world

Article

Characterizing Management Practices in High- and Average-Performing Smallholder Dairy Farms under Contrasting Environmental Stresses in Tanzania

Dismas Said Shija [1,*], Okeyo A. Mwai [2], Perminus K. Migwi [1], Raphael Mrode [2] and Bockline Omedo Bebe [1]

1 Department of Animal Sciences, Egerton University, Njoro P.O. Box 536-20115, Kenya
2 International Livestock Research Institute, Nairobi P.O. Box 30709-00100, Kenya
* Correspondence: dismas.shija@sua.ac.tz; Tel.: +255-786-444-700

Abstract: This study characterized breeding, housing, feeding and health management practices in positive deviants and typical average performing smallholder dairy farms in Tanzania. The objective was to distinguish management practices that positive deviant farms deploy differently from typical farms to ameliorate local prevalent environmental stresses. In a sample of 794 farms, positive deviants were classified on criteria of consistently outperforming typical farms ($p < 0.05$) in five production performance indicators: energy balance $\geq$ 0.35 Mcal NEL/d; disease-incidence density $\leq$ 12.75 per 100 animal-years at risk; daily milk yield $\geq$ 6.32 L/cow/day; age at first calving $\leq$ 1153.28 days; and calving interval $\leq$ 633.68 days. The study was a two-factor nested research design, with farms nested within the production environment, classified into low- and high-stress. Compared to typical farms, positive deviant farms had larger landholdings, as well as larger herds comprising more high-grade cattle housed in better quality zero-grazing stall units with larger floor spacing per animal. Positive deviants spent more on purchased fodder and water, and sourced professional veterinary services ($p < 0.001$) more frequently. These results show that management practices distinguishing positive deviants from typical farms were cattle upgrading, provision of larger animal floor spacing and investing more in cattle housing, fodder, watering, and professional veterinary services. These distinguishing practices can be associated with amelioration of feed scarcity, heat load stresses, and disease infections, as well as better animal welfare in positive deviant farms. Nutritional quality of the diet was not analyzed, for which research is recommended to ascertain whether the investments made by positive deviants are in quality of feeds.

Keywords: breeding practices; feed cost; healthcare cost; positive deviants; stressful production environment

Citation: Shija, D.S.; Mwai, O.A.; Migwi, P.K.; Mrode, R.; Bebe, B.O. Characterizing Management Practices in High- and Average-Performing Smallholder Dairy Farms under Contrasting Environmental Stresses in Tanzania. *World* **2022**, *3*, 821–839. https://doi.org/10.3390/world3040046

Academic Editor: Mario D'Amico

Received: 31 August 2022
Accepted: 28 September 2022
Published: 5 October 2022

1. Introduction

Smallholder dairy farming in the tropics is practiced under multiple and variable environmental stresses, of which prevalent are feed scarcity, disease infections and heat load stresses. These environmental stresses either limit or reduce dairy productivity [1,2], and subsequently impact on livelihood benefits of dairy farming to the households. For improving smallholder livelihoods, it becomes necessary to identify management practices that enable farmers to ameliorate prevalent environmental stresses and minimize the resultant limitation or reduction in dairy productivity. Development agencies have invested in identifying and scaling appropriate management practices, which smallholder farmers can deploy to ameliorate the prevalent environmental stresses [3]. Of importance are management practices that farmers can adopt or adapt in their local production systems to attain livelihood benefits from dairy farming [2,4,5].

Positive deviance is an approach gaining importance in identifying management practices deployed to ameliorate local prevalent environmental stresses under similar production circumstances. In a given population, success in ameliorating local environmental stresses is associated with a few farmers exhibiting positive deviant behavior. The positive deviants exhibit outstanding performance, implying that they deploy positive deviant behavior that enables them to successfully ameliorate locally prevalent environmental stresses. The success of positive deviant farmers can then be shared, learnt and scaled in the locality to peer farmers who also face similar biophysical or resource constraints [6–8]. Interactions between different stakeholders can hasten the learning process of deploying those appropriate management practices in the locality.

Positive deviant behavior was initially applied in designing food supplementation programmes in Central America. Identification of dietary practices developed by mothers for their children was endogenous in nature [9]. The successes were extended to designing food supplementation and other nutritional promotion in the larger population. This was on the assumption that endogenously developed practices, although atypical, would be feasible and culturally acceptable, having been developed indigenously and not extraneously in the locality. Since then, positive deviant behavior has attracted research attention and application in public health, agriculture, and even in smallholder livestock systems [10–13].

In several studies of positive deviants in a population facing similar production challenges, distinguishable management practices is apparent. For example, in Northern Ghana, positive deviants deployed supplementary feeding, health management, animal housing at night and increased landholdings for growing crops and fodder [14]. In deploying these practices, they increased feed resource base with which they were able to enlarge the number of animals, improve animal welfare and address animal theft and production constraints. In the pastoral community-dominated area of West Gollis in Somaliland, positive deviants practice rotational reseeding, strip grazing, a mixture of Rhodes grass and lablab legume pastures, and sourcing alternative feeds [13,15]. In deploying these practices, they succeeded in preserving their rangelands and addressed feed scarcity by assuring stable access to animal feeds throughout the year. In the Ecuadorian Amazon, positive deviant farms that adopted rotational grazing and sourcing alternative sources of animal feeds were able to reduce pressure on pasture and slow down grazing-induced deforestation [13,16]. Management practices distinguishing positive deviant farms in organic dairy farming have also been documented in the Netherlands. By integrating and balancing the whole farm system, the positive deviant farms managed to keep healthy animals and realized optimal productivity with the minimal use of antibiotics [17].

These previous studies of positive deviance, especially in smallholder livestock farming, used cross-sectional survey data to distinguish associated management practices. This assumes that indicator variables observed reflect average animal performance over time. However, smallholder dairy farming is very dynamic, due to multiple roles that animals play and valued by the households. In such cases, a longitudinal dataset provides more informative average animal performance, from which may be discovered transferable management practices defining outperformance under similar levels of environmental stresses [14,17,18]. Longitudinal data has the advantage that it allows variables of interest to be assessed over time, and to monitor changes towards or away from positive deviance behavior.

Another weakness in the previous studies is sampling design that do not account for contrasting environmental stresses when assessing production performance. Using the same sample farms as used in the present study, Shija et al. [19] objectively isolated positive deviants from average typical performing farms under low- and high-stress dairy-production environments. However, the study did not distinguish management practices underpinning observed outperformance. The longitudinal data was for a period of 42 months, which is sufficient to allow for distinguishing management practices over time to account for the dynamic nature of smallholder dairy farming. Dairy cattle persistently exposed to multiple environmental stresses experience disrupted physiological functioning, a depressed welfare status and immune system, and subsequently fail to express full genetic production potential. Longitudinal data can reveal distinguishable management practices that positive deviant farms deploy differently to ameliorate persistent multiple environmental stresses in their production systems. This study characterized breeding, housing, feeding and health management practices in positive deviants and typical farms to distinguish management practices that they deploy to ameliorate local prevalent environmental stresses.

This paper first describes the research areas and the design of the research, then next follows with an explanation of how management data from smallholder dairy farms was collected, processed and analyzed. Following this are the results, discussion and conclusion, and recommendations that are presented seperately.

2. Materials and Methods

2.1. Data Source

This study is an extension of an earlier study [19] in which methodology was in detail of the study area, research design, data collection and identification process of positive deviants and typical farms. In this paper, complementary and objective specific information to present paper is described.

Data was accessed from 794 sample smallholder dairy farms in the Northern (Kilimanjaro region) and Eastern (Tanga region) milksheds of Tanzania. The farms were affiliated to the African Dairy Genetic Gains (ADGG) Program, a breeding improvement intervention being implemented to deliver superior heifers and bulls for artificial insemination [3]. The ADGG facilitates farmer access to superior dairy crossbred heifers, improved bulls and artificial insemination services. To support this, ADGG has developed a genetic gains platform that uses on-farm performance information and basic genomic data to identify and prove superior crossbred bulls for artificial insemination delivery and planned natural mating. The Northern milkshed is classified a low-stress dairy-production environment while the Eastern milkshed is classified a high-stress environment.

