Evaluation of the Causes of Infertility in Dairy Cattle on Smallholder Farms in Tanzania

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Declaration

I hereby declare that I am the sole author of this thesis, entitled: "Evaluation of the causes of infertility in dairy cattle on smallholder farms in Tanzania", submitted as partial fulfilment of the requirements for the degree of Doctor of Philosophy in Veterinary Science.

This work is the result of my own research, except where otherwise acknowledged, correctly and completely.

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007) of the United Republic of Tanzania.

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Abstract

Smallholder dairy cattle farming plays a crucial socio-economic role for many households across rural, peri-urban and urban areas in Tanzania. Despite its importance, the sector faces numerous challenges, with reproductive issues, particularly infertility, being among the major barriers to productivity and sustainability. This study explored farmer demographics and their knowledge, attitudes and practices (KAP) regarding infertility in dairy cattle, alongside an assessment of reproductive performance in cows and heifers. A cross-sectional survey was conducted on 301 smallholder farms across 13 districts in six key dairy-producing regions: Arusha, Kilimanjaro, Mbeya, Morogoro, Njombe and Tanga. Despite the shared similarities in demographics depicted by farmers, regional differences were notable. For instance, men dominated most regions except Njombe, where gender representation was more balanced. Education levels varied, with Morogoro farmers having higher education levels than others, while a higher proportion of farmers in Morogoro and Tanga had herds >4 animals. Acquisition of the first cattle beast also differed; cash purchases dominated, except in Mbeya, where cattle were often received as gifts (referred to as 'kufufya'). The top-reported farming constraints included high input costs (93%), feed unavailability (71%), insufficient land (68%), and livestock diseases (62%). Overall, 95% of farmers reported having infertility in their herds, with the key reported causes being poor nutrition and housing (93%), livestock disease (89%), poor farm record keeping (85%) and poor heat detection (83%). Nearly all farmers (98%) considered infertility as having a major impact, with repeat breeding (95%) and failure to produce a calf in a year (69%) having the most impact. Reproductive performance was poor, with only 46% of animals pregnant and a median inter-calving interval of 468 days (despite excluding cows that were sold or culled before getting pregnant). Analysis of influencing factors showed that region was an important predictor of reproductive performance, followed by herd size and farmer experience. Larger herds were linked with better performance, while less experienced farmers surprisingly reported more pregnant animals, with better ability to recognise infertility signs. These findings highlight the need for regionally tailored strategies to improve reproductive outcomes and sustain smallholder dairy cattle farming in Tanzania.

Keywords: Smallholder dairy farmers, reproductive performance, cattle infertility

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Key Abbreviations

AI - Artificial Insemination

PD – Pregnancy Diagnosis

ICI – Inter-calving Interval

CCI - Calving to Conception Interval

CFSI – Calving to First Service Interval

FSCI – First service to Conception Interval

CI - Confidence Interval

OR - Odds Ratio

HR -Hazard Ratio

TALIRI – Tanzania Livestock Research Institute

DC – District Council

TC – Town Council

MC – Municipal Council

CC - City Council

Thesis outline and publications

This thesis has been prepared partly via publication. Thus, chapters 1, 2, and 7 were not written for publication. However, chapters 3 to 6 were written for publication, and all chapters have been submitted to the journal for publication (see Table 1.1).

Table 1.1. Thesis outline and publications

Chapter	Publication/write-up	Status
Chapter One	General Introduction	Not written for publication
Chapter Two	Literature review	Not written for publication
Chapter Three	Ngou, A., Laven, R., Parkinson, T., Kashoma, I., & Donaghy, D. Understanding Smallholder Dairy Farming in Tanzania: A Cross-Sectional Survey of Farmer Demographics and Management Constraints	Submitted to the Veterinary Medicine and Science Journal
Chapter Four	Ngou, A., Laven, R., Parkinson, T., Kashoma, I., & Donaghy, D. Knowledge, Attitudes, and Practices of Smallholder Dairy Cattle Farmers in Tanzania: A Cross-sectional Survey on Cattle Infertility.	Published: Veterinary Sciences Journal: https://doi.org/10.3390/vetsci12100993
Chapter Five	Ngou, A., Laven, R., Parkinson, T., Kashoma, I., & Donaghy, D. A cross-sectional study of reproductive performance of improved dairy cattle under smallholder dairy farming in Tanzania	Submitted to Tropical Animal Health and Production Journal
Chapter Six	Ngou, A., Laven, R., Parkinson, T., Kashoma, I., & Donaghy, D. The Impact of Socioeconomic and Management Predictors on the Recognition of Infertility Signs and Reproductive	Submitted to the Journal of the South African Veterinary Association

	Performance in Smallholder Dairy Cattle Farming in Tanzania	
Chapter Seven	General Discussion	Not written for publication

Chapter One: General Introduction

1.0. Background Information

There is a growing demand for milk and dairy products in Tanzania, driven by the increasing human population and higher per capita consumption of dairy products. Much of this demand has been met by imports of milk products, especially from South Africa and the Middle East. However, to meet the increasing in demand for milk products from local sources, there has been a significant increase in the number of dairy cattle farmers and dairy cattle. There has also been a shift away from native cattle to imported, higher-producing 'European' dairy breeds and crosses (i.e. Holsteins, Ayrshire and Jersey) (Michael et al., 2018).

However, progress in developing the Tanzanian national dairy herd has been hampered by poor fertility, which has become one of the key limiters to productivity in its domestic dairy farming (Swai et al., 2005b). Good fertility is crucial for optimising farm productivity and, hence, profitability. Sub-optimal fertility, both directly and indirectly, reduces milk yield, increases involuntary culling, reduces overall welfare, and reduces longevity and lifetime productivity (Dijkhuizen et al., 1985). It also reduces calf sales and increases breeding costs (Plaizier et al., 1998). In most developing countries with burgeoning domestic dairy industries, optimising the livelihoods of dairy farmers in terms of herd productivity and profitability is essential to achieve benefits to the broader local community, as well as to national requirements.

