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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

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Abstract: In smallholder dairy-cattle farming, identifying positive deviants that attain outstanding performance can inform targeted improvements in typical, comparable farms under similar environmental stresses. Mostly, positive deviants are identified subjectively, introducing bias and limiting generalisation. The aim of the study was to objectively identify positive deviant farms using the Pareto-optimality ranking technique in a sample of smallholder dairy farms under contrasting stressful environments in Tanzania to test the hypothesis that positive deviant farms that simultaneously outperform typical farms in multiple performance indicators also outperform in yield gap, productivity and livelihood benefits. The selection criteria set five performance indicators: energy balance, disease-incidence density, daily milk yield, age at first calving and calving interval. Findings proved the hypothesis. A few farms (27: 3.4%) emerged as positive deviants, outperforming typical farms in yield gap, productivity and livelihood benefits. The estimated yield gap in typical farms was 76.88% under low-stress environments and 48.04% under high-stress environments. On average, total cash income, gross margins and total benefits in dairy farming were higher in positive deviants than in typical farms in both low- and high-stress environments. These results show that the Pareto-optimality ranking technique applied in a large population objectively identified a few positive deviant farms that attained higher productivity and livelihood benefits in both low- and high-stress environments. However, positive deviants invested more in inputs. With positive deviant farms objectively identified, it is possible to characterise management practices that they deploy differently from typical farms and learn lessons to inform the uptake of best practices and extension messages to be directed to improving dairy management.

Keywords: smallholder dairy; positive deviants; Pareto-optimality ranking; multiple indicators; yield gap; productivity; livelihood benefits

1. Introduction

Smallholder dairy farming has multifunctional livelihood roles and benefits in rural households. Smallholders integrate subsistence and market objectives in their production systems [1]. In Tanzania, for instance, dairy cattle provide nutrition and food security for household wellbeing, income for cash needs, and manure used in restoring soil fertility for crop production. Furthermore, cattle are live assets which households can liquidify in emergency or hold to accumulate wealth and gain the benefits of financing and insurance roles [2,3].

However, there are large variations in the extent to which households derive livelihood roles and benefits from this. This is because dairy-cattle genotypes which smallholders

utilise are sensitive to prevalent environmental stresses of heat load, nutritional scarcity and infections [4,5]. Under pervasive exposure to these environmental stresses, dairy cattle experience discomfort, and subsequently reduce their feed intake and become prone to an impaired immune system and increased susceptibility to disease [5]. The aggregate impacts of environmental stresses are suboptimal performance in growth, fertility and milk yield. With the production potential suppressed, dairy cattle manifest significant low productivity, yield gaps and the loss of livelihood benefits to farmers who keep dairy cattle for livelihood and market benefits [6].

However, in the production environments, where smallholder dairy-cattle farming predominates, some farmers do successfully ameliorate environmental stresses. By so doing they attain higher productivity, lower the yield gaps and gain more livelihood benefits from dairy farming under the same stressful production environment [6,7]. The farmers who attain outstanding performance are labelled positive deviants while the average performers are labelled typical farmers.

Achieving outstanding performance under same local production circumstances suggests that positive deviant farms deploy more effective ameliorative strategies in addressing the effects of environmental stresses. Because of their remarkable success in production performance, positive deviant farms stand out within their communities and therefore could be local model farms from which lessons can be learned.

The identification of positive deviants in a population to inform one's choice of ameliorative practices for managing environmental stresses in a locality has been applied in community health, ecology, agriculture and livestock [7,8]. In identifying positive deviants, researchers have mostly applied subjective approaches, involving peers and expert knowledge dialogues, participatory ranking and snowballing sampling [7,8]. The data sources are cross-sectional surveys complemented with expert knowledge typologies and peer judgement to construct farm clusters. The participatory ranking has been based on observable assets as subjectively judged by knowledge experts or key informants. The outperformance of subjectively identified positive deviants in a population was mostly conducted on the criterion of a single performance indicator.

The subjective identification of positive deviants in a population on a single performance indicator introduces biases. Some workers have addressed bias in the identification of positive deviants. For instance, some workers have applied empirical methods that assess multiple development dimensions simultaneously (food security, income, nutrition, environmental sustainability, and social equity) [9]. In a population with similar resource levels, positive deviants outperformed typical farms in the food-security indicator, but were not markedly better in social equity. Because dairy cattle on smallholder farms are pervasively exposed to multiple environmental stresses, multiple performance indicators are impacted. With this knowledge, the objective identification of positive deviants would be more informative and of broader application if the criteria are on multiple performance indicators. In contrast to subjective and biased approaches, objective approaches in the identification of positive deviants have applied multivariate statistics including principal component analysis with cluster analysis using a set of selected performance variables to distinguish farm types. The use of multivariate statistics has the advantage of reproducibility [10]. However, multi-collinearity remains a problem when multiple performance-indicator variables are used.

A deviation from other studies is the application in this study of an objective and quantitative approach, using the Pareto-optimality ranking technique to identify truly positive deviant farms in a sample population. With the application of the Pareto-optimality ranking technique, this study tested the hypothesis that positive deviant farms that simultaneously outperform typical farms in total energy balance, disease-incidence density, daily milk yield, age at first calving and calving interval also outperform in productivity, yield gap and livelihood benefits under similar environmental stresses. The milk yield gap is defined as the difference between actual and potential attainable yield. The actual yield is the average yield attained while the potential yield is the maximum attained

yield [6,11]. This hypothesis was tested among smallholder dairy farms in high- and low-stress production environments using 42-month-period longitudinal observations of animal performance data.

2. Materials and Methods

2.1. The Study Area

This study was in Tanzania, specifically in the ‘northern milkshed’ (Kilimanjaro region) and ‘eastern milkshed’ (Tanga region). These two milksheds were selected to represent low- and high-stress dairy production environments, respectively (Figure 1). Both low- and high-stress environments have a high concentration of dairy cattle and are beneficiaries of the African Dairy Genetic Gain (ADGG) Project. The ADGG is a dairy development intervention, collecting on-farm performance data which is used to identify and prove superior dairy crossbred bulls and heifers for artificial insemination service delivery to farmers.