The low-stress environment is a high-altitude region with moderate and lower tropical temperatures, with average temperature-humidity index (THI) reaching 68.20. Dairy cattle farming in this agroecological zone is predominantly a stall-feeding system, where pastures are cut and carried to the cattle shed. Rainfall is bimodal pattern supporting high year-round fodder biomass supply for dairy cattle feeding. The disease incidences are also considered relatively lower [19]. Dairy production, as practiced in both low- and high-stress environments, is rainfed mixed crop-livestock production systems. In these production systems, both crops and livestock support livelihoods, nutrition and food security, income for cash needs, and manure used to restore soil fertility. The high-stress environment is a coastal lowland zone where a combination of high humidity, low altitude and high temperatures reaching a THI of 77.29 expose dairy cattle to mild to moderate heat stress levels. The disease incidences are relatively higher, especially tick-borne diseases that include East Coast Fever, Babesiosis, Anaplasmosis and other parasitic worm infestations.

Dairy cattle feeding in rainfed crop-livestock system here is stall feeding or pasture grazing in which supplemental fodder, crop residues and agro-industrial by-product-based concentrates are offered at strategic times. In both low- and high-stress environments, herd are often fewer than ten cows of either Holstein-Friesian, Ayrshire, Jersey cattle breeds, or their crosses with the local Tanzanian shorthorn zebu cattle breeds. Breeding is both by natural mating with bulls or artificial insemination. Farmers milk by hand twice a day, in the morning and evening.

2.2. Research Design

The study used a two-factor nested research design. The environment (low- and high-stress) was a fixed factor, while farms (positive deviants and typical farms) nested within the environment was a random factor. The farms represented the experimental units [20]. Nested design is a multilevel research design in which levels of one factor (farm) are nested within levels of another factor (environment). This type of model is used to analyze data that has a hierarchical structure [21]. In a nested design, the variation introduced at each hierarchy layer is assessed relative to the layer below it [22]. This design suited the objectives of this, as positive deviant farms under a low-stress environment are not the same positive deviant farms under a high-stress environment. This also applies to typical farms under low- and high- stress environments. The study objective was to distinguish management practices that positive deviant farms deploy differently from typical farms when nested/clustered within low- and high-stress environments to ameliorate local prevalent environmental stresses. The nesting design accounted for sources of variability in the hierarchical layers (farm within environment) [19,21,22].

The present study is building upon an earlier empirical study, which objectively identified positive deviant farms from large sample farms using the Pareto-Optimality ranking technique [19]. The isolated positive deviant farms were those that consistently outperformed ($p < 0.05$) their peers (typical farms) in the five production performance indicators. A positive deviant farm had to attain performance above the population threshold point, which was set to: daily milk yield $\geq$ 6.32 L/cow/day; age at first calving $\leq$ 1153.28 days; calving interval $\leq$ 633.68 days; energy balance $\geq$ 0.35 Mcal NEL/d; and disease-incidence density $\leq$ 12.75 per 100 animal-years at risk.

Isolation of positive deviant farms was a step-wise process implemented in four steps: (i) quantifying current performance indicator variables at farm level in each of the 794 sample farms; (ii) quantifying threshold points for each of the five performance variables at the population average; (iii) executing Pareto-Optimality ranking technique with standardized indicator variables to generate a set of Pareto-Optimality ranking solutions; and (iv) isolating truly positive deviant dairy farms from a wide array of Pareto-Optimal solutions by comparing Pareto-Optimal solutions against the set population threshold points for each of the five criteria production indicators. In subjecting the 794 sample farms to the Pareto-Optimality ranking technique, truly positive deviant farms could be identified (3.4%; 27/794).

2.3. Data Collection and Processing

This subsection provides explanations on how data from a sample of smallholder dairy farms was collected and processed. The ADGG is using Livestock Field Officers/ para-professional veterinary assistants (PPVAs), also known as Performance Recording Agents (PRAs), assigned to visit each farm once or twice a month. During each visit, they record detailed events of animal performance data including milk yield, breeding, feeding and animal healthcare management using an Open Data Kit tool installed on Android Tablets. The ADGG granted access to their database for animal performance data collected from 2016 through 2020 for the purpose of this scientific study. The database is hosted by the International Livestock Research Institute (https://www.adgg.ilri.org/uat/auth/auth/login, accessed on 1 July 2020). Additional data was collected on management during visits of the individual farms, with assistance of the PPVAs. During the visits, farm records were examined, face-to-face interviews were held with the farmers and direct on-farm observations were made and recorded.

From the ADGG database, management data was extracted for processing to create the variables needed for differentiating management practices deployed in positive deviant farms from typical farms. The variables included land size in acres, number of animals in a herd, house floor spacing per animal, cowshed construction materials (wood, stone/brick walls, grass/makuti roofing and corrugated iron sheet roofing), dairy cattle breeds (Holstein-Friesian, Ayrshire and Jersey), breed composition (25%, 50% or >75% of exotic blood levels and purebred), type of cowshed (either permanent or semi-permanent), feeding systems, and proportion of different feed resources in the animal diet (fodder, crop residues and concentrates). Some of the variables were computed from obtained information, including the cost of feeds, watering and health services.

Health costs accounted for deworming, dipping and vaccination costs, while health treatment costs accounted for drugs and service costs only. The feed cost accounted for fodder growing, feed purchase and transportation, while the watering cost was for water bills and transportation expenses. The dimensions of the cowshed, including length and width, were measured using a rolling tape. Floor spacing/area (m^2) per animal was computed as the total width × length of the cowshed (including stalls, alleys and crossovers), divided by the number of dairy cattle present in the cowshed at the time of assessment. Anima health service providers were grouped into professional animal health service providers (animal health service providers/paravet, government veterinarian, project/NGO staff, co-operative/group staff and agrovet shop) and fellow farmers (self with professional advice, neighbor with professional advice, self without professional advice and neighbor without professional advice).

2.4. Statistical Analysis

This subsection describes how data on management practices collected from smallholder dairy farmers were analyzed. All statistical analyses for scale variables were performed in SAS software [23], fitting the linear mixed model to account for variables that could be correlated or with non-constant variability. Means separation was achieved with least significant difference for direct pairwise comparisons between means. Statistical testing was set at $\alpha = 0.05$, and the model fitted was in the form

$$Y_{ijk} = \mu + PE_i + FT(PE)_{ij} + e_{ijk} \quad (1)$$

where, Y_{ijk} = dependent variables, μ = overall mean, PE_i = fixed effect of production environment (low- and high-stress environments), $FT(PE)_{j(i)}$ = random effect of farm nested within the production environment, and $e_{k(ij)}$ = random error. The dependent variables were land size, number of animals, house floor spacing per animal, and the cost of watering, feed, and health costs. Analyses for categorical and count data were performed in SPSS software [24]. A bivariate correlation was performed to determine the association between feed cost and milk yield. Chi-Square tests was used for count and categorical data to test for the differences in the observed frequencies.

3. Results

This section is divided into several subsections to provide a concise description of the results.

3.1. Housing and Breeding Management Practices

Results indicate that majority of farmers in the sample were males, and were aged over 45 years, regardless of whether there were positive deviants or typical farmers in low- or high-stress environments. The average landholding, number of animals and floor spacing per animal in stall zero-grazing units is presented in Table 1 for positive deviants and typical farms and for low- and high-stress environments. Results reveal differences ($p < 0.05$) between positive and typical farms in landholding size owned in both low- and high-stress environments, the number of animals in low-stress environment and in house floor spacing per animal in high-stress environment. Compared to typical farms, positive deviant farms were larger in size, about three times larger (2.7–2.9) in low- and high-stress environments. However, the number of animals was only higher in positive deviant farms found in low-stress environment, about two times larger (1.7) relative to typical farms. In the positive deviant farms, house floor space per animal was only about two times larger in a high-stress environment. A comparison between positive deviants and typical farms revealed no difference ($p > 0.05$) in the number of animals under a high-stress environment and in floor spacing under a low-stress environment.

Table 1. Means (mean ± SE) of land size, the number of animals and stall floor spacing per cow in positive deviants and typical farms under contrasting environments.