The symptoms of poor fertility on Tanzanian dairy farms include critical issues such as grossly extended inter-calving intervals (Kanuya et al., 2000) and high rates of culling due to failure to become pregnant (Swai et al., 2005b). These problems have to be understood in the context of the modern high-producing dairy cow, which has significantly poorer fertility compared to its predecessors (Royal et al., 2000; Moore & Thatcher, 2006; Weigel, 2006). Globally, multiple factors are responsible for this decline, including genetics, environment and management, which interact to produce a complex suite of infertility problems (Walsh et al., 2011). The limiting factors vary significantly across systems: for example, in the US and UK (high production, high intake of non-forage feeds, year-round calving), a lack of oestrus behaviour and underlying poor conception rates are the most significant manifestations of infertility, whereas in NZ (lower production and pasture-based seasonal calving) anovulatory anoestrus is the most important problem (Lucy, 2001; Dillon et al., 2006; Macdonald et al., 2008a).

The infertility of the Tanzanian dairy cow is likely to be due to a subset of these global problems, overlain with further local country- or region-specific issues. Hence, as it is crucial to have system-specific data to identify problems and suggest solutions when investigating infertility, such that more data are needed across different systems and regions in Tanzania on the causes and effects of infertility in dairy cattle. Thus, a detailed investigation is needed into the factors affecting fertility in dairy cattle under the tropical/subtropical conditions of Tanzania, including effects caused by the cows' underlying physiology and the effects of their nutrition; whilst also focusing on the demographic, managemental and physical factors that could exacerbate or mitigate farmers' ability to profitably manage dairy cows.

1.1. Thesis objectives

The studies reported in this thesis were therefore designed to generate information on the causes of infertility and poor reproductive performance of dairy cattle in Tanzania. The project was a mix of farm-focused information and data collection, aiming to:

i. Evaluate the demographics of the smallholder dairy cattle farmers across the study regions,
ii. Evaluate the knowledge, attitudes, and practices of dairy cattle farmers in Tanzania towards infertility across the study regions,
iii. Investigate the reproductive outcomes of dairy cows in the different dairying regions of Tanzania.
iv. Determine which of these factors are likely to be the critical limiters and/or the most amenable to management intervention for the improvement of the dairy industry.

1.2. Importance of this Thesis

This thesis is important for addressing the key causes of infertility and poor reproductive performance in Tanzania's smallholder dairy cattle. By assessing farmers' demographics, understanding and practices towards dairy cattle infertility, alongside reproductive performance across regions. This thesis identifies critical limiting factors to smallholder dairy cattle farming development in Tanzania. It also highlights the factors most responsive to management and offers practical guidance for improving fertility and productivity in the dairy sector.

1.3. References

Dijkhuizen, A. A., Stelwagen, J., & Renkema, J. A. (1985). Economic aspects of reproductive failure in dairy cattle. I. Financial loss at farm level. *Preventive Veterinary Medicine*, *3*(3), 251-263-263. https://doi.org/10.1016/0167-5877(85)90020-0

Dillon, P., Berry, D. P., Evans, R. D., Buckley, F., & Horan, B. (2006). Consequences of genetic selection for increased milk production in European seasonal pasture based systems of milk production. *Livestock Science*, *99*(2-3), 141-158. https://doi.org/10.1016/j.livprodsci.2005.06.011

Kanuya, N., Kessy, B., Bittegeko, S., Mdoe, N., & Aboud, A. (2000). Suboptimal reproductive performance of dairy cattle kept in smallholder herds in a rural highland area of northern Tanzania. *Preventive Veterinary Medicine*, *45*(3-4), 183-192. https://doi.org/https://doi.org/10.1016/S0167-5877(00)00134-3

Lucy, M. (2001). Reproductive loss in high-producing dairy cattle: where will it end? *JOURNAL OF DAIRY SCIENCE*, *84*(6), 1277-1293. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(01)70158-0

Macdonald, K. A., Verkerk, G. A., Thorrold, B. S., Pryce, J. E., Penno, J. W., McNaughton, L. R., Burton, L. J., Lancaster, J. A., Williamson, J. H., & Holmes, C. W. (2008a). A comparison of three strains of holstein-friesian grazed on pasture and managed under different feed allowances. *J Dairy Sci*, *91*(4), 1693-1707. https://doi.org/10.3168/jds.2007-0441

Michael, S., Mbwambo, N., Mruttu, H., Dotto, M., Ndomba, C., da Silva, M., Makusaro, F., Nandonde, S., Crispin, J., & Shapiro, I. (2018). Tanzania Livestock Master Plan (2017/2018-2021/2022). *United Republic of Tanzania, Ministry of Livestock and Fisheries*.

Moore, K., & Thatcher, W. (2006). Major advances associated with reproduction in dairy cattle. *Journal of Dairy Science*, *89*(4), 1254-1266. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(06)72194-4

Plaizier, J., Lissemore, K., Kelton, D., & King, G. (1998). Evaluation of overall reproductive performance of dairy herds. *Journal of Dairy Science*, *81*(7), 1848-1854. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(98)75755-8

Royal, M., Mann, G. E., & Flint, A. P. (2000). Strategies for reversing the trend towards subfertility in dairy cattle. *Vet J*, *160*(1), 53-60. https://doi.org/10.1053/tvjl.1999.0450

Swai, E., Bryant, M., Karimuribo, E., French, N., Ogden, N., Fitzpatrick, J., & Kambarage, D. (2005b). A cross-sectional study of reproductive performance of smallholder dairy cows in coastal Tanzania. *Tropical Animal Health and Production*, *37*(6), 513-525.

Walsh, S. W., Williams, E. J., & Evans, A. C. (2011). A review of the causes of poor fertility in high milk producing dairy cows. *Anim Reprod Sci*, *123*(3-4), 127-138. https://doi.org/10.1016/j.anireprosci.2010.12.001

Weigel, K. A. (2006). Prospects for improving reproductive performance through genetic selection. *Anim Reprod Sci*, *96*(3-4), 323-330. https://doi.org/10.1016/j.anireprosci.2006.08.010

Chapter Two: Literature Review

2.0. Introduction

This chapter provides a comprehensive review of the literature relevant to the present study, with a focus on smallholder dairy cattle farming in Tanzania. It is organised into six main sections: 1) dairy farming system in Tanzania, 2) fertility management in dairy cows, 3) dairy development and its impacts, 4) control of the oestrous cycle for improved fertility, 5) dairy cow reproductive management 6) evaluation of herd fertility and 7) body condition and review summary and conclusion.