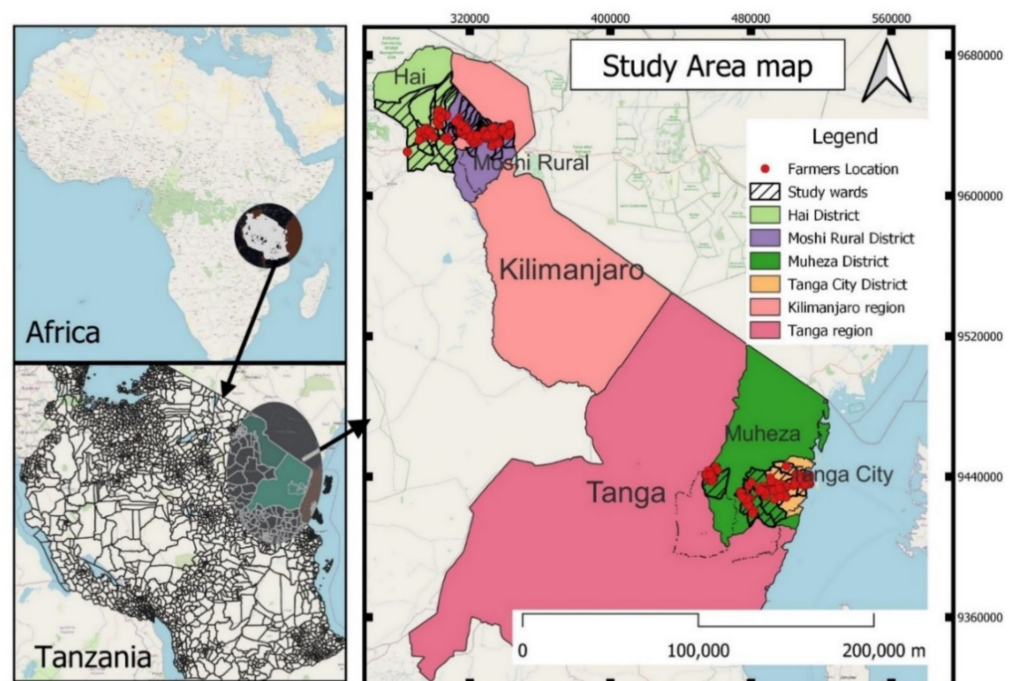


Figure 1. Study area map showing low- and high-stress dairy production environments from the two milksheds in Tanzania.

On average, herd size is 4 to 7 head of cattle per farm, with a wide range from 1 to 30 heads. The breeds and genotypes can be a mixture of Holstein-Friesian, Ayrshire, and Jersey cattle breeds, or their crosses with the local zebu cattle breeds. The milk yield was estimated recently at 8.3 L/d, translating to a lactation milk production of under 2500 litres [12].

The areas representing low-stress environments were Hai and Moshi Rural districts located between 3.19752° latitude and 37.21095 longitude. These areas are in the upper highland zone with high altitude (1228.67 to 1384 M ASL) and reliable, bimodal rainfall (~1558 mm annual). The high altitude moderate tropical temperatures to lower levels towards those of temperate conditions, which do not favour the thriving of many tropical disease vectors. The bimodal rainfall patterns in the low-stress environment support year-round fodder biomass supply for dairy cattle feeding, hence a thriving dairy industry. Representatives of a high-stress environment were Muheza (646.95 M ASL) and Tanga City (18.99 M ASL) districts. These districts are located in the coastal lowland zone between latitude 4° to 6° S and longitude 37° to 39° E at an average altitude of 499.46 M ASL. The annual rainfall ranges from 800 to 1400 mm with a bimodal distribution pattern. These conditions support crop production and fodder biomass for dairy-cattle feeding. A

combination of high humidity, low altitude and high temperature in the coastal zone is associated with high heat load and high prevalence of many tropical diseases. Common tropical diseases include east coast fever, babesiosis, anaplasmosis and helminths infections.

2.2. Research Design

The study used a two-factor nested research design, with farms nested within the environment. The factors were environmentally classified into low- and high-stress levels and the farm defined by level of production performance as positive deviant or typical farms. The individual farms represent the experimental units [13]. All dairy farms in this study were affiliated with the ADGG Project. The project offered access to a monthly test-day database for animal performance data collected from October 2016 through July 2020. The database is hosted by the International Livestock Research Institute (<https://www.adgg.ilri.org/uat/auth/auth/login>, accessed on 1 July 2020).

2.3. Data Collection and Processing

This subsection describes how data for the temperature–humidity index (THI), animal performance indicators and livelihood benefits were collected and processed. The data on temperature and humidity were sourced from a meteorological database for local stations within the two milksheds. Farm data was collected by trained Livestock field officers also known as performance recording agents (PRAs) operating Open Data Kit installed on Android tablets. These enumerators were used a structured questionnaire designed to collect data on production performance and management practices. These practices included animal health, feeding, watering, housing, breeds and breeding practices. Additional market data on product prices were sourced from government departments and from literature to compute livelihood roles and benefits (financing and insurance roles) of dairy farming in rural economies.

2.3.1. Temperature–Humidity Index

Monthly THI was computed from monthly averages of air temperature (°C) and relative humidity (%) data were obtained from meteorological database sources (<https://www.worldweatheronline.com/machame-weather/kilimanjaro/tz.aspx> and <https://www.worldweatheronline.com/tanga-weather/tanga/tz.aspx>, accessed on 18 December 2019). The THI is an indicator for heat-load stress that dairy cattle are exposed to at the level of production environment [14,15]. Mean THI was calculated a priori for each environment, applying a formula from Dikmen and Hansen [14] using over 42 monthly averages. The formula is:

$$\text{THI} = (1.8 \times T + 32) - [(0.55 - 0.0055 \times \text{RH}) \times (1.8 \times T - 26.8)] \quad (1)$$

where T is air temperature (°C) and RH is relative humidity (%). The THI categories as developed by Zimbelman et al. [15] represent neutral heat load (<68), heat stress threshold (68 to 71), mild to moderate heat stress (72 to 79), moderate to severe heat stress (80 to 89), severe heat stress (90 to 98) and extremely severe heat stress (>98).

