Commission for Science and Technology (Ref. No. TLRI/RCC.21/003 of 2 August 2021).

Conflicts of Interest

The authors declare no conflict of interest.

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