2.1. Dairy farming in Tanzania

In the 2019/2020 livestock census, Tanzania had the second-largest population of cattle in Africa, with 33.9 million head of cattle (second only to Ethiopia, which had 60.4 million). Of the cattle kept in Tanzania, 33.8 million are owned by smallholder farmers, and only 143,000 are found on large-scale farms (NBS&OCGS, 2021). The cattle population is concentrated in the Lakes area, central Tanzania, and the Northern and Southern Highland regions (Figure 1) (Kurwijila et al., 2012; CSIRO, 2020). Tanzanian cattle are kept for multiple purposes, including meat, draft power and milk, and as a readily accessible form of savings (NBS&OCGS, 2021).

The 2019/20 livestock census (NBS&OCGS, 2021) reported that Tanzanian cattle produced 3.1 billion litres of milk. Most of this milk (approximately 90%) is produced in low-input, low-yield systems and is directly consumed by the producer's household (CSIRO, 2020; NBS&OCGS, 2021). Most (70%) of the milk comes from local zebu cattle (Nell et al., 2014). The remaining 30% comes from dairy-grade cattle (crosses of exotic and indigenous breeds), even though such cattle account for only 2% (i.e. 700,000 head) of the total cattle population (NBS&OCGS, 2021).

Dairy cattle in Tanzania are most commonly crosses of European dairy breeds (*Bos taurus*), for example, Friesian, Jersey, and Ayrshire, with local Zebu (*B. indicus*), especially Tanzanian Shorthorn Zebu (TSHZ), but also Boran and Sahiwal (Njombe et al., 2011; Swai & Karimuribo, 2011) cattle. Tanzanian dairy development efforts have focused on the geographical areas that are most suitable for European dairy cattle. These 'high potential' areas are primarily located in the highlands, including the Northern Highlands (Arusha, Kilimanjaro and Tanga), with almost 43.5 dairy cattle per km^2, and Southern Highlands (Iringa, Njombe and Mbeya), with 2.5 dairy cattle per km^2, which have been identified as ideal places for dairy farming (Swai & Karimuribo, 2011).

Dairy farming with improved dairy cattle in Tanzania can be divided into three systems: i) rural smallholder dairy, ii) urban/peri-urban smallholder dairy, and iii) medium and large-scale dairy farming (Nell et al., 2014).

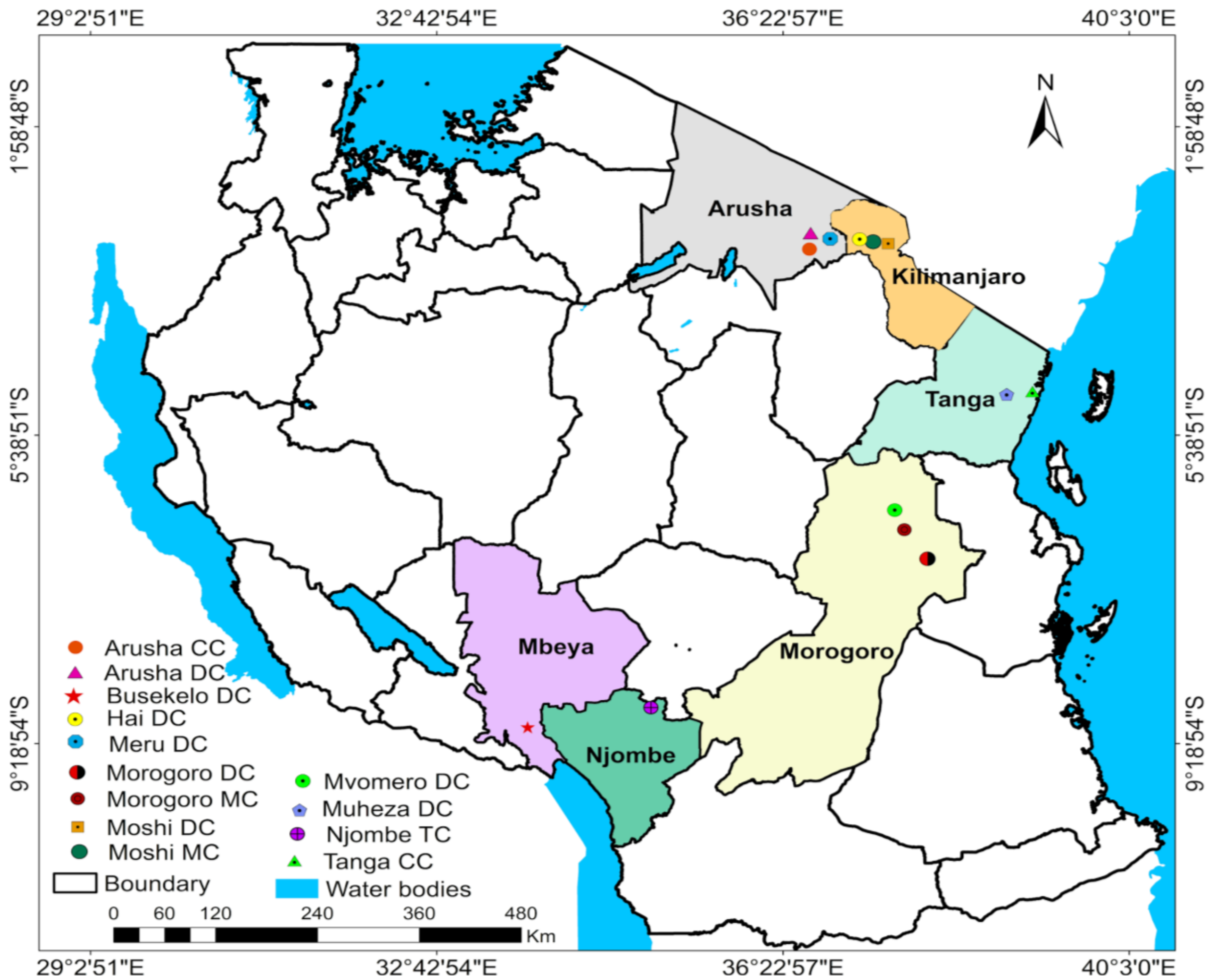

Figure 1. Map of Tanzania showing study regions: Southern Highland regions (Mbeya, Iringa and Njombe), Northern Highland regions (Arusha, Kilimanjaro and Tanga) and Morogoro. (**Key:** DC - District council, TC - Town council, MC - Municipal council and CC - City council).