2.3.2. Animal Performance Indicator Variables

A literature review of environmental stresses in dairy cattle reared in the tropics informed the selection of animal performance indicators. The total energy balance was selected as an objective indicator for nutritional stress and disease-incidence density as an indicator for disease stress [16,17]. The other performance indicators were daily milk yield, age at first calving and calving interval, which are animal-production and functional traits of economic importance in dairy farming [18]. The individual dairy farms were selected on the criteria of having a complete set of five performance indicators (total energy balance, daily milk yield, age at first calving, calving interval and incidence density) for identifying outperforming farms (positive deviants). These performance indicators are sensitive to environmental stresses and subsequently impact on the livelihoods and benefits

that farmers gain from dairy farming [19]. With the data extracted from the ADGG database including monthly test-day milk yields, farm averages were computed for total energy balance, disease-incidence density, daily milk yield, age at first calving and calving interval. The computational process for each indicator is provided:

- (i) Total energy balance (change in total energy balance (ΔTEB) per cow in the farm) is an indicator of nutritional stress and was calculated using an equation adapted from Tedeschi et al. [17]:

$$\Delta\text{TEB}_i = \text{TE}_i - \text{TE}_{i-1}; i \geq 2 \quad (2)$$

where ΔTEB_i is a change in total energy (Mcal), and subscripts i and $i - 1$ represent actual and previous TE values, respectively. The TEB values are obtained following Tedeschi et al. [17] as:

$$\text{TE}_i = 9.367 \times \text{TF}_i + 5.554 \times \text{TP}_i \quad (3)$$

where TF_i is the amount of body fat (kg), TP_i is the amount of body protein (kg), TE_i is the total energy (Mcal), and the subscript i is the i th period. A negative ΔTEB value indicates a situation where reserve energy is mobilized for milk production. The amount of milk produced, supported from mobilized reserves, is added to the diet-allowable milk production. A positive ΔTEB value indicates that the energy intake is greater than the energy required for milk production. In this case, part of the available energy is used for reserve deposition besides milk production. Therefore, the amount of energy deposited can be used to reduce the diet-allowable milk production.

- (ii) Disease-incidence density at farm level is an indicator of the rapidity with which new cases of disease develop overtime. In this study, disease-incidence density is an indicator of tick-borne diseases and helminths infections in the entire herd and is computed as the number of new cases that occurred in a population over a period of 42 months, adapting the formula of Thrusfield [16]:

$$\text{ID} = \left(\frac{\text{number of new cases diagnosed and treated in 42 months}}{\text{the sum, over all individuals, of the length of time at risk}} \right) \quad (4)$$

where ID refers to disease-incidence density, the number of new cases diagnosed and treated in 42 months refers to the number of cattle diagnosed and treated for diseases in a particular farm during a period of 42 months; and the sum, over all individuals, of the length of time at risk refers to the sum, over all individuals, of the length of time at risk of developing disease in a particular farm. As computed, the disease-incidence density is the rate per animal-years at risk in a predefined period and was translated into a rate per 100 animal-years at risk (by multiplying them 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 (including death or the end of study) and its date of entry (or the beginning of the study).

- (iii) The daily milk yield (MY) in litres per cow in the farm was calculated from monthly test-day lactation records obtained from ADGG database collected over a period of 42 months for 1551 cows in 794 farms.
- (iv) Age at first calving (AFC) for female animals in each herd was calculated as the number of days from birth to first calving over a period of 42 months. Data on AFC were available for 1625 heifers in 794 farms.
- (v) The calving interval (CI) for the cows within each herd was calculated as the interval in days between two consecutive normal calvings. Data on calving interval were available from 1348 records of 1348 cows in 794 farms.

2.3.3. Estimating Livelihood Benefits

This subsection describes how livelihood benefits were estimated. Livelihood benefits were computed on an annual basis per animal in the herd for fair comparison and to account for multiple functions of cattle in smallholder households. To estimate livelihood benefits, indicators were selected for both tangible and intangible benefits frequently used in smallholder dairy-farming systems in the tropics. These functions include: milk, stock, manure as fertiliser, financing and insurance benefits derived by smallholder farmers from keeping dairy cattle. Intangible benefits reflect unobserved income components resulting from products other than milk or stock. In contrast, intangible benefits account for a substantial proportion of the total benefits in smallholder dairy-production systems in the tropics [20]. The economic value of milk was computed by multiplying the total monthly milk produced by the market milk price (TZS 842.00 per litre; TZS 2297.5295 = USD 1 at the exchange rate on the 1 July 2020 (<https://www.bot.go.tz/ExchangeRate/>, accessed on 1 July 2020)).

Monthly milk production was estimated from monthly records:

$$\text{MILK} = \text{Milk output (litres)} \times \text{average milk price per litre} \quad (5)$$

where MILK is the total economic value of milk, and milk output in litres is the quantity of milk produced for the number of days in milk.

The value of manure was computed from the average daily dry-matter faecal output and the average nitrogen and phosphorus contents of the faecal dry matter (faecal DM). Manure production was computed by multiplying the live weights of the average herd by 0.8% in reference to faecal DM in a day for a ruminant animal, with the DM of 40% [20,21]. Manure has a value as organic fertiliser [20]: 1.4% nitrogen, 0.6% phosphorus and 1.34% potassium, which can be equated to synthetic N fertiliser [22] hence it was priced at the value of N in DAP and urea (at the average price of a 50 kg bag):

$$\text{MANURE} = \text{Fertilizer price} \times (\text{N}_{\text{manure}} + \text{P}_{\text{manure}}) \quad (6)$$

where MANURE is the total economic value of manure at the herd level used as fertiliser for one year (TZS), fertiliser price is the economic value of DAP and urea fertilisers (TZS/kg); N_{manure} , and P_{manure} are Kg N and Kg P in manure used as fertiliser. The N and P of manure used for fertilising were computed by multiplying the amounts of manure produced on the farm for the period of one year.

In a rural economy, a household avoids paying interest on loans by selling cattle to finance a cash need at hand, unlike borrowing from a bank or from an informal money lender [21]. Building on this, the financing benefit of the credit buffer of cattle is related to the avoidance of paying interest on borrowed money and hence was computed as:

$$\text{FINANCE} = \text{Head}_{\text{price}} \times b_f \quad (7)$$

where FINANCE is the economic value of cattle as finance or the benefit of financing or having a credit buffer during one year (TZS); $\text{Head}_{\text{price}}$ is the economic value of cattle in the herd if they were sold to finance a household's cash needs during the observation period or the value of cattle sold due to reasons of finance; b_f is the prevailing local interest rate per annum. For this case, an interest rate of 17% was applied, corresponding to the interest rate charged by a popular bank (National Microfinance Bank (NMB)). An average market price observed when disposing cattle for cash need in the study areas was TZS 731,250 and 689,564.03—and 600,000 and 547,156.86 per head in positive deviants—and this was typical under low- and high-stress dairy-production environments.