Factor	Level	Land Size (Acres)	Number of Animals	Stall Floor Spacing (m^2/Cow)
Environment				
	Low-stress	4.85 ± 0.78	5.89 ± 0.68	7.80 ± 0.82
	High-stress	7.92 ± 0.95	4.33 ± 0.82	9.68 ± 0.99
	Mean difference	3.07 *	1.55 ^{NS}	1.88 ^{NS}
Farm (Environment)				
	Low-stress			
	Positive deviants	7.08 ± 1.52	7.33 ± 1.32	7.54 ± 1.59
	Typical	2.61 ± 0.37	4.44 ± 0.32	8.06 ± 0.38
	Mean difference	4.47 **	2.89 *	0.53 ^{NS}
	High-stress			
	Positive deviants	11.83 ± 1.86	4.17 ± 1.61	13.19 ± 1.94
	Typical	4.00 ± 0.35	4.50 ± 0.31	6.17 ± 0.37
	Mean difference	7.83 ***	0.34 ^{NS}	7.01 ***
Farm				
	Positive deviants	9.46 ± 1.20	5.75 ± 1.04	10.36 ± 1.25
	Typical	3.31 ± 0.25	4.47 ± 0.22	7.12 ± 0.27
	Mean difference	6.15 ***	1.28 ^{NS}	3.24 *

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ^{NS} $p > 0.05$.

Table 2 presents the distribution frequency of type of cattle housing and construction materials in positive deviants and typical farms under low- and high-stress environments. Cattle in both positive deviants and typical farms were predominantly housed in stalls (≥94.4% farms), but the quality was comparatively better in positive deviants, where permanent housing were more (76.9% vs. 47.8%) with cement or brick walls (80% vs. 60%) and iron sheet roofing (100% vs. 74%).

Holstein-Friesian dominated over Ayrshire or Jersey dairy cattle breeds in the sample smallholder farms (Table 3). A difference in breed composition was observed between the environments ($p < 0.001$), but not between the farms ($p > 0.05$). Results reveal dominance of Holstein-Friesian cattle breed under a high-stress environment, despite being considered to suffer high sensitivity to disease infections, heat loads and higher nutritional demand needed to support potentially high productivity levels.

Table 2. Distribution frequency (percentage) of cattle housing and construction materials in positive deviant and typical farms under contrasting stressful environments.

Factor	Positive Deviant Farms (n = 15)	Typical Farms (n = 322)	Chi-Square Test
Housing type (%)			
Permanent house	76.9	47.8	*
Semi-permanent house	23.1	52.2	
Housing materials (%)			
Wood	100.0	87.9	NS
Stone/brick wall	80.0	60.1	NS
Grass/makuti roofing	0.0	25.5	*
Corrugated iron sheet roofing	100.0	74.1	*

* $p < 0.05$; NS $p > 0.05$.

Table 3. Animal distribution frequency (percentage) by breeds in positive deviant and typical farms under stressful environments.

Factor	Level	Holstein-Friesian	Ayrshire	Jersey	Chi-Square Tests
Environment					
	Low-stress (n = 1059)	68.5	26.0	5.6	***
	High-stress (n = 1819)	81.3	16.1	2.6	
Farm (Environment)					
	Low-stress				
	Positive deviants (n = 51)	60.8	37.3	2.0	NS
	Typical (n = 1008)	68.8	25.4	5.8	
	High-stress				
	Positive deviants (n = 59)	81.4	13.6	5.1	NS
	Typical (n = 1760)	81.3	16.1	2.6	
Farm					
	Positive deviants (n = 110)	71.8	24.5	3.6	NS
	Typical (n = 2768)	76.8	19.5	3.7	

*** $p < 0.001$; NS $p > 0.05$.

Crossbreeding is a common practice of upgrading dairy cattle in smallholder farming systems. The animal distribution frequency by upgrading levels in positive deviants and typical farms under stressful environments is summarized in Table 4. Cattle upgraded to higher grade levels (≥75% exotic breed) were a larger proportion of the total number of animals in positive deviant farms than in typical farms in both high-stress (76% vs. 61.7%) and low-stress environments (14.3% vs. 8.4%). Higher-grade (≥75% exotic breed) cattle were also a larger proportion of the total number of animals in a high-stress environment than in a low-stress production environment (62.3% vs. 8.8%).

Table 4. Animal distribution frequency (percentage) by upgrading levels in positive deviant and typical farms under contrasting stressful environments.

Factor	Level	Upgrading Level (% of Exotic Blood Levels)				Chi-Square Tests
		25%	50%	>75%	Purebred	
Environment						
	Low-stress (n = 973)	7.0	84.3	6.7	2.0	***
	High-stress (n = 1068)	5.1	32.6	61.6	0.7	
Farm (Environment)						
	Low-stress					
	Positive deviants (n = 42)	4.8	81.0	11.8	2.4	NS
	Typical (n = 931)	7.1	84.4	6.4	2.1	
	High-stress					
	Positive deviants (n = 50)	-	24.0	72.0	4.0	**
	Typical (n = 1018)	5.3	33.0	61.1	0.6	
Farm						
	Positive deviants (n = 92)	2.2	50.0	44.6	3.2	*
	Typical (n = 1949)	6.2	57.6	35.0	1.3	

n = number of animals; *** $p < 0.0001$; ** $p < 0.001$; * $p < 0.05$, ^{NS} $p > 0.05$.

3.2. Feeding and Health Management Practices

Table 5 presents the mean proportions of fodder, concentrates and crop residues in a cattle diet on positive deviants and typical farms under contrasting stressful environments. Diet composition only differed between the environments ($p < 0.05$), but not between positive deviants and typical farms ($p > 0.05$). Under a low-stress environment, purchased fodder was a larger proportion of the diet in positive deviant farms, 11% to 13% more than was observed in typical farms. Diets were relatively higher in fodder and crop residues in a low-stress environment than in a high-stress environment. The fodder consisted of green fodder and pastures from on-farm, communal land or market purchases. A larger proportion of purchased fodder and crop residues in the diet was observed in a low-stress environment, while a larger proportion of on-farm fodder and pasture in the diet was observed in a high-stress environment.

Table 5. Mean (±SD) proportions of fodder, concentrates and crop residues in the diets fed to dairy cattle in positive deviants and typical farms under contrasting environments.

Factor	Level	Fodder	Concentrates	Crop Residues
Environment				
	Low-stress (n = 164)	0.5 ± 0.2	0.2 ± 0.04	0.3 ± 0.2
	High-stress (n = 173)	0.4 ± 0.08	0.3 ± 0.03	0.2 ± 0.1
	Mean difference	0.01 **	0.1 NS	0.01 **
Farm (Environment)				
	Low-stress			
	Positive deviants (n = 9)	0.5 ± 0.1	0.3 ± 0.01	0.3 ± 0.1
	Typical (n = 155)	0.4 ± 0.2	0.2 ± 0.04	0.3 ± 0.2
	Mean difference	0.1 NS	0.1 NS	0.0 NS
	High-stress			
	Positive deviants (n = 6)	0.5 ± 0.01	0.3 ± 0.01	0.3 ± 0.01
	Typical (n = 167)	0.4 ± 0.1	0.3 ± 0.03	0.2 ± 0.01
	Mean difference	0.1 NS	0.0 NS	0.1 NS
Farm				
	Positive deviants (n = 15)	0.5 ± 0.1	0.3 ± 0.01	0.3 ± 0.1
	Typical (n = 322)	0.5 ± 0.2	0.3 ± 0.01	0.3 ± 0.1
	Mean difference	0.0 NS	0.0 NS	0.0 NS

** $p < 0.01$; NS $p > 0.05$.

Figures 1–4 illustrate the differences in feed cost, watering cost and health management cost as percentage difference, and the mean difference in cost per treatment event under low- and high-stress environments. A positive value for low-stress environment indicated that the cost was higher in a low-stress environment than was in a high-stress environment, while a positive value for positive deviants indicated that the cost was higher in positive deviants than was in typical farms. A negative value indicated the opposite.