2.1.1. Rural smallholder dairy farming

Almost 80% of dairy farms are rural smallholdings. These are generally mixed farms with both crops and livestock (Alonso et al., 2014; Nell et al., 2014). Traditionally, this farming system has been mostly practised in high-potential highland areas with cooler subtropical climates (Fernandes et al., 1984; Swai & Karimuribo, 2011; Kurwijila et al., 2012). Fertile soil, steep slopes and high rainfall characterise these areas. Typical smallholder dairy farming areas include Mount Kilimanjaro, Mount Meru, and the Pare mountains in the North; and, in the South, the highland regions of Iringa, Njombe and Mbeya (Spear, 1997; Kurwijila et al., 2012). Smallholder dairy farming is, however, currently practised all over the

Tanzanian mainland (Nell et al., 2014) and in Zanzibar (Suleiman et al., 2016), with smallholder dairying gradually expanding into areas outside of its traditional range (i.e. into the arid, semi-arid, sub-humid and humid areas of Tanzania (MLFD, 2010; Njombe et al., 2011).

Mean herd size in the smallholder farming system is ~4, ranging from 1 to 12 cattle per household (McDermott et al., 2010; Njombe et al., 2011; Alonso et al., 2014; Nell et al., 2014; Suleiman et al., 2016). Smallholders generally keep cattle under limited grazing systems, with feeding based on forages such as Napier grass (Pennisetum purpureum), cultivated along the farm boundaries, crop residues, and cut grasses from waste or communal land (Ngigi et al., 2010; Gillah et al., 2012, 2013a). Animals graze outside for several hours during the day and are then confined at night, when they receive supplementary feed (Gillah et al., 2013b). Farmers typically invest little in farm management, resulting in a generally low level of input into breeding (artificial insemination, bull services), animal health (veterinary care), and feed supplements and feed conservation (Nell et al., 2014). Supplementary feeds are derived from the main crops found on smallholder dairy farms. These include perennial crops such as bananas and coffee in the Northern Highlands (Kilimanjaro/Arusha), North-west (Kagera region), and the Southern Highlands (Iringa, Njombe, and Mbeya), as well as annual crops like maize and cereals in the central regions (Kurwiljila, 2010). These crops are principally grown for human consumption, but their by-products are fed to cattle.

The genotype of the dairy cows in rural smallholder dairy farming is mainly dairy *Bos indicus* (most commonly Friesian and Ayrshire) crossed with local *Bos taurus* breeds (Bee et al., 2006; Nell et al., 2014), with the occasional purebred dairy cow. The principal sources of improved heifers for most smallholders are dairy development programmes (DDPs), such as those in Tanga (Tanga Dairy Development Programmes), Kagera (Kagera Livestock Development Programmes) and the Southern Highlands Dairy Development Programmes (SHDDP); and Heifer-in-Trust schemes (Msangya et al., 2015). These schemes and programmes distribute crossbred (*Bos indicus x Bos taurus*) heifers/in-calf heifers to rural smallholder farmers (MLFD, 2010; Swai & Karimuribo, 2011; Nell et al., 2014; Msangya et al., 2015). Other less important sources include government organisations, i.e. Livestock Multiplication Units (LMUs) and National Ranching Company (NARCO) and Non-Governmental Organizations (NGOs) (MLFD, 2010).

Rural smallholder dairy farming is characterised by low levels of milk productivity, accompanied by low production costs due to the use of 'low-tech' solutions, management, and reliance on locally produced, low-cost feeds (i.e., a low-input, low-yield system) (Hemme & Otte, 2010). Generally, in smallholder dairy farming systems, cows have the potential to produce ~15 litres per day, but the average milk production is around only 8 litres per day (Kavana & Msangi, 2005; Kivaria et al., 2006; Hemme & Otte, 2010; Gillah et al., 2013b). The principal driver of this low milk production is likely underfeeding with feeds of poor nutritional value, as well as poor feeding management at critical times, especially during early lactation and the dry period (Kavana & Msangi, 2005; Gillah et al., 2013b). The cattle in such systems, therefore, have the potential to produce higher yields, but to do so would require improved nutrition and management (e.g. breeding management, calf rearing), as well as better animal health services and infrastructure (Msangi et al., 2005; McDermott et al., 2010; Alonso et al., 2014; Suleiman et al., 2016). The lack of infrastructure in rural Tanzania is a significant constraint on milk production, as direct marketing to consumers or manufacturers is limited, and smallholder farmers must rely on milk collecting centres or middlemen (Nell et al., 2014).

2.1.2. Urban and peri-urban smallholder dairy farming

Peri-urban dairy farming is found in the coastal belt, mainly near Dar es Salaam, Tanga, Morogoro and other urban centres, where many retired officers, civil servants and businessmen/women have taken up dairying as a means of generating either principal income (Kavana & Msangi, 2005) or additional income (Kurwiljila, 2010). Urban and peri-urban smallholder farms have a mean herd size of ~9 cattle (Gillah et al., 2013b). This does not differ much from that of rural smallholder farms, but farmers use more inputs, resulting in the production of more milk per cow: on average, ~10 L/day (Nell et al., 2014). Where grazing is used, it is usually more intensive than in rural smallholdings, but zero grazing is common. Animal genetics in this system is either purebred dairy (i.e. Friesian, Ayrshire or Jersey), or crossbreed (Gillah et al., 2013b; Nell et al., 2014).