The insurance (security) function or cover of dairy cattle arises from cattle having the potential to be sold during emergencies. Therefore, the benefit of insurance is estimated by assuming that the whole herd is available to provide household insurance or security through liquidation at any time when cash need or an emergency arises [23]. It was

quantified as a product of the insurance factor (estimated from the opportunity cost of insurance) and the monetary value of the annualized household herd. This was calculated as follows:

$$\text{INSURANCE} = \text{Stock}_{\text{value}} \times b_i \quad (8)$$

where INSURANCE is the economic value of the cattle stock as an insurance for the household (TZS); $\text{stock}_{\text{value}}$ is the economic value of the average cattle stock for one year (computed by the average number of animals during the study period); b_i is the insurance premium or factor, that is, the cost that cattle owners would need to pay to purchase insurance cover equal to the capital value of their herd (the value of the annualized household herd during the observation period). An insurance premium of 6% was applied for all farms. The size of b_i was determined based on the existing insurance rate charged by most banks in the country.

Additionally, credit-processing benefits (a loan-processing fee) of 0.75% charged by NMB Bank were similarly applied for all farms. Therefore, the net benefits of keeping dairy cattle or the total benefit from dairy activities counted for tangible and intangible benefits less total production costs (feed, watering and healthcare-management costs).

$$\text{TB} = \text{VA} + \text{Financing benefits} + \text{Insurance benefits} + \text{Credit processing benefits} \quad (9)$$

where,

$$\text{VA} = \text{TCI} - \text{PC} \quad (10)$$

$$\text{TCI} = \text{Milk sales} + \text{Manure sales} \quad (11)$$

$$\text{PC} = \text{Feed cost} + \text{Healthcare cost} + \text{Watering cost} \quad (12)$$

where TB is the total livelihood benefits from dairy activities, VA is the total value added, TCI is the total cash income attained from the tangible benefits of keeping dairy cattle and PC is the total production cost incurred.

Gross margins due to milk sales is an economic indicator of productivity attained by farmers from the production costs incurred in rearing the animals. Thus, this is a measure of profitability in the use of resources available in small-scale dairy farming. The production costs in this case included feed, watering and healthcare-management costs. Thus, gross margins at farm level were computed using the model:

$$\text{Gross margins} = \text{Gross production value} - \text{Production cost} \quad (13)$$

where gross margins are the margins due to milk production value, and gross production value is the value at farm level, which was the product of selling prices and quantity of milk produced in litres.

2.4. Identification of Positive Deviants Using Pareto-Optimality Ranking Technique

This subsection describes how positive deviants were identified through the Pareto-optimality ranking technique in a sample of 794 smallholder dairy farms. The Pareto-optimality ranking technique is an objective and quantitative approach with which it is possible to isolate positive deviants in a population on multiple performance indicators simultaneously without a bias [8,9]. This technique is not sensitive to multi-collinearity and avoids bias in the identification of the positive deviants. The technique identifies the farms that outperform others in one or more indicators, without being outperformed in any other indicator themselves. The technique is implemented without subjective weighting to avoid bias. The pioneering application of the Pareto-optimality ranking technique was by Goldberg [24] and later by others in ecology, agriculture and livestock studies [7–9], but longitudinal data on smallholder dairy farming systems have not been used. Pareto-optimality ranking software was freely accessed [8].

The identification of positive deviants was implemented in four steps: (i) quantification of current farm performance in all performance-indicator variables; (ii) quantification of

threshold points for each performance-indicator variable, (iii) execution of the Pareto-optimality ranking technique using standardised indicator variables to generate a set of Pareto ranking solutions; (iv) comparison of the Pareto-optimal solutions based on current farm performance with a threshold point to isolate truly deviating farms from a wide array of Pareto-optimal solutions.

The first step involved computing averages for each performance indicator in each of the 794 individual farms. The second step was the computation of overall farm averages for each performance indicator in order to set the threshold points (population mean). The threshold points are presented in Table 1.

Table 1. A summary of threshold points for each performance-indicator variable set for identifying positive deviant farms in 794 sample farms.

| Performance Indicator | Population Mean Threshold Point for Positive Deviant Farms | Data |
|---------------------------|--|---|
| Energy balance | ≥ 0.35 Mcal NE _L /d | 1551 cows |
| Milk yield | ≥ 6.32 L/cow/day | 1551 cows |
| Age at first calving | ≤ 1153.28 days | 1625 heifers |
| Calving interval | ≤ 633.68 days | 1348 records of 1118 cows |
| Disease-incidence density | ≤ 12.75 per 100 animal-years at risk | 1912 health treatment events of 849 animals |

In step three, the averages of each performance indicator for each of the 794 individual farms obtained in step one was standardised by z-transformation to obtain z-scores. The z-scores is computed from the residuals divided by their standard deviation [9]. For each indicator variable, the distribution mean was subtracted from the score to obtain the distance from the mean in standard deviation units. This process makes the indicator distributions comparable despite being originally of different units and scales. The resultant performance scores for the 794 sample farms were subjected to the Pareto-optimality ranking algorithm [8]. The procedure allows for the choice of direction, whether to maximise or to minimise the indicator variable. In this study, the preferred directions of change were: maximizing total energy balance and daily milk yield, while minimizing age at first calving, calving interval and disease-incidence density. The preferred directions reflected the management goals in dairy production for increasing productivity and livelihood benefits.

Pareto-optimality ranking assigns Pareto-optimal solutions to rank 1 for farms not dominated by other farms. The Pareto-optimal solutions are those farms with Pareto-optimal performance for the performance-indicator variables. These farms outperform other farms with equivalent characteristics in at least one dimension without being outperformed in any other dimension. Next, the farms with rank 1 are removed from the set and the procedure is repeated by identifying the next set of non-dominated farms, which are assigned to rank 2. This ranking procedure is repeated until the sample farms are all ranked. The resulting farms are called Pareto-optimal or non-dominated solutions.

The set of Pareto-optimal solutions define the Pareto frontier while the solutions below the frontier are performing below the potential optimal level (suboptimal or dominated solutions). These suboptimal solutions can be improved in multiple indicators up to the Pareto frontier, which, therefore, represents the scope of improvement within the population [7,8]. However, Pareto-optimality ranking identifies a wide array of Pareto-optimal solutions, including extreme cases, which are solutions that excel in one indicator but perform very poorly in all the others (Table S1). Confronted with such cases, Modernel et al. [7] turned to expert knowledge to rule out the win-lose and lose-win farms to define the win-win farms amongst Pareto-optimal solutions [8]. In this study, instead of turning to expert knowledge, a comparison was made between the individual farm performance obtained in step one and the threshold points set in step two to identify the truly positive deviant farms.

In the last step, step four, comparison of farm performance was made against a threshold value to identify which farms do truly deviate from the average or beyond

expected performance on each indicator variable. From a set of Pareto-optimal farms, the 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 (Table 1). The selection process involved the sorting of multiple indicator variables to complement the Pareto-optimality ranking. This exercise defined a narrow set of truly positive deviant farms with consistent outstanding performances for each of the indicator variables simultaneously from rank 1.