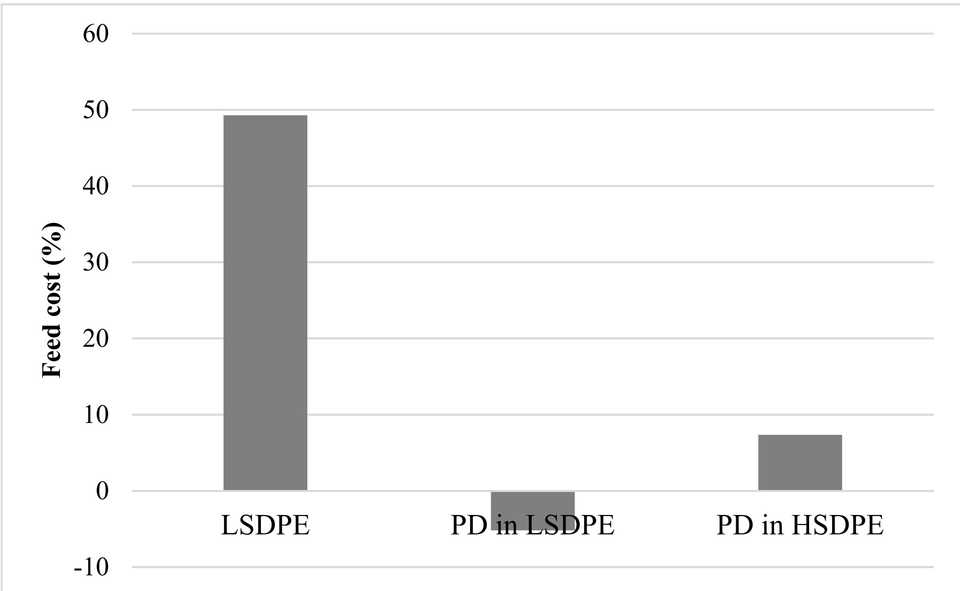

Figure 1. Mean percentage differences in feed cost per animal per year in positive deviants (PD) and typical farms under low-stress (LSDPE) and high-stress (HSDPE) environments.

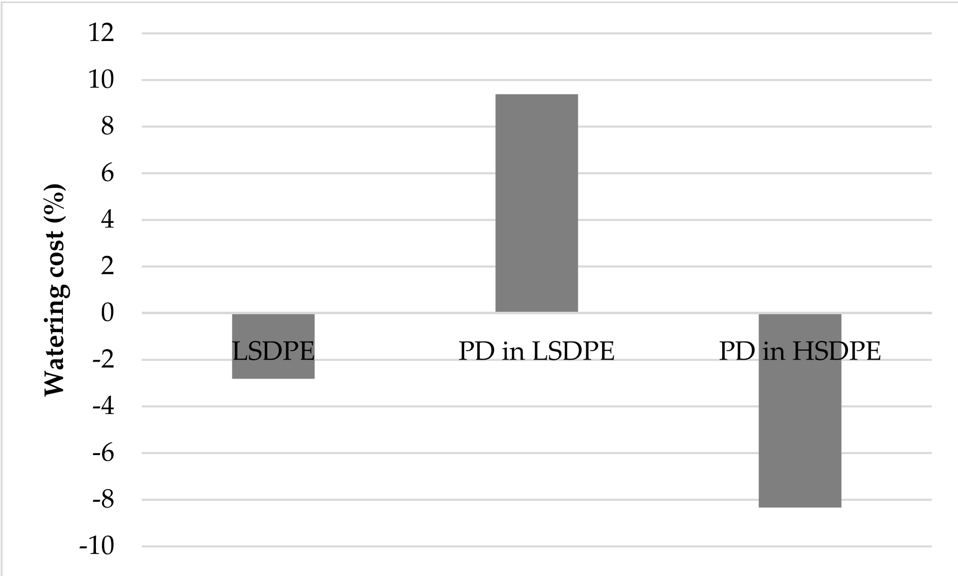

Figure 2. Mean percentage differences in watering cost per animal per year in positive (PD) and typical farms under low-stress (LSDPE) and high-stress (HSDPE) dairy environments.

Feeding was predominantly in stalls, a cut and carry feeding practice locally popular as zero-grazing. This was regardless of the farm management style (100% positive deviants vs. 94.4% typical farms). Figure 1 reveals that higher feed costs were incurred in a low-stress environment than in a high-stress environment, and in positive deviants than in typical farms under a high-stress environment, but not under a low-stress environment. A bivariate correlation between feed cost and milk yield was positive and highly significant (r = 0.275, $p < 0.001$), indicating that milk yield increased with increased investment in feeds.

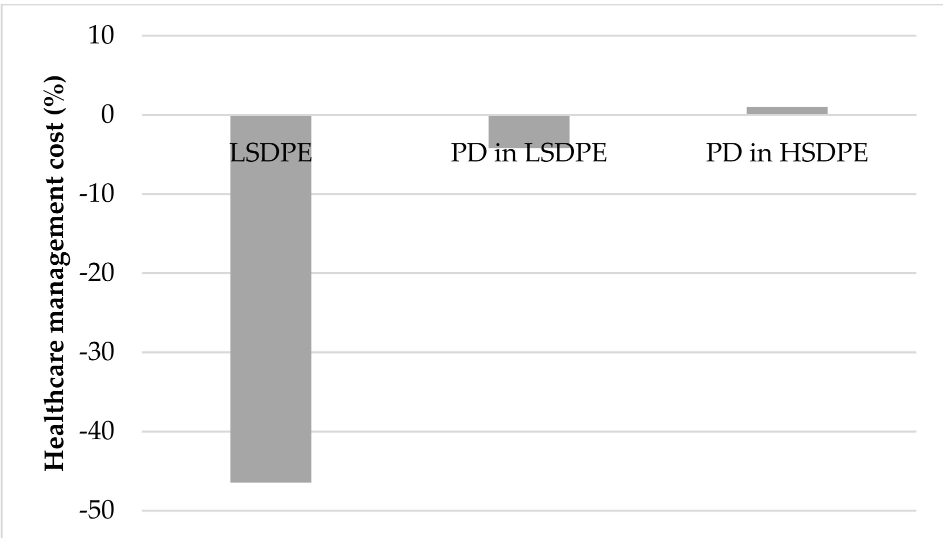

Figure 3. Mean percentage differences in healthcare management cost per animal per year in positive deviants (PD) and typical farms under low-stress (LSDPE) and high-stress (HSDPE) environments.

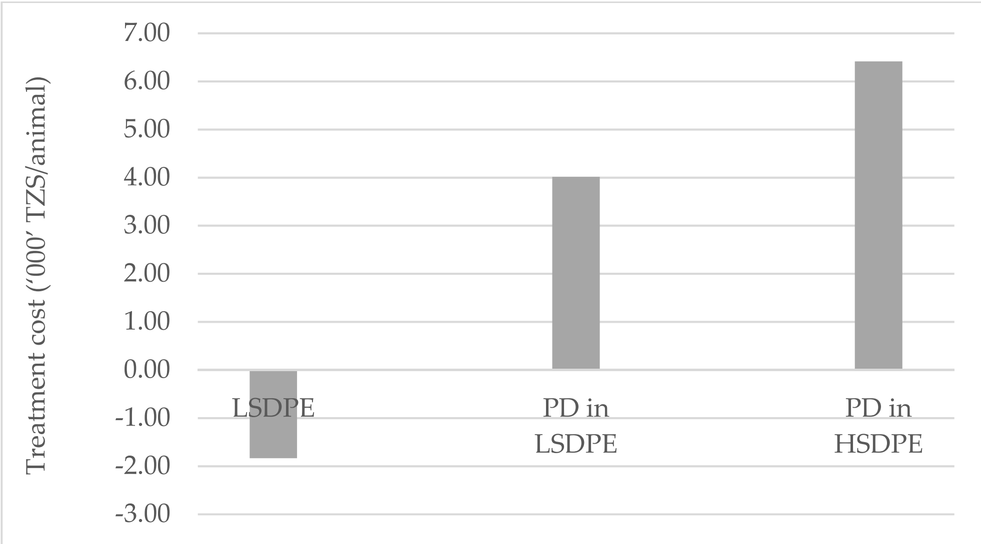

Figure 4. Mean differences in treatment cost per animal ('000' TZS/animal) in positive deviants (PD) and typical farms under low-stress (LSDPE) and high-stress (HSDPE) environments (2297.53 TZS = 1 US Dollar).

The watering cost, illustrated in Figure 2, reveals that watering costs were lower in a low-stress environment than in a high-stress environment. By farms, watering costs were higher in positive deviants than in typical farms under a low-stress environment, but lower under a high-stress environment. On average, positive deviant farms incurred more on water (1.9%) for cattle than was incurred in typical farms. Regardless of the farm management style, the source of water was predominantly tap water or wells. A bivariate correlation between watering cost and distance from the farm to the main water source during the dry season was positive and significant (r = 0.336, $p < 0.001$), indicating that during dry seasons, the cost of water increased with the increase in distance to the water source.

The health cost, as illustrated in Figure 3, show that health management costs (deworming; dipping and vaccinations) were substantially lower in a low-stress environment than in a high-stress environment. However, comparison between farms show that health costs were relatively lower (7.6%) in positive deviant farms compared to typical farms in a low-stress environment, and marginally higher (1%) in positive deviant farms than in typical farms under a high-stress environment.