As grazing land around the towns or cities is more expensive and less available, cattle are mainly stall-fed 'cut and carry' natural grasses, principally Napier grass (*Pennisetum purperium*) and Guatemalan gamagrass (*Tripsacum laxum*), as well as crop residues(maize and sorghum stover, rice straw and bean straw) (Kavana & Msangi, 2005; McDermott et al., 2010; Maleko et al., 2016). In this system, forage vending, where young boys cut forage from open areas/fallow land and sell it to smallholder dairy farmers, is very common, especially near large urban areas such as Morogoro or Dar es Salaam, with most of the forage transactions being made along the highways (Gillah et al., 2013b). The quality of naturally occurring green pasture is generally only moderate, with a mean *in vitro* digestible organic matter content of 56%, ranging from 55% to 70% during the rainy season and slightly lower during the dry season. A typical feed analysis for such pasture is: 35% dry matter; 12% ash in dry matter; 7% crude protein; 56% *in vitro* dry matter digestibility; 56% *in vitro* organic matter digestibility, and 9.0 $MJ/kgDM^{-1}$ of metabolizable energy (Kavana & Msangi, 2005). Thus, forage quality is a significant constraint on milk production near major cities (Kavana & Msangi, 2005). In other urban areas where land is more freely available (i.e. the highlands), most dairy farmers (~78%) produce much of their forage requirements from farm-established fodder units (Swai et al., 2005a), such that forage quality and quantity are less significant constraints.

Supplementation with energy-rich home-made concentrates is common in both lactating and dry cows (Gillah et al., 2013). The concentrates are typically made of maize bran and rice polish (60-70%), sunflower seed or cottonseed cake (~25%), mineral supplement (2%) and salt (1%) (Kashoma & Ngou, 2021). Supplementing early postpartum cows and pregnant cows in the last trimester ('steaming up' of dry cows) is most common in farmers with fewer than 10 cows (Mellau et al., 2009; Gillah et al., 2013b). Breeding practice is a mix of AI (either locally produced or imported semen) and natural mating using a bull (often borrowed from a neighbour) (Gillah et al., 2013b; Nell et al., 2014). Most dairy farmers in this system prefer natural service over AI (Gillah et al., 2013b) since unreliable AI services, low conception rates and high costs have put off many smallholder farmers from using the service (Msangi et al., 2005). In places where AI is abundantly used as the means of breeding (i.e. around the cities of Dar es Salaam, Arusha, and Mbeya), and urban and peri-urban areas in the highlands and Kagera, cows produce more than they do in the areas where AI is rare (Gillah et al., 2013b).

2.1.3. Medium and large-scale dairy farming

Medium and large-scale dairy farms are rare in Tanzania and account for only 5% of milk production (Nell et al., 2014). Many are government-owned farms, including LMUs (Sao Hill-Iringa; Ngerengere-Morogoro; Mabuki-Mwanza; Nangaramo, Mtwara and Kitulo dairy farm, Makete-Njombe), Livestock Training Agencies farm (LITA), and Universities (Sokoine University). There are also some medium and large-scale farms, which are either privately owned or belong to religious institutions (MLFD, 2010). Medium-sized commercial specialised dairy (CSD) (farms with more than 100 cattle to 450 cattle on average) have their input delivery systems (Mbwambo et al., 2019).

Genetically, most of the animals in these farms are purebred Friesian, Ayrshire or Jersey (Gillah et al., 2013b), with some crosses with Tanzania Shorthorn Zebu (Bee et al., 2006; Kanuya et al., 2006). The grazing system used depends on where the farm is located. In the highlands and less populated areas, where there is ample land available for forage production and conservation (in the form of hay or silage) for the dry season, grazing is generally extensive (Nell et al., 2014). On the other hand, in urban and peri-urban areas, zero grazing with the cut-and-carry system is the most common method (Gillah et al., 2012, 2013b). Medium- and large-scale farms predominantly use AI, with natural service or mating using farm-raised bulls being less common (Msalya, 2017b).

2.2. Management of fertility in dairy cows

Generally, the lactation curve of dairy cattle peaks at 40-80 days post-calving, followed by a progressive decline until the cow is dried off (Otwinowska-Mindur & Ptak, 2016; Atashi et al., 2021). This decline is more prominent in multiparous (multiparous cows) than in primiparous (primiparous heifers), which tend to have a flatter curve (albeit with a lower peak), so they remain producing yields near their peak yield for longer (Hudson et al., 2018; Atashi et al., 2021). Because of the lactation curve, the lifetime productivity of a dairy cow is dependent on the number of periods during which the cow is producing its peak milk yield. Optimising lifetime productivity (also maximising the contribution of grazing for maintaining lactation) under pastoral or low-input systems thus requires regular calving (i.e. one calf per year per cow, or one calf every 365 days: (Strandberg & Oltenacu, 1989; Burgers et al., 2021a). To achieve the goal of having one calf per year, cows must become pregnant in a short period after calving (Louca & Legates, 1968; Ghoribi et al., 2001): as the average gestation length of cattle is 282 days, the target average interval between calving and conception is <90 days (Louca & Legates, 1968; Silva et al., 1992).

Being an important aspect for determining the milk production pattern of a dairy cow, the lactation curve should underpin the farm management on productivity and management. Tanzanian dairy production is dominated by smallholder dairy cattle farmers, and cut-and-carry forage feeding is a common practice (Swai & Karimuribo, 2011). Even though the lactation curve of smallholder dairy cows is highly affected by nutrition, breed and diseases, they are still found to follow the standard pattern, i.e. with an initial rise in milk soon after calving, peaking around 4-6 weeks, followed by a gradual decline. Nonetheless, Dismas Said et al. (2022) reported that other herds had suboptimal curves with lower peak yields and a more post-peak rapid decline, which indicates inadequate nutrition and health management that undermines lactation persistence.

The interval between calving and conception depends on two factors: (i) the interval between calving and first breeding, and (ii) the interval between first breeding and conception. One of the key determinants of the length of the former is the interval between calving and when a cow becomes eligible to mate (voluntary waiting period: VWP). The VWP is determined by farm management and can be set either at the herd or individual level. VWP is highly influenced by the lactation curve (for individual cows) and by the replacement policy of a particular farm (VanRaden et al., 2004; Cassandro, 2014). In seasonally calving herds, where there is a defined breeding season, there is no VWP *per se*, as cows are bred as soon as they are observed in oestrus in the season, while those detected in oestrus before the start of the season are not bred until the beginning of the season. Culling is the final fate for cows that fail to become pregnant (Orpin & Esslemont, 2010). The decision about how long non-pregnant cows can be kept after calving is farm and system-dependent and also the cow's lactation persistency (Dekkers et al., 1998; Hudson et al., 2018; Burgers et al., 2021b).