Additionally, the selection was extended to include all farms that scored rank 2 and 3 with all other criteria held constant (Table S1). This was done to increase the positive deviant sample size for subsequent analyses. As implemented, a farm having a high value in one indicator does not decrease the values of the other indicators, although they do not necessarily perform best on one of the indicators. The result is that the true positive deviant farms were those farms that consistently outperformed above threshold points among Pareto-optimal solutions on five performance indicators simultaneously.

2.5. Statistical Analyses

Following data collection and processing, this subsection describes the statistical analysis for THI, productivity, yield gap and livelihood benefits.

2.5.1. Determining Temperature-Humidity Index (THI)

The THI was subjected to generalised linear model procedure of SAS software [25] to assess the extent of cattle exposure to heat-load stress between low- and high-stress environments. The statistical model fitted was specified as:

$$Y_{ij} = \mu + PE_i + E_{ij} \quad (14)$$

where Y_{ij} = THI, μ = overall mean, PE_i = fixed effect of production environments (low- and high-stress) and E_{ij} = random error.

2.5.2. Determining Productivity and Yield Gap

The farm averages of total energy balance, milk yield, age at first calving, calving interval and disease-incidence density at the farm level were compared between the positive deviant and typical farms, building upon already objective identification of these farms in Section 2.4. These production performance-indicator variables were subjected to the linear mixed model analysis procedure of SAS software [25]. This procedure can fit variables that are correlated or with no constant variability and where the response variable is not necessarily normally distributed. The fitted model was specified as:

$$Y_{ijk} = \mu + PE_i + FT(PE)_{ij} + E_{ijk} \quad (15)$$

where, Y_{ijk} = dependent variable of total energy balance, milk yield, age at first calving, calving interval and disease-incidence density, μ = overall mean, PE_i = fixed effect of production environment (low- and high-stress dairy production environments), $FT(PE)_{ij}$ = random effect of farm-type nested within production environment and E_{ijk} = random error. Means separation used least significant difference for direct mean pairwise comparisons.

Adopting the definition already in application [26], the milk yield gap in this study was defined as the difference between the actual yield as obtained on typical farms and the potential yield as the yield achieved on positive deviant farms. The potential yield implies average milk yield under the limitations set by the prevalent environmental stresses in a production environment.

2.5.3. Estimating Livelihood Benefits

Following objective identification of positive deviants and typical farms, a comparative analysis between these farms was performed to establish differences in livelihood benefits.

A mixed model analysis of variance in SAS software [25] was used to test for difference in livelihood benefits at the farm level:

$$Y_{ijk} = \mu + PE_i + FT(PE)_{ij} + E_{ijk} \quad (16)$$

where, Y_{ijk} = dependent variable (i.e., total production cost, total cash income, gross margins and total benefits at farm level), μ = overall mean, PE_i = fixed effect of stressful production environment (low and high), $FT(PE)_{ij}$ = random effect of farm-type (positive deviants and typical dairy farms) nested within production environment and E_{ijk} = random error. Differences in least square means were tested using Fisher's least significant difference, with a PDIFF option.

3. Results

3.1. Temperature-Humidity Index (THI) Estimate

Table 2 presents mean THI estimates to give indication of the levels of exposure to heat-load stress that dairy cattle were experiencing in the low- and high-stress environments. The results show that dairy cattle were exposed to significantly ($p < 0.0001$) lower heat-stress levels in the low-stress environment than in the high-stress environment. Dairy cattle in the low-stress environment were exposed to lower heat-stress threshold conditions (68.20 ± 0.39 THI) while those in the high-stress environment were exposed to mild to moderate heat-stress levels (77.29 ± 0.39 THI).

Table 2. Least square means of temperature-humidity index (THI) for the low- and high-stress dairy-production environments.

| Production Environment | THI Units |
|------------------------|------------------|
| Low-stress | 68.20 ± 0.39 |
| High-stress | 77.29 ± 0.39 |
| <i>p</i> -value | <0.0001 |

3.2. Positive Deviants and Typical Farms Identified

The application of the Pareto-optimality ranking technique to a sample of 794 farms isolated 105 (13.22%) farms located on the trade-off frontier (rank 1 or Pareto-optimal solutions). Further subjecting these farms in Pareto-optimal solutions to multiple indicator-variable sorting isolated only 17 (2.14%) farms. When multiple indicator-variable sorting was extended to include farms scored in rank 2 and 3, an additional 10 (1.26%) farms were isolated, resulting in 27 (3.4%) positive deviant farms. These farms were the true positive deviant farms that consistently performed above threshold points among Pareto-optimal solutions on the five performance indicators simultaneously. These positive deviant farms were fairly distributed within low- ($n = 15$) and high-stress environments ($n = 12$).

Variations in the five performance-indicator variables between positive deviants and TYP farms nested within the environments are presented in Table 3. Results reveal considerable significant variations ($p < 0.05$) between positive deviants and typical farms, with animals in positive deviant farms attaining better performance in both low- and high-stress environments. In positive deviant farms, the total energy balance and daily milk yield were higher, age at first calving earlier, calving interval shorter and disease-incidence density lower, when compared with typical farms.

Though not significantly different, animals tended to experience a lower positive energy balance and higher disease-stress exposure in the high-stress environment relative to animals in the low-stress environment. In production performance, average daily milk yield was higher by 0.63 litres in the low-stress environment than the milk yield attained in the high-stress environment ($p < 0.001$). Though age at first calving and calving interval were not significantly different between low- and high-stress environments ($p > 0.05$), a pattern is observed that animals tended to attain first calving age earlier (0.61 months)

and also realise a shorter calving interval (0.97 months) in low- relative to high-stress environments.