The mean differences in cost per treatment per animal (drugs plus service costs) between positive deviant farms and typical farms under low- and high-stress environments are illustrated in Figure 4. Per case of treatment, results reveal that positive deviant farms were on average spending more ($p < 0.05$) than typical farms to treat a reported case. Table 6 results reveal that higher treatment costs in positive deviant farms were related to more frequent sourcing of professional animal health service providers in both a high-stress environment (45.5% vs. 40.6%) and a low-stress environment (75.0% vs. 66.5%). Positive deviant farms more frequently sourced professional animal health services in a low-stress environment than in a high-stress environment (67.0% vs. 40.7%).

Table 6. Distribution frequency (percentage) of animal health service providers sourced by positive deviant and typical farms under contrasting stressful environments.

Factor	Level	Fellow Farmers	Professional Animal Health Service Providers	Chi-Square Tests
Production environment				
	Low-stress (n = 221)	33.0	67.0	***
	High-stress (n = 297)	59.3	40.7	
Farm (Environment)				
	Low-stress			
	Positive deviants (n = 12)	25.0	75.0	NS
	Typical (n = 209)	33.5	66.5	
	High-stress			
	Positive deviants (n = 11)	54.5	45.5	NS
	Typical (n = 286)	59.4	40.6	
Farm				
	Positive deviants (n = 23)	39.1	60.9	NS
	Typical (n = 495)	48.5	51.5	

*** $p < 0.001$; NS $p > 0.05$.

4. Discussion

This study characterized management practices that differentiate positive deviants from average typical farms under similar levels of environmental stresses. Characterization was on breeding, housing, feeding and health management practices, which farms may deploy to ameliorate heat load stress, feed scarcity or disease infections, as these either limit or reduce dairy productivity [25,26]. Positive deviant farms were defined narrowly—that is, a farm had to consistently outperform above the population mean in five production indicators: energy balance $\geq$ 0.35 Mcal NEL/d; disease-incidence density $\leq$ 12.75 per 100 animal-years at risk; daily milk yield $\geq$ 6.32 L/cow/day; age at first calving $\leq$ 1153.28 days; and calving interval $\leq$ 633.68 days. The identification of positive deviant farms was with the use of Pareto-Optimality ranking technique [19].

Multiple production performance indicators used in the Pareto-Optimality ranking technique correspond to the econometric measure of farm efficiency that accounts for multiple inputs [27]. Farm efficiency has two components; technical efficiency, which reflects the firm's capacity to maximize output from a given set of inputs, and allocative efficiency, which reflects the capacity of a firm to utilize the inputs in the best combinations possible, given their respective prices.

The two-factor nested research designs employed in this study are a multilevel model suitable for analyzing hierarchical data. For this study, the objective was to identify the management practices that positive deviant farms deploy differently from typical farms nested within low- and high-stress environments. The nesting allowed for fitting random effects to analyze variability in the layers of the hierarchical structure [21,22].

4.1. Breeding Practices

Breeding practices that differentiated positive deviant farms from typical farms were the large number of animals comprising higher-grade cattle ($\geq$75% exotic blood), predominantly the Holstein-Friesian cattle breed. This points to positive deviant farmers pursuing cattle upgrading objective and preference for breeds with high milk-yielding potential. Dairy cattle upgrading is a technological intervention deployed to improve milk production and productivity, especially for a small number of animals, characteristically fewer than ten [28]. High-grade Holstein-Friesian dairy cattle are potentially higher-yielding than the Ayrshire or Jersey breeds [5]. To a household, high milk-yielding potential is important in breed choice for provision of a regular stream of milk for quality food as a source of protein and for income. This is supportive to the production objective of smallholders in adopting improved dairy cattle to increase milk production for both home consumption and marketable surplus for cash income [29–32].

Higher levels upgrading of dairy cattle observed in positive deviants than typical farms under high-stress environment points to positive deviants being early adopters of artificial insemination (AI) and improved bulls. This dairy upgrading has further been promoted by the ADGG project since 2016 in the study areas [3]. The project facilitates farmer access to superior dairy crossbred heifers, improved bulls and AI services [33]. Both positive deviants and typical farms had access to these dairy breeding technologies, so early adopter behavior of positive deviants is likely aided by ownership of more production resources and commercial orientation in production. In a high-stress environment, there is a milk processing plant (Tanga Fresh Ltd., Tanga, Tanzania) with uptake capacity of 50,000 L/day of raw milk. This is a milk market that commercially oriented positive deviant producers can find attractive to invest in dairy production. This observation is supported by the results that indicated that positive deviants were investing more in dairy than typical farmers. This could be that positive deviants access credit facility from Tanga Model to buy quality heifers from public and private dairy multiplication farms established in high-stress environments [8,34]. Tanga Model is a credit facility operated in a high-stress environment to promote dairy cattle farming. Therefore, empowering typical farmers is necessary to engage in these economic opportunities to improve their production performance.

Upgrading dairy cattle adaptable to local production environment through crossbreeding is a common management practice in smallholder farming. Crossbreeding between indigenous and exotic dairy cattle has been implemented extensively in the tropics to improve production performances of indigenous [4]. It is hypothesized that crossbred cattle would be more productive and resilient to prevalent environmental stresses in smallholder farming systems. In most cases, however, crossbreeding in the tropics and in particular smallholder farming systems is not well structured, resulting in farmers keeping a range of mixed crossbred genotypes aiming to improve productivity [5,35]. Appropriate organizational structures to support a long-term planned crossbreeding program thus remains necessary.

4.2. Housing Management

The cattle housing management practices differentiating positive deviants from typical farms were larger floor spacing per animal (10.4 vs. 7.1 m^2/cow) in better quality zero-grazing stall units. The recommended floor spacing is 7.4 to 9.3 m^2/cow to allow for proper air movement and natural expression of animal behavior [36]. This is because natural air movement increases convection, which reduces environmental temperatures and accumulation of ammonia gas inside the zero-grazing stall units. Therefore, in typical farms, animals were allowed inadequate spacing (6.2 m^2 per animal), especially under a high-stress environment where animals most needed to be protected from heat stress exposure. On positive deviant farms, floor spacing area per animal allowed exceeded the recommended area, so a larger floor spacing can be associated with more comfort and better animal welfare, and these do have an ameliorative effect on heat load stresses [37,38].

Under tropical conditions, adequate house floor spacing per animal can be associated with improved cow comfort. This is supported by observations [36,38,39] that increasing floor area per animal has a decreasing effect on air temperature inside the cow barn. This is important in a high-stress environment, where ameliorating heat stress will improve microclimate in animal housing [36,39,40]. Animals in good welfare status have improved dry matter intake, and are able to utilize the nutrients for milk production, which explains the observed higher production performance of the cattle in positive deviant farms.

Better comfort and improved animal welfare is especially important in the coastal lowland zone, classified as a high-stress dairy-production environment [41,42]. Here, animals were exposed to mild to moderate heat stress indicated by lower spacing of 6.2 m^2 per animal in typical farms and a THI of 77.29 [5,19], a level at which animals begin to exhibit heat stress signs. In dairy cattle, heat stress signs are associated with poor growth, suboptimal reproduction and lower milk production, due to elevated blood insulin and protein catabolism [43,44].

In positive deviant farms, the zero-grazing stall units were made of durable materials (cement or brick walls and concrete floors with corrugated iron sheet roofing), which do confer better quality housing conditions. This allows for easy cleaning to maintain high standards of hygiene, subsequently improving animal comfort, health and welfare status. The use of durable construction materials in positive deviant farms indicates high-quality housing and more investment to improve animal welfare, but also to secure livestock assets from theft [14]. Durable construction materials can help to protect animals against bacterial infections due to ease of cleaning to improve sanitation [38,40,45,46]. However, current findings suggest that positive deviant farmers were ameliorating environmental stresses more successfully with increased investments in dairy farming because they were spending more to purchase inputs, probably being more resource-endowed.