2.3. Dairy development and its impacts

Over recent decades, major advances have occurred in the management, feeding and breeding practices of dairy cows. Genetic advancement has resulted in the development of heavier breeds that have larger abdominal capacity, are leaner and have a higher milk yield potential (MacDonald et al., 2007; Berry et al., 2014). Conversely, these animals also have challenges related to animal health and fertility, some of which have been exacerbated by genetic advancement, especially with high milk production (Royal et al., 2000; Pryce & Veerkamp, 2001; Walsh et al., 2011). Although the link between selection for milk yield and reduced fertility is clear at the population level, this does not mean that high-producing cows will necessarily have poorer fertility (Gutierrez et al., 1999; Weigel, 2006). Within the same system, high-producing herds, there could be a small proportion in the herd that will often have fertility that is as good as, if not better than, low-producing ones, and, in well-managed herds, high-producing cows will have fertility that is as good as, if not better than, their lower-yielding herd-mates (Kearney et al., 2004; Oltenacu & Algers, 2005). Currently, breeding programmes have started to include fertility traits to reverse the trend towards reduced fertility (Crowe et al., 2018) without reducing milk yield (Weigel, 2006; Marchitelli et al., 2017).

The other major change that has occurred globally on dairy farms in recent decades has been a dramatic increase in herd size (Butler, 2000; Galina & Orihuela, 2007; Crowe et al., 2018). This has been most pronounced in high-income countries, particularly North America (Hadley et al., 2002) and China (Fuller et al., 2005), but has also been observed in dairy-focused commercial farms in lower-income countries, including Tanzania (Kurwijila et al., 2012). The increase in the number of cows per herd has led to a decrease in the time spent monitoring an individual cow, as each farm worker is responsible for more cows (Waiblinger & Menke, 1999; Kerbrat & Disenhaus, 2004; Stevenson & Britt, 2017). This has had a substantial impact on the effectiveness of oestrus detection (Butler, 2000; Galina & Orihuela, 2007) and, hence, important fertility information, such as when cows come into oestrus and the characteristics of that oestrus, is often missing (Dobson et al., 2008). This commonly leads to mistimed insemination and missed oestrus (McLeod et al., 1991).

Traditionally, cows are monitored for visual oestrus signs such as ‘standing to be mounted’ (regarded as the primary sign of oestrus) by herd mates (Sveberg et al., 2015; Stevenson & Britt, 2017). A cow in oestrus also shows other signs referred to as ‘secondary’ oestrus signs, e.g. non-sexual behavioural activity and external genital changes (Yoshida & Nakao, 2005), which include mounting other cows; restlessness; swelling, relaxation and congestion of the vulva; clear mucus discharge, metoestral bleeding after oestrus and reduction of appetite and milk yield (Diskin & Sreenan, 2000; Lyimo et al., 2000; Sveberg et al., 2015). These signs can be observed before, during or after the period of true oestrus changes (Yoshida & Nakao, 2005). If cows are unable to display standing oestrus activity e.g. those kept in tie-stall barns (Firk et al., 2002; Sakaguchi, 2011), secondary signs can be used in identifying oestrus in the cow. Differences in climate, nutrition, and management can all influence the display of oestrus signs (secondary or primary), so consequently, there can be large variations in the characteristics of oestrous behaviour from place to place and region to region (Yoshida & Nakao, 2005).

Observation of cows by trained observers for 30 minutes twice a day (i.e. morning and evening) is usually sufficient to identify the optimal time for insemination (Van-Eerdenburg et al., 2002; Yoshida & Nakao, 2005). However, the proportion of oestrus animals that stand to be mounted has been declining, dropping from 80% to 50%, along with a reduction in the duration of oestrus from 15 to 5 hours (Dobson et al., 2008). This is coupled with an inability to detect heat due to poor oestrus expression and incorrect insemination time as a result of genetic factors that influence the development of the dominant follicle (Evans & Fortune, 1997; Aerts & Bols, 2010). These trigger the development of different methods to increase oestrus detection (Roelofs et al., 2010). For example, after calving, detection of first oestrus via visual observation should ideally be accompanied by regular (preferably every two weeks starting from 7-21 days postpartum) checks for uterus and ovary recovery. These reproductive checks that can use vaginoscopic examination, palpation per rectum/rectal scanning, and “metrichecking” cows at risk from endometritis are valuable. For the second oestrous cycle, observation of individual cows should be intensified starting from the 19th day after the previous oestrus (Yoshida & Nakao, 2005).

Artificial insemination is traditionally done based on the AM-PM rule, meaning that cows detected on oestrus in the morning are inseminated in the evening, while those detected in the evening are inseminated the next morning (Nebel et al., 2000). However, this rule is being increasingly questioned in systems where oestrus detection rates are poor (Diskin, 2018). Paradoxically, it may also be ineffective where oestrus detection rates are high: i.e. when a large proportion of animals being presented are in early oestrus (Xu, 2017). In such circumstances, it appears that a once-daily insemination regimen is as effective as twice daily and providing a twice-daily insemination service is likely to increase costs without necessarily improving insemination success (Xu, 2017).

Visual detection of oestrus can be hindered by housing and footing surfaces (e.g. concrete flooring), especially in intensively managed dairy cows (Britt et al., 1986; Dobson et al., 2008; Stevenson & Britt, 2017). Other studies have shown that large herd size affects heat detection efficiency and hence herd reproductive performance (Dobson et al., 2007; Dobson et al., 2008; Michaelis et al., 2014). The behaviour of a cow (i.e. dominant or subordinate) can also affect the effectiveness of oestrus detection, such that, for example, subordinate cows may have shorter oestrus length and /or be less willing to be mounted than the dominant cows in a group (Landaeta-Hernández et al., 2004). The impact of fewer staff and shorter, less intense oestrus expression is exacerbated in non-seasonal herds, where only a few animals come into heat at the same time (Van Eerdenburg et al., 2002; Kerbrat & Disenhaus, 2004). In contrast, in seasonal calving herds, the presence of larger sexually active groups (SAGs) helps in the detection of oestrus (Williamson et al., 1972; Kilgour et al., 1977; Sveberg et al., 2013). This tendency of cows in oestrus to approach and remain in the vicinity of other cows, even when other signs of oestrus are not expressed, is well-known among farmers (Sveberg et al., 2013). The SAG is normally comprised of cows that are in oestrus, those that are coming into oestrus (pro-oestrus), those coming out of oestrus (metoestrus) and some dominant cows (strangers) that, for unknown reasons, want to be in the SAG.