Table 3. Estimated means (LSMEANS \pm SE) for performance-indicator variables of cattle managed on positive deviants and typical smallholder dairy farms nested within production environments.

| Factor | Level | EB (Mcal NE _L /d) | MY (L/d) | AFC (Months) | CI (Months) | ID |
|-------------------------------|-------------------|------------------------------|------------------|------------------|------------------|------------------|
| Production environment | Low-stress | 5.09 \pm 3.28 | 8.86 \pm 0.15 | 35.60 \pm 0.85 | 18.01 \pm 0.57 | 6.25 \pm 1.70 |
| | High-stress | 6.65 \pm 2.28 | 8.23 \pm 0.11 | 36.21 \pm 0.91 | 17.04 \pm 0.67 | 9.55 \pm 1.89 |
| | <i>p</i> -value | 0.6956 | 0.0006 | 0.6219 | 0.2707 | 0.1945 |
| Farm (Production environment) | Low-stress | | | | | |
| | Positive deviants | 9.53 \pm 6.45 | 11.32 \pm 0.29 | 32.56 \pm 1.65 | 15.66 \pm 1.11 | 2.89 \pm 3.33 |
| | Typical | 0.64 \pm 1.19 | 6.40 \pm 0.06 | 38.64 \pm 0.39 | 20.36 \pm 0.28 | 9.60 \pm 0.67 |
| | <i>p</i> -value | 0.1757 | <0.0001 | 0.0003 | <0.0001 | 0.0489 |
| | High-stress | | | | | |
| | Positive deviants | 12.10 \pm 4.48 | 9.83 \pm 0.21 | 34.04 \pm 1.80 | 14.13 \pm 1.31 | 2.73 \pm 3.73 |
| | Typical | 1.19 \pm 0.82 | 6.64 \pm 0.04 | 38.39 \pm 0.34 | 19.95 \pm 0.27 | 16.37 \pm 0.65 |
| <i>p</i> -value | 0.0166 | <0.0001 | 0.0175 | <0.0001 | 0.0003 | |

EB = Energy balance (Mcal NE_L/day); MY = Milk yield (Litres/day); AFC = Age at first calving (Months); CI = Calving interval (Months); ID = Disease-incidence density (per 100 animal-years at risk).

3.3. Attained Yield Gap, Productivity and Livelihood Benefits Differentiating Positive Deviant Farms from Typical Farms

Table 4 presents the milk yield gap estimates in typical farms relative to positive deviant farms and in the low-stress relative to the high-stress environment. The difference in milk yield between positive deviant and typical farms and between low- and high-stress environments represents the yield gap, as the potential percentage improvement in the actual yield presently realised. Animals in the low-stress environment attained more 0.63 litre of milk per cow compared to animals in the high-stress environment, which translates to 7.65% yield gap in the high-stress environment. Relative to animals in typical farms, the animals in positive deviant farms produced more 4.92 litres of milk per cow per day in the low-stress environment translating to 76.88% yield gap while in the high-stress environment animals produced more 3.19 litres of milk per cow per day, translating into 48.08% milk yield gap.

Table 4. Estimated means (\pm SE) for milk yield and yield gaps in typical farms relative to positive deviant farms and in the low-stress environment relative to the high-stress environment.

| Factor | Level | Milk Yield (L/cow/d) | Yield Gap | |
|-----------------------------------|-----------------------------------|----------------------|----------------------|------------|
| | | | Milk Yield (L/cow/d) | % Increase |
| Environment | Low-stress (<i>n</i> = 386) | 8.86 \pm 0.15 | 0.63 | 7.65 |
| | High-stress (<i>n</i> = 498) | 8.23 \pm 0.11 | | |
| Farm(environment) | Low-stress | | | |
| | Positive deviant (<i>n</i> = 15) | 11.32 \pm 0.29 | 4.92 | 76.88 |
| | Typical (<i>n</i> = 371) | 6.40 \pm 0.06 | | |
| | High-stress | | | |
| Positive deviant (<i>n</i> = 12) | 9.83 \pm 0.21 | 3.19 | 48.04 | |
| Typical (<i>n</i> = 396) | 6.64 \pm 0.04 | | | |

Figure 2 illustrates production cost and total cash income while Figure 3 illustrates gross margins and total benefits from dairy cattle farming obtained in positive deviant and typical farms when farms are nested within the environments. The units are TZS per animal per year for fair comparison between the farms. Results show that positive deviant farms incurred higher production cost, with which they attained higher total cash income (Figure 2), gross margins and total benefits (Figure 3) than typical farms both in low- and high-stress environments. There was a significant difference ($p < 0.05$) in total

cash income between positive deviant and typical farms in the low-stress environment. Positive deviants attained 235,541 TZS higher total cash income than typical farms under the low-stress environment. However, under the high-stress environment, positive deviant farms attained 221,024 TZS higher than typical farms, but not significantly different. The overall results show that positive deviant farms significantly ($p < 0.05$) gained more than typical farms in total cash income, gross margin and total benefits by 228,283, 208,319 and 222,129 TZS per animal per year.

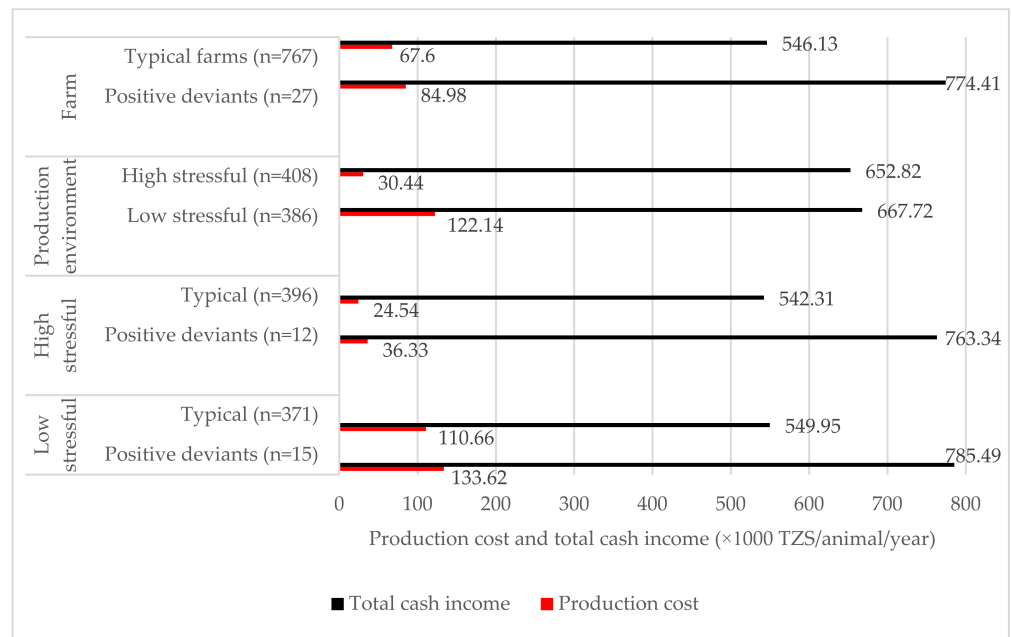


Figure 2. Total production cost and total cash income from dairy cattle on positive deviants and typical farms nested within production environment (Exchange rate 2297.5295 Tanzanian Shillings (TZS) = 1 US dollar).