4.3. Feeding Practices

Feeding practices that differentiated positive deviants from typical farms were greater investment in external sourcing of fodder and water to address feed scarcity. This investment was important for improving dairy productivity, as feed scarcity is a production limitation in smallholder dairy farming. Positive deviant farms were larger landholding, which can be associated with producing more fodder and accessing more crop residues for dairy cattle feeding. Though positive deviants had about three-times-larger landholdings relative to typical farms (9.0 vs. 3.3 acres), they still sourced fodder externally, indicating insufficient on-farm fodder production. With a large number of animals of high-grade Holstein-Friesian cattle breed, positive deviant farms were likely under more pressure to supply forage fodder from own-farm sources [28,47,48]. Own-produced fodder can reduce feed costs associated with market sourced feeds. By investing more in producing milk, positive deviants used more inputs. This corroborates the findings of Kibiego et al. [27], who observed that farmers increased milk produced with increasing the variable costs. In this study, feed quality of on-farm and market-sourced fodder was not assessed to inform on whether investment is also on quality of the feed. This is a knowledge gap in this study, for which research is recommended to inform dairy farmers and extension services for decision making.

Fodder supply indicated that more feed is needed in a high-stress environment than in a low-stress environment. This contrasts a previous study in the same sample farms which did not reveal any significant difference in energy balance (Mcal NE_L/d) for lactating cows between low- and high-stress environments [19]. It can be interpreted that feed scarcity is experienced in both low- and high-stress environments, but at a greater magnitude in high-stress environments. For optimal productivity, options to increase feed supply cheaply is sourcing alternative feeds rich in energy and protein, as conventional feed resources are costly. For example, growing a mixture of Rhodes grass and Desmodium species or Lablab legume pastures, in addition to outsourcing, can assure stable access to animal feeds throughout the year in both production environments. For successful dairy farming, reliability in supply of sufficient and quality fodder is necessary to support higher productivity levels [42,49]. Producing improved fodder needs capacity building of farmers in selection of suitable forage species, forage agronomy and soil management to sustain forage supply [32,50].

Higher investment in water supplies observed in positive deviant farms can be associated with ameliorating heat stress and improving animal welfare [26,38]. This is alternative to heavier investment needed in using high energy-demanding technologies such as fans, misters and showers to ameliorate heat stress in dairy cattle. The effective use of watering to ameliorate heat stress for cattle in the zero-grazing stall units will, however, require adequate water supplies at increased investments. This brings a need for public investment in water harvesting, storage and supply infrastructure in dairy milksheds, particularly in the high-stress environment.

4.4. Animal Health Management Practices

Animal health management practices could be differentiated between positive deviants and typical farmers. More investment in professional veterinary services and lower cost in healthcare management differentiated positive deviants from typical farmers. Lower healthcare management cost can be related to spending more on preventive than curative health practices, as positive deviants more frequently consulted professional veterinary service providers, in both low-stress (75.0% vs. 66.5%) and high-stress (45.5% vs. 40.7%) environments. It is more important in a high-stress environment, which is a coastal lowland zone classified a high-stress dairy production environment because of persistent animal exposure to a combination of high humidity with mild to moderate thermal heat stress (77.29 THI units) and prevalent disease infections.

After 72 THI units, animals begin to exhibit heat stress, which physiologically depress their feed intake and subsequently also lower their immune system. So, more frequently sourcing professional animal health services observed among positive deviant farms indicates that they were ameliorating disease infections at a fee. In other words, this is implying that they had higher ability to reliably pay for the veterinary services.

Frequent sourcing of professional services could mean investment in more preventive than curative healthcare management in positive deviant farms compared to typical farms. In regularly consulting professional health service providers, positive deviants were more likely to ensure appropriate prescription for the right veterinary product, thus avoiding unnecessary costs and misuse of drugs [51]. Professional animal health services can also be associated with the delivery of high-quality animal health services, which is supportive to keeping high-grade dairy cattle in better health status to attain increasing productivity [32,52]. However, farmers need resources to spend on disease prevention and curative services. Farmers with limited resources spent much less on treatment than those who are better off in resource ownership, and this is important for diseases with a high morbidity but comparatively low mortality rate [53].

In the sample farms, positive deviants were relatively more production resource-endowed than typical farms. This is indicated by ownership of larger landholding and the number of dairy cattle, more capital invested in water, veterinary, and durable and quality animal housing. These enabled positive deviants to access quality veterinary inputs and services [51], which supports the need for cooperative membership to allow farmers to access quality veterinary inputs and services to ameliorate disease infection stresses [51,54,55]. This shows that technical innovations that enhance management of cow health, genetic quality and nutrition are critical for increasing dairy productivity. Along these improvements, it is necessary to improve the efficiency of the dairy supply chain through organizational and institutional innovations, which should include access to affordable credits [56]. Farmer cooperative movement offers a viable intervention for both positive deviants and typical farms, as cooperatives can hire professional veterinarians and stock quality veterinary inputs and arrange for access to these inputs and services at affordable and conveniently arranged credit facility. This should improve the delivery of animal health services for smallholder dairy farmers [57].

Implementation of the strategies proposed here can benefit from deeper understanding of underlying farmers' attitudes, intention and perceptions that influence positive deviants' motives to improve their management practices. This is because the adoption of management practices is a highly nuanced multivariate behavior [58]. This requires considering a number of factors when promoting effective management strategies, including farmers' attitudes and neighbour pressure that can drive the subjective norm as was observed in the Loess Plateau of China [59]. In addition, perceptions of farmers' ability to affect recommended innovations is a significant determinant of farmers' intention to adopt and apply dairy innovations. In the current study areas, members of cooperative societies be able to access affordable credit to accelerate adoption of dairy innovations [27,56].

5. Conclusions

Evidence generated in this study show that management practices differentiating positive deviants from typical farms are cattle upgrading, allowing for larger animal floor spacing and investing more in cattle housing, fodder, watering, and professional animal health services. Investing more in fodder and watering reflects efforts to ameliorate feed scarcity. Upgrading is crossbreeding that improves adaptability of the dairy breed under tropical stresses, larger animal floor spacing and investing more in cattle housing, professional animal health services are interventions supportive to ameliorating disease infections. Dairy crossbreeding in the upgrading, larger animal floor spacing, and investing more in cattle housing and watering reflects interventions to ameliorate heat stress. Therefore, these practices can be associated with the amelioration of feed scarcity, disease infections and heat load stresses, subsequently supporting better animal welfare status and lowering health management cost in positive deviant farms. However, nutritional quality of the diet was not analyzed to inform whether positive deviants direct the investments to improving feed quality. This knowledge gap will require research to close.

Author Contributions: Conceptualization, D.S.S. and B.O.B.; methodology, D.S.S. and B.O.B.; software, D.S.S.; validation, D.S.S., B.O.B., O.A.M. and P.K.M.; formal analysis, D.S.S.; investigation, D.S.S.; resources, D.S.S., O.A.M. and R.M.; data curation, D.S.S.; writing—original draft preparation, D.S.S.; writing—review and editing, D.S.S., B.O.B. and O.A.M.; visualization, D.S.S., B.O.B. and P.K.M.; supervision, D.S.S., B.O.B., O.A.M., P.K.M. and R.M.; project administration, D.S.S., B.O.B., O.A.M., P.K.M. and R.M.; and funding acquisition, D.S.S., O.A.M. and R.M. All authors have read and agreed to the published version of the manuscript.

Funding: The study was funded by the World Bank Centre of Excellence in Sustainable Agriculture and Agribusiness Management (CESAAM) at Egerton University, Kenya, grant number: IDA Credit P151847 and the African Dairy Genetic Gains (ADGG) Project, Tanzania's ADGG component implemented through TALIRI/ILRI Contract Research Agreement No. 005/2016 dated 11 March 2016, as amended in 2018, 2019 and 2021 to facilitate data collection.

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).

Informed Consent Statement: Not applicable.

Data Availability Statement: Research data are available from the authors upon request.