Multiple technologies have been developed for aiding the detection of oestrus, ranging from relatively cheap aids such as tail paint and heat mount detectors to more expensive technology such as pedometers and activity/rumination collars (Dolecheck, 2015; Talukder, 2015). The increased use of such technology has occurred alongside the development of computer software packages to capture, store, and analyse fertility data. Nevertheless, on many farms, human detection of oestrus remains the cornerstone of oestrus detection (The_cow_vets, 2000; DairyNZ, 2023). This is particularly so on smallholder dairy farms, which may depend on hired labour with little or no knowledge of oestrus detection.

2.4. Control of estrous cycle for improved fertility

The rate of detection of oestrus remains stubbornly low on many large-scale commercial dairy farms, especially in North America (Lucy, 2007; Saint-Dizier & Chastant-Maillard, 2012). This has led to the development of hormonal methods of oestrous cycle control so that observation of oestrus can be targeted (Hansel & Echternkamp, 1972; Hansel & Dowd, 1986), or, increasingly, the timing of AI can be fixed (Thatcher et al., 2006; Lucy, 2007).

Works on the control of the oestrous cycle using hormones started in the 1970s when studies reported how hormonal manipulations could control the oestrus cycle in cow, ewe and sow. Hormones such as progesterone, oestrogen, prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) and other intra-ovarian factors like cytokines were studied (Hansel & Echternkamp, 1972; Hansel

& Dowd, 1986). These studies laid the physiological groundwork for the manipulation of the cycle. However, with time, more practical protocols were established. The use of luteolytic agents such as $PGF_{2\alpha}$ signalled the age of 'targeted breeding' (Larson & Ball, 1992; Pursley et al., 1995). However, the use of $PGF_{2\alpha}$ only produces a luteolytic effect with no direct effect on follicular dynamics, resulting in the interval between $PGF_{2\alpha}$ injection and ovulation being too variable to ensure high conception rates with fixed time AI (FTAI) (Stevenson et al., 1987; Moore & Thatcher, 2006), particularly in parous animals. This led to the development of the ovulation synchronisation (Ovsynch) protocol, which combines $PGF_{2\alpha}$ with a gonadotropin-releasing hormone (GnRH) analogue (Pursley et al., 1995; Moore & Thatcher, 2006). This protocol is summarised in Figure 2. In this protocol, timed AI should occur 16 to 24 hours after the second GnRH injection. This protocol eliminates the need for detection of oestrus as it allows all treated cows to be inseminated using a single fixed time AI (Pursley et al., 1995). Since its initial development, the protocol has continued to evolve with changes made to produce greater synchronisation of lactating cows across more animals, to increase the conception rate to the FTAI (Pursley et al., 1995; Moore & Thatcher, 2006). As the ability of the first GnRH injection to induce follicle turnover is dependent on the age of the follicle, newer protocols have been developed that reduce the variability in the age of the dominant follicle at the first GnRH injection, e.g. 'presynchronisation' programs (Moore & Thatcher, 2006; Herlihy et al., 2012). In seasonally calving herds, where anovulatory anoestrus at the beginning of the breeding season is the major limiter to fertility, the addition of progesterone-releasing devices into the Ovsynch protocol has been used to increase conception rates (McDougall, 2010).

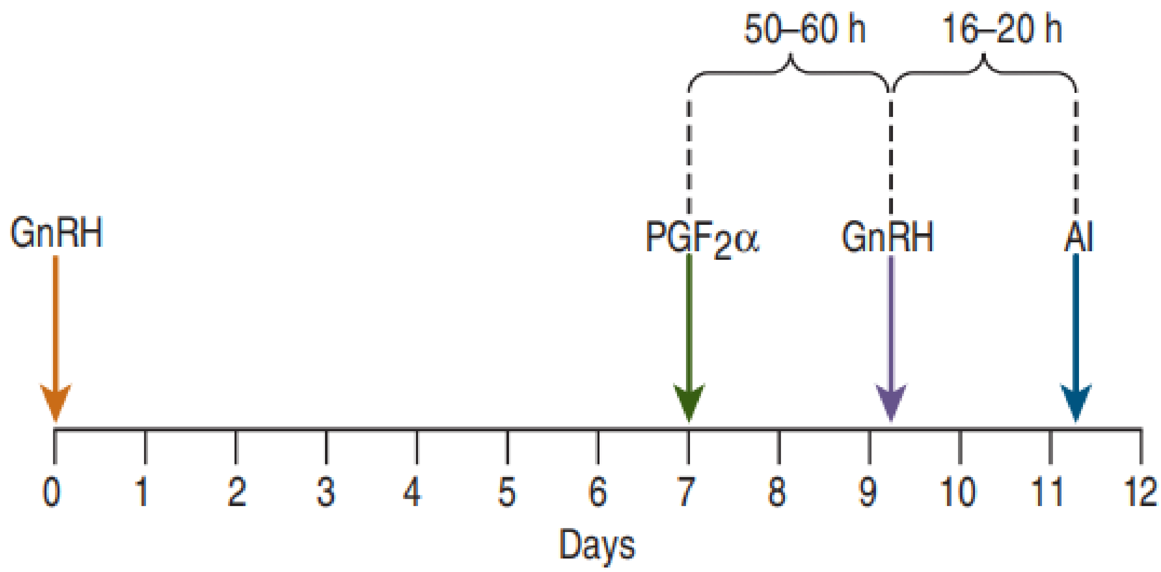

Figure 2. Ovsynch Programme - Protocol for oestrus-synchronisation, using a combination of GnRH and $PGF_{2\alpha}$ followed by a single fixed-time AI.