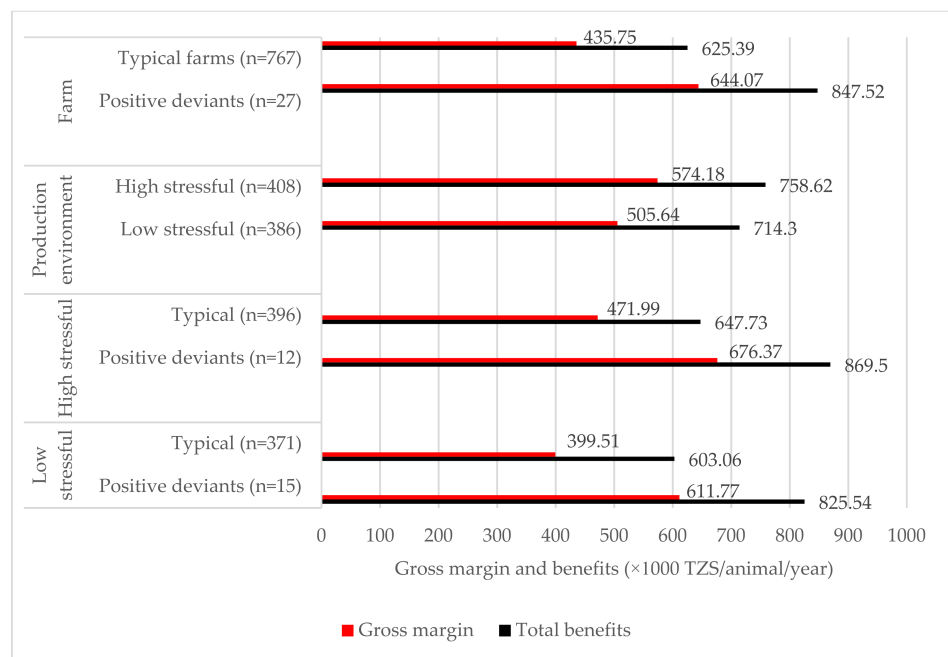


Figure 3. Gross profit margins and total benefits from dairy cattle on positive deviant and typical farms nested within production environments (Exchange rate 2297.5295 TZS = 1 USD).

4. Discussion

4.1. Temperature-Humidity Index (THI) Estimate

The THI indicated that dairy cattle were exposed to relatively higher heat stress, in the mild to moderate range, in the high-stress environment than were the animals in the low-stress environment ($p < 0.0001$). These findings suggest that interventions are required to address heat stress in smallholder dairy farming in the high-stress environment because THI exceeded 72 threshold points when dairy cattle begin to be affected and thus need protection from heat stress. Farmers have several options to ameliorate heat stress affecting their cattle. The options include careful selection of genotypes, improved nutrition, watering and physical modification of the environment such as adequate house floor spacing per animal to create suitable microclimate in the cowshed [27]. These practices are more important for farmers keeping Holstein-Friesian cattle in the high-stress environment, because the breed is sensitive to thermal stress. If there is exposure to mild thermal stress peaks in the afternoons during the dry seasons, the animal increases physiological and hematological responses [28].

4.2. Identifying Positive Deviants in a Sample Population

The approach of identifying positive deviants in a population in this study deviates from previous studies in many ways to avoid subjectivity and bias so as to support broad generalisation of the findings. This was achieved with the Pareto-optimality ranking technique that accounted for multiple production performance indicators. Production performance indicators that were used in this study included total energy balance, daily milk yield, age at first calving, calving interval and disease-incidence density. Unlike most of positive deviance studies conducted in the agricultural domain with cross-sectional surveys [7,9], the data in this study were longitudinal measurements over a period of 42 months in a random sample of 794 farms. The advantage of longitudinal study is that the variables of interest can be monitored and checked for movement towards or away from deviance behaviour over time. The selected performance indicators are sensitive to the prevalent environmental stresses, with impacts manifesting in attained productivity levels and the magnitude of livelihood benefits from dairy farming.

With application of the Pareto-optimality ranking technique, 27 (3.4%) positive deviant farms were identified that consistently outperformed comparable farms (average or typical farms) exposed to similar environmental stresses in a production environment. These few individual positive deviant farms are the positive outliers, exhibiting positive deviance behaviour with the achievement of outstanding performance under similar environmental stresses. The approach used identified far fewer positive deviants (3.4%) than are observed in many other related studies of the positive deviant phenomenon. Mostly, positive deviants are in the range of ten percent (10%) of the sample, when a single performance indicator is used as the criterion [29] or less when multiple performance indicators are used [7]. The authors of Modernel et al. [7], who used Pareto-optimality ranking on multiple performance indicators complemented by expert knowledge, isolated a smaller proportion of positive deviants (1.79%: 5/280). In contrast, Steinke et al. [9], who also used Pareto-optimality ranking on multiple performance indicators, isolated a larger proportion of positive deviants (10.8%: 54/500). Similarly, Adelhart Toorop et al. [8] ended up with a larger proportion of positive deviants (13.95%: 6/43), which originated from a smaller sample size with limited heterogeneity. This is likely due to differences in sorting farms scored rank 1 to complement the Pareto-optimality ranking where multiple indicator variables are involved. The present study included farms scored rank 2 and 3 to define a narrow set of truly positive deviants with consistent outstanding performances for each of the five indicator variables simultaneously. This present study indicates that when multiple-objective indicator variables, obtained longitudinally, are simultaneously considered in a large and random population, positive deviants attaining exceptional performance would be fewer than five percent (5%). This was the case in the present study in contrasting stressful environments, where only 3.9% (15/386) positive deviant farms in low- and 2.9%

(12/408) in high-stress environments could be isolated objectively. This is in contrast to studies that set a singular performance-indicator variable such as milk yield to identify positive deviants, and then equate the top 10% of performers in a sample with the positive deviants [6].

Most previous studies that identified positive deviants relied on a single performance-indicator variable to classify a group of outperforming farms in a sample obtained in a cross-sectional survey [30]. Given the complexity of the livestock production systems that smallholders manage, where farmers pursue multiple objectives, there is likely no one single best indicator variable of performance suited for an objective identification of positive deviants. For the multiple-objective system that smallholder dairying is, the Pareto-optimality ranking technique, a multi-objective analytic technique, offers advantages over expert knowledge or participatory approaches accompanied by a single indicator variable when identifying positive deviants in a sample. The identification of positive deviants with the criteria of multiple indicator variables better reflects the exposure to multiple environmental stresses. In addition, having multiple indicator variables reflects the multiple roles of cattle and livelihood benefits that smallholders desire from their dairy farming. With multiple indicator variables, farms that emerge as positive deviants are a better reflection of their cumulative outstanding performance outcome with the management practices that they effectively ameliorate environmental stresses.