Acknowledgments: We are thankful to CESAAM under the leadership of George Owuor for funding this study. Also, we thank the ADGG Project Management to facilitate data collection process and granting access to the database. We appreciate the hard work of the Tanzanian ADGG Project Team, led by Daniel M. Komwihangilo. We especialy appreciate the efforts of the operations team i.e., Eliamoni Lyatuu, Neema Joseph Kelya, Edwin Oyieng and David Mogaka for data and farms access. We are grateful to all Performance Recording Agents i.e., Judith Shayo, Deogratius Mfuko, Rashid Seif Abdul-Azizi, Edward Moshi and Daudi Kisakeni for data collection and farms access. The same to all animal resource officers in the study areas and farmers for their greater cooperation during the data collection period.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. van der Linden, A.; Oosting, S.J.; van de Ven, G.W.J.; de Boer, I.J.M.; van Ittersum, M.K. A framework for quantitative analysis of livestock systems using theoretical concepts of production ecology. *Agric. Syst.* **2015**, *139*, 100–109. [CrossRef]
2. VanLeeuwen, J.A.; Mellish, T.; Walton, C.; Kaniaru, A.; Gitau, R.; Mellish, K.; Maina, B.; Wichtel, J. Management, productivity and livelihood effects on Kenyan smallholder dairy farms from interventions addressing animal health and nutrition and milk quality. *Trop. Anim. Health Prod.* **2012**, *44*, 231–238. [CrossRef]
3. ILRI. *African Dairy Genetic Gains: Building the Business Case*; International Livestock Research Institute: Nairobi, Kenya, 2019; p. 32.
4. Gojam, Y.; Tadesse, M.; Efffa, K.; Hunde, D. Performance of crossbred dairy cows suitable for smallholder production systems at Holetta Agricultural Research Centre. *Ethiop. J. Agric. Sci.* **2017**, *27*, 121–131.

5. Mbuthia, J.M.; Mayer, M.; Reinsch, N. Modeling heat stress effects on dairy cattle milk production in a tropical environment using test-day records and random regression models. *Animal* **2021**, *15*, 100222. [CrossRef] [PubMed]
6. Mekoya, A.; Oosting, S.J.; Fernández Rivera, S.; Zijpp, A.J. van der. Farmers' perceptions about exotic multipurpose fodder trees and constraints to their adoption. *Agrofor. Syst.* **2008**, *73*, 141–153. [CrossRef]
7. Gellynck, X.; Kühne, B. Horizontal and Vertical Networks for Innovation in the Traditional Food Sector. *Int. J. Food Syst. Dyn.* **2010**, *1*, 123–132. [CrossRef]
8. Cadilhon, J.-J.; Pham, N.D.; Maass, B.L. The Tanga Dairy Platform: Fostering Innovations for more Efficient Dairy Chain Coordination in Tanzania. *Int. J. Food Syst. Dyn.* **2016**, *7*, 81–91. [CrossRef]
9. Wishik, S.M.; Vynckt, S. The use of nutritional "positive deviants" to identify approaches for modification of dietary practices. *Am. J. Public Health* **1976**, *66*, 38–42. [CrossRef]
10. Herington, M.J.; Fliert, E. van de. Positive Deviance in Theory and Practice: A Conceptual Review. *Deviant Behav.* **2018**, *39*, 664–678. [CrossRef]
11. Albanna, B.H.; Heeks, R. Positive deviance, big data, and development: A systematic literature review. *Electron. J. Inf. Syst. Dev. Ctries.* **2019**, *85*, e12063. [CrossRef]
12. Adelhart Toorop, R.; Ceccarelli, V.; Bijarniya, D.; Jat, M.L.; Jat, R.K.; Lopez-Ridaura, S.; Groot, J.C.J. Using a positive deviance approach to inform farming systems redesign: A case study from Bihar, India. *Agric. Syst.* **2020**, *185*, 102942. [CrossRef]
13. Albanna, B.H.; Heeks, R.; Pawelke, A.; Boy, J.; Handl, J.; Gluecker, A. Data-powered positive deviance: Combining traditional and non-traditional data to identify and characterise development-related outperformers. *Dev. Eng.* **2022**, *7*, 100090. [CrossRef]
14. Savikurki, A. Positive Deviance in Smallholder Crop-Livestock Farming Systems in Northern Ghana. Master's Thesis, University of Helsinki, Helsinki, Finland, 2013.
15. Abdullahi, H.; Albanna, B.; Barvels, E. Rangelands Defying the Odds: A Data Powered Positive Deviance Inquiry in Somalia. *Medium*. 12 April 2021. Available online: https://dppd.medium.com/rangelands-defying-the-odds-a-data-powered-positive-deviance-inquiry-in-somalia-90772de392dd (accessed on 13 August 2022).
16. Grijalva, A.M.; Jiménez, P.; Albanna, B.; Boy, J. Deforestation, Cows, and Data: Data Powered Positive Deviance Pilot in Ecuador's Amazon. *Medium*. 9 June 2021. Available online: https://dppd.medium.com/deforestation-cows-and-data-data-powered-positive-deviance-pilot-in-ecuador-s-amazon-648aa0de121c (accessed on 13 August 2022).
17. de Adelhart Toorop, R.; Gosselink, K. *Analysis of Positive Deviants among Organic Dairy Farmers in The Netherlands*; Wageningen University & Research: Wageningen, The Netherlands, 2013. Available online: https://dl.dropboxusercontent.com/u/17758665/Final_draft_thesis_Roos.pdf (accessed on 17 May 2019).
18. Ulukan, D.; Grillot, M.; Benoit, M.; Bernes, G.; Dumont, B.; Magne, M.-A.; Amaral Monteiro, L.; Parsons, D.; Veysset, P.; Ryschawy, J.; et al. Positive deviant strategies implemented by organic multi-species livestock farms in Europe. *Agric. Syst.* **2022**, *201*, 103453. [CrossRef]
19. Shija, D.S.; Mwai, O.A.; Migwi, P.K.; Komwihangilo, D.M.; Bebe, B.O. Identifying positive deviant farms using Pareto-Optimality ranking technique to assess productivity and livelihood benefits in smallholder dairy farming under contrasting stressful environments in Tanzania. *World* **2022**, *3*, 639–656. [CrossRef]
20. Tempelman, R.J. Invited review: Assessing experimental designs for research conducted on commercial dairies. *J. Dairy Sci.* **2009**, *92*, 1–15. [CrossRef] [PubMed]
21. Krzywinski, M.; Altman, N.; Blainey, P. Nested designs. *Nat. Methods* **2014**, *11*, 977–978. [CrossRef]
22. Field, A.P. *Discovering Statistics Using SPSS*, 3rd ed.; SAGE Publications: Los Angeles, CA, USA, 2009; ISBN 978-1-84787-906-6.
23. SAS Institute Inc. *SAS/ACCESS®9.4 Interface to ADABAS: Reference*; SAS Institute Inc.: Cary, NC, USA, 2013.
24. IBM Corp. *IBM SPSS Statistics for Windows, Version 25.0*; IBM Corp: Armonk, NY, USA, 2017.
25. Gustafson, C.R.; VanWormer, E.; Kazwala, R.; Makweta, A.; Paul, G.; Smith, W.; Mazet, J.A. Educating pastoralists and extension officers on diverse livestock diseases in a changing environment in Tanzania. *Pastoralism* **2015**, *5*, 1. [CrossRef]
26. Polsky, L.; von Keyserlingk, M.A.G. Invited review: Effects of heat stress on dairy cattle welfare. *J. Dairy Sci.* **2017**, *100*, 8645–8657. [CrossRef]
27. Kibiego, M.B.; Lagat, J.K.; Bebe, B.O. Assessing the Economic Efficiency of Dairy Production Systems in Uasin Gishu County, Kenya. *J. Econ. Sustain. Dev.* **2015**, *6*, 146–153.
28. Kebebe, E.G.; Oosting, S.J.; Baltenweck, I.; Duncan, A.J. Characterisation of adopters and non-adopters of dairy technologies in Ethiopia and Kenya. *Trop. Anim. Health Prod.* **2017**, *49*, 681–690. [CrossRef]
29. Bebe, B.O.; Udo, H.M.J.; Rowlands, G.J.; Thorpe, W. Smallholder dairy systems in the Kenya highlands: Cattle population dynamics under increasing intensification. *Livest. Prod. Sci.* **2003**, *82*, 211–221. [CrossRef]
30. Vercillo, S.; Kuuire, V.Z.; Armah, F.A.; Luginaah, I. Does the New Alliance for Food Security and Nutrition impose biotechnology on smallholder farmers in Africa? *Glob. Bioeth.* **2015**, *26*, 1–13. [CrossRef]
31. Niyas, P.A.; Kunnath, C.; Shaji, S.; Sejian, V.; Madiajagan, B.; Bhatta, R.; Rao, G.; Kurien, K.; Girish, V. Adaptation of Livestock to Environmental Challenges. *J. Vet. Sci. Med. Diagn.* **2015**, *4*, 2. [CrossRef]
32. Marshall, K.; Salmon, G.R.; Tebug, S.; Juga, J.; MacLeod, M.; Poole, J.; Baltenweck, I.; Missohou, A. Net benefits of smallholder dairy cattle farms in Senegal can be significantly increased through the use of better dairy cattle breeds and improved management practices. *J. Dairy Sci.* **2020**, *103*, 8197–8217. [CrossRef]

33. Mrode, R.; Ojango, J.; Ekine-Dzivenu, C.; Aliloo, H.; Gibson, J.; Okeyo, M.A. Genomic prediction of crossbred dairy cattle in Tanzania: A route to productivity gains in smallholder dairy systems. *J. Dairy Sci.* **2021**, *104*, 11779–11789. [CrossRef] [PubMed]
34. Solidaridad Focus on Farmers Essential to Grow the Tanzanian Dairy Sector. Available online: https://www.solidaridadnetwork.org/news/focus-on-farmers-essential-to-grow-the-tanzanian-dairy-sector/ (accessed on 14 August 2022).
35. Ojango, J.M.K.; Mrode, R.; Rege, J.E.O.; Mujibi, D.; Strucken, E.M.; Gibson, J.; Mwai, O. Genetic evaluation of test-day milk yields from smallholder dairy production systems in Kenya using genomic relationships. *J. Dairy Sci.* **2019**, *102*, 5266–5278. [CrossRef]
36. Bewley, J.M.; Robertson, L.M.; Eckelkamp, E.A. A 100-Year Review: Lactating dairy cattle housing management. *J. Dairy Sci.* **2017**, *100*, 10418–10431. [CrossRef] [PubMed]
37. Moran, J.; Doyle, R. *Cow Talk: Understanding Dairy Cow Behaviour to Improve Their Welfare on Asian Farms*; CSIRO Publishing: Clayton South, VIC, Australia, 2015; ISBN 978-1-4863-0161-4.
38. Bang, N.N.; Gaughan, J.B.; Hayes, B.J.; Lyons, R.E.; Chanh, N.V.; Trach, N.X.; Khang, D.N.; McNeill, D.M. Characteristics of Cowsheds in Vietnamese Smallholder Dairy Farms and Their Associations with Microclimate—A Preliminary Study. *Animals* **2021**, *11*, 351. [CrossRef] [PubMed]
39. Galama, P.J.; Ouweltjes, W.; Endres, M.I.; Sprecher, J.R.; Leso, L.; Kuipers, A.; Klopčič, M. Symposium review: Future of housing for dairy cattle. *J. Dairy Sci.* **2020**, *103*, 5759–5772. [CrossRef] [PubMed]
40. Beaver, A.; Ritter, C.; von Keyserlingk, M.A.G. The Dairy Cattle Housing Dilemma: Natural Behavior Versus Animal Care. *Vet. Clin. N. Am. Food Anim. Pract.* **2019**, *35*, 11–27. [CrossRef] [PubMed]
41. Armstrong, D.V. Heat Stress Interaction with Shade and Cooling. *J. Dairy Sci.* **1994**, *77*, 2044–2050. [CrossRef]
42. Britt, J.H.; Cushman, R.A.; Dechow, C.D.; Dobson, H.; Humblot, P.; Hutjens, M.F.; Jones, G.A.; Mitloehner, F.M.; Ruegg, P.L.; Sheldon, I.M.; et al. Review: Perspective on high-performing dairy cows and herds. *Animal* **2021**, *15*, 100298. [CrossRef]
43. Wang, J.; Li, J.; Wang, F.; Xiao, J.; Wang, Y.; Yang, H.; Li, S.; Cao, Z. Heat stress on calves and heifers: A review. *J. Anim. Sci. Biotechnol.* **2020**, *11*, 79. [CrossRef]
44. M'Hamdi, N.; Darej, C.; Attia, K.; El Akram Znaidi, I.; Khattab, R.; Djelailia, H.; Bouraoui, R.; Taboubi, R.; Marzouki, L.; Ayadi, M. Modelling THI effects on milk production and lactation curve parameters of Holstein dairy cows. *J. Therm. Biol.* **2021**, *99*, 102917. [CrossRef]
45. Slaghuis, B. Source and significance of contaminants on different levels of raw milk production.; International Dairy Federation, 1996. In Proceedings of the Symposium on Bacteriological Quality of Raw Milk, Wolfpassing, Austria, 13–15 March 1996; Available online: https://scholar.google.com/scholar_lookup?title=Source+and+significance+of+contaminants+on+different+levels+of+raw+milk+production&author=Slaghuis%2C+B.+%28Research+Station+for+Cattle%2C+Sheep+and+Horse+Husbandry%2C+Lelystad+%28Netherlands%29%29&publication_year=1996 (accessed on 26 May 2022).
46. Gillah, K.A.; Kifaro, G.C.; Madsen, J. Effects of management practices on yield and quality of milk from smallholder dairy units in urban and peri-urban Morogoro, Tanzania. *Trop. Anim. Health Prod.* **2014**, *46*, 1177–1183. [CrossRef]
47. Chagwiza, G. Cost-Effective Forage and Browse Legume Feed for Dairy Production: An Optimisation Approach Using Jaya Optimisation Algorithm. *Adv. Agric.* **2022**, *2022*, e5838723. [CrossRef]
48. Brett, C.I. A New Way to Boost Smallholder Dairy Productivity in Tanzania. *worldbank.org/voices*. 2019. Available online: https://blogs.worldbank.org/voices/new-way-boost-smallholder-dairy-productivity-tanzania (accessed on 1 August 2022).
49. Collier, P.; Dercon, S. African Agriculture in 50 Years: Smallholders in a Rapidly Changing World? *World Dev.* **2014**, *63*, 92–101. [CrossRef]
50. Marshall, K.; Gibson, J.P.; Mwai, O.; Mwacharo, J.M.; Haile, A.; Getachew, T.; Mrode, R.; Kemp, S.J. Livestock genomics for developing countries—African examples in practice. *Front. Genet.* **2019**, *10*, 297. [CrossRef]
51. Schumacher, C. Veterinary Services: Improving Accessibility for Smallholder Farmers. *GALVmed*. 2020. Available online: https://www.galvmed.org/veterinary-services-improving-accessibility-for-smallholder-farmers/ (accessed on 1 August 2022).
52. Campbell, Z.; Coleman, P.; Guest, A.; Kushwaha, P.; Ramuthivheli, T.; Osebe, T.; Perry, B.; Salt, J. Prioritizing smallholder animal health needs in East Africa, West Africa, and South Asia using three approaches: Literature review, expert workshops, and practitioner surveys. *Prev. Vet. Med.* **2021**, *189*, 105279. [CrossRef]
53. Heffernan, C. Panzootics and the poors: Devising a global livestock disease prioritisation framework for poverty alleviation. *Rev. Sci. Tech. OIE* **2009**, *28*, 897–907. [CrossRef]
54. Sumner, C.L.; von Keyserlingk, M.A.G.; Weary, D.M. Perspectives of farmers and veterinarians concerning dairy cattle welfare. *Anim. Front.* **2018**, *8*, 8–13. [CrossRef]
55. Thapa Shrestha, U.; Adhikari, N.; Kafle, S.; Shrestha, N.; Banjara, M.R.; Steneroden, K.; Bowen, R.; Rijal, K.R.; Adhikari, B.; Ghimire, P. Effect of deworming on milk production in dairy cattle and buffaloes infected with gastrointestinal parasites in the Kavrepalanchowk district of central Nepal. *Vet. Rec. Open* **2020**, *7*, e000380. [CrossRef]
56. Wairimu, E.; Mburu, J.; Ndambi, A.; Gachuiri, C. Factors affecting adoption of technical, organisational and institutional dairy innovations in selected milksheds in Kenya. *Agrekon* **2022**, *61*, 324–338. [CrossRef]
57. Perry, B.D.; Randolf, T.F.; McDermott, J.J.; Sones, K.R.; Thornton, P.K. *Investing in Animal Health Research to Alleviate Poverty*; International Livestock Research Institute: Nairobi, Kenya, 2002; ISBN 92-9146-108-3.

58. Dezdar, S. Green information technology adoption: Influencing factors and extension of theory of planned behavior. *Soc. Responsib. J.* **2017**, *13*, 292–306. [CrossRef]
59. Deng, J.; Sun, P.; Zhao, F.; Han, X.; Yang, G.; Feng, Y. Analysis of the ecological conservation behavior of farmers in payment for ecosystem service programs in eco-environmentally fragile areas using social psychology models. *Sci. Total Environ.* **2016**, *550*, 382–390. [CrossRef] [PubMed]