This focus on using hormones to control oestrus has become the main plank of dairy cow breeding and fertility management in many developed countries (Kim & Francisco, 2010; McDougall, 2010). However, in Europe, the blanket use of hormones to get cows pregnant has raised ethical and welfare concerns (Higgins et al., 2013a; 2013b). The principal issue is the requirement for multiple injections in cows without reproductive pathology. The standard Ovsynch programme requires three injections, but if a pre-synchronisation and resynchronisation programme is used, then cows can receive up to 10 injections before they are diagnosed as pregnant (Moore & Thatcher, 2006; McDougall, 2010; Stevenson & Britt, 2017) and considerably more if they fail to get pregnant the first or second time. The key criticism is that routine use of hormones occurs without identifying and correcting the issues underlying poor fertility (Higgins et al., 2013a), leading to sub-optimally fertile cows remaining in the herd and cows being selected based on their response to hormones rather than their underlying natural fertility (Higgins et al., 2013b). This difference between prevailing opinions in the US and Europe highlights the large differences in attitudes among stakeholders involved in dairy farming. The discussion also highlights that hormones can be a large source of income for veterinary practices, so shifting away from blanket hormone use will automatically reduce practice income (Higgins et al., 2013a).

In Tanzania, smallholder dairy farmers sometimes use hormones such as $PGF_{2\alpha}$ for oestrus induction so that they can effectively utilise the availability of AI or a service provider (veterinarian or AI technician) and improve the pregnancy rate (Mgongo et al., 2009). There is a paucity of published information on the use of hormones by smallholder dairy farmers and veterinarians in Tanzania. Still, anecdotally, veterinarians report using or advising the use of hormones. Nevertheless, hormone use will be very much more limited than in the US or Europe due to cost and availability (Mekonnen & Gebremariam, 2024). In other developing countries, control of the oestrous cycle using hormones has been reported for dairy cattle in Ethiopia (Mossie & Wondmnew, 2016; Fesseha & Degu, 2020). Reproductive hormones are used for synchronisation and treatment of repeat-breeder and anoestrus cows in Bangladesh (Ahammed et al., 2018), and as a tool for cross-breeding programs in twelve African countries (Kathambi et al., 2025).

2.5. Dairy cow reproductive management

There are fundamental changes taking place in dairy herd health management worldwide. These changes are needed as a result of changes in the technologies available for dairy cow reproductive management (Breen et al., 2019), alongside increases in the herd and farm size and productivity (McDougall, 2010; Crowe et al., 2018).

Genetic selection programmes in dairy cattle have been predominantly focused on milk production, at the expense of other traits such as health and fertility (Berry et al., 2014). The challenge of managing cows bred for milk production is also affecting Tanzanian dairy farmers, as they are now using such cows and their crosses (Njombe et al., 2011; Swai & Karimuribo, 2011; NBS&OCGS, 2021) that are affected by production-related health problems, e.g. increased susceptibility to mastitis, lameness, infertility (Shanks et al., 1978; Knight et al., 1999) and heat stress (Shehab-El-Deen et al., 2010; Giannone et al., 2023; Habimana et al., 2023; Ojo et al., 2025). The impact of breeding for milk production has therefore limited the development of dairy herds based on exotic dairy cattle in Tanzania. This is primarily because poor fertility has resulted in high rates of culling due to failure to reproduce and consequent low numbers of heifer replacements. This, in turn, has necessitated the continuous importation of replacement animals of exotic breeds (Msalya, 2017b), which has resulted in the continuation of challenges in Tanzanian dairy herds as the imported dairy cattle continue to succumb to disease and to underperform. For smallholders, such cattle are thus rightly seen as being demanding in terms of management, nutrition, and disease, which creates the impression that they and their F1 crossbreeds have little to offer the smallholder dairy farm.

During early lactation, high milk yield in improved dairy breeds is related to a high capacity to mobilise body reserves to produce milk (Tamminga et al., 1997). This mobilisation leads to negative energy balance (NEB). Cows with a higher genetic merit for milk production have longer periods of mobilisation of body reserves and NEB (Macdonald et al., 2008a), particularly when on forage-based diets. Longer periods of NEB lead to reduced body condition and are associated with increased disease and reduced fertility (Macmillan et al., 1996; Tamminga et al., 1997; Mulligan et al., 2006; Sheehy et al., 2017). There has been a significant focus on transitioning the cow from dry to lactating, but even in large-scale commercial dairy herds, the '*periparturient period remains a large hurdle to* *animal welfare, farm profitability, and dairy sustainability*' (Horst et al., 2021). It has long been recognised that the involvement of a veterinarian in the management of transition cows is thus important (Mulligan et al., 2006; LeBlanc, 2010), but Tanzanian smallholder dairy farmers have limited involvement of veterinarians in the management of their dairy cows (Alonso et al., 2014). This also exacerbates the proportion of crossbred dairy cows in Tanzania that succumb to reproductive disorders and production diseases (Muhairwa et al., 2014).

The development of the modern dairy cow and the management systems that go with that cow have changed the role of a veterinarian concerning dairy herd fertility. Whereas formerly the veterinarian focused on infectious causes of infertility (such as *Brucella abortus*), mineral imbalances (e.g. phosphorus and copper deficiencies), pregnancy checks, and hormonal treatments (Donofrio et al., 2007; Mee, 2007; Crowe et al., 2018), the focus, especially on larger farms (Fahey et al., 2002), has changed to whole herd management, performance metrics and non-infectious production disorders (Mee, 2007; van Belzen, 2017), with repeated evaluations of herd health status (Crowe et al., 2018). These changes have been seen principally on larger farms; even in Europe and North America, the changes on smaller farms have been less dramatic, and there is still a focus on the clinically based approach (Fahey et al., 2002; Mee, 2007).

In the Tanzanian situation, little has changed on smallholder farms. Veterinary or veterinary paraprofessional input is still rare and is almost always on a reactive clinical basis rather than on a proactive herd health approach. This reactive approach has also been reported in Kenya, Ethiopia, Nigeria and Uganda, where an insufficient number of trained professionals, high cost and bad infrastructure hinder the application of proactive reproductive or health services (Asrat et al., 2016; Faramade et al., 2016; Ilukor, 2017; Jaime et al., 2022). Conversely, improvements have been reported in some countries like Kenya, where farmers' cooperatives and integrated extension services have facilitated timely access to veterinary services, which have led to improved oestrus detection and general reproductive efficiency (Ojango et al., 2016). This underscores the need for combining policy support with localised delivery models to overcome systemic challenges in veterinary access across smallholder systems in the tropics (Otte et al., 2019).

2.6. Evaluation of herd fertility

Accurate assessment of herd fertility requires accurate recording of reproductive events (Fetrow et al., 2007; Stevenson & Britt, 2017). Precise