The Pareto-optimality ranking technique achieved these advantages without subjective weighting or biases while accommodating multiple indicator variables simultaneously in the process of identifying consistently outstanding farms [8]. Therefore, management practices on positive deviant farms can better inform good local lessons for innovating and up-scaling ameliorative management practices to overcome prevalent environmental stresses.

4.3. Attainable Productivity and Livelihood Benefits in Positive Deviant Farms

Within a production environment with similar prevalent environmental stresses, dairy cattle in positive deviant farms outperformed those in typical farms in production and functional trait indicator variables. This would suggest differences between positive deviants and typical farms in how they deploy management practices to ameliorate prevalent environmental stresses. Dairy cattle in positive deviant farms attained better performance, both in high- and in low-stress environments. For example, the total energy balance was positive but higher in positive deviant farms than in typical farms, indicating that positive deviant farms were more effectively ameliorating nutritional stress. For example, this could be achieved with provision of a well-balanced diet of fodder adequately supplemented with concentrates. Similarly, disease-incidence density, a proxy measure of disease stress, was lower in positive deviant farms than in typical farms, pointing to positive deviant farms as more effectively ameliorating disease stresses through animal-health practices.

These observations corroborate the assessment of environmental stresses in dairy production in several studies that have used THI to assess heat-load stress, total energy balance to assess nutritional stress and disease-incidence density to assess disease infection stress [31]. In the high-stress environment, a lower total energy balance for animals in typical farms is likely a consequence of a decrease in nutrient intake, alteration in rumen function during heat stress and hormonal imbalance [32]. As a consequence, a depression in milk yield follows because a decrease in dry matter intake accounts for an up to 35% reduction in milk yield with the remainder (65%) attributable to other physiological effects of heat stress [33]. The associated effects of lower energy balance and higher heat stress in the high-stress environment can be extended to the observed older age at first calving and longer calving intervals attained in typical farms. Under heat stresses and inadequate nutrition, 50% of the standing periods of oestrus pass undetected, with a resultant delayed age at first calving and long calving interval [34]. Pervasive exposure of dairy cattle to heat stress of greater than the 72 THI threshold impacts production and functional traits where deliberate effective ameliorative strategies are not deployed to check these stresses. The

earlier age at first calving, shorter calving intervals and higher daily milk yields attained in positive deviant farms compared to typical farms are further supportive evidence of a likelihood of more effective amelioration of environmental stresses in positive deviant farms than in typical farms. Because of these apparent differences in management practices, characterising specific practices that positive deviant farms deployed differently to more effectively ameliorate stresses of heat load, nutritional scarcity and infections becomes necessary. This is for lesson learning, to inform the uptake of best practices and by extension messages at the farm level.

With a larger herd size that attained better performance in production and functional traits, positive deviant farms realised higher daily milk productivity levels, up by 3.19 litres in high- and 4.92 litres in low-stress dairy production environments. This difference translates to a huge yield gap in typical farms, the extent being larger in a low- than in a high-stress environment (76.88% vs. 48.04%). The yield gap implies a greater opportunity to increase milk production in typical than in positive farms and in low- than in the high-stress environment. This is because heat stress has a reduction effect on production in livestock. This points to the need to invest more in heat-stress-management practices in order to optimise benefits when nutritional and disease stresses are ameliorated.

The quantification of tangible and intangible economic benefits resulting from dairy-cattle farming was to account for the multiple livelihood benefits of dairy cattle to a rural farming households, who integrate the objectives of subsistence needs with profit making. In this study, the total monetary value of dairy farming was a summation of multiple functions which contribute to the total benefits of keeping dairy cattle in a smallholder household [21]. However, quantifying intangible benefits is challenging and should be interpreted with caution as all animals in the herd regardless of class were assumed to provide multiple functions to the household. The total benefits could not account for some important socio-cultural values where cattle are part of status display or have a value in dowry payments. This is because households do not provide reliable data on these aspects.

Results showed that positive deviant farms gained more than typical farms from dairy-cattle farming in total cash income, gross margins and total benefits both in high-and low-stress environments. The gains were greater ($p < 0.05$) in positive deviants than typical farms per animal annually in TZS by 235,541 in cash income, 212,263 in gross margins and 222,483 in total benefits in the low-stress environment. Total cash income, gross margins and total benefits were higher in positive deviants than typical farms by 221,024, 204,375 and 221,775 TZS in the high-stress environment. It is possible that positive deviant farms attained these higher gains with higher investment and effective utilisation of ameliorative practices targeted to the prevalent environmental stresses. This is because their average production cost was 22,958 and 11,799 TZS more than was in typical farms in low- and high-stress environments (Figure 2). Further, the observation points to positive deviant farms paying more attention to ameliorating environmental stresses than typical farms because the total cash incomes, gross margins and total benefits realised were significantly higher in positive deviant farms (Figures 2 and 3). These results support the need to invest more in ameliorative practices, technologies and innovations in the high-stress environment. In this environment, a combination of limitation factors (nutritional scarcity) and production-reducing factors (heat-load and disease stresses) aggregately impact attainable yield gaps, productivity and livelihood benefits in dairy-cattle farming.

5. Conclusions

The findings of this study show that the Pareto-optimality ranking technique applied in a large population objectively identified a few positive deviant farms that attained higher productivity and livelihood benefits in both low- and high-stress environments. The Pareto-optimality ranking technique objectively accounted for multiple indicator variables which limit (nutritional scarcity) and reduce production (heat-load and disease stresses). The variables used to identify positive deviants have relevance for the aggregate impact on productivity and livelihood benefits in dairy-farming systems. They are also relevant

to accounting for the multiple functions of dairy farming in smallholder households. These results suggest the need to invest more in ameliorative management practices, technologies and innovations to address the different environmental stresses hindering dairy productivity, especially in typical farms. Thus, where positive deviants have been isolated, those ameliorative practices can be characterised to better understand which practices distinguish positive deviants from typical farms. This is valuable lesson learning to inform best practices and by extension design messages that target improvements in typical farms.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/world3030035/s1>, Table S1: Pareto rankings, number of observations, ranges of standardised variables per rank, positive deviants and the percentages of positive deviant farms in the population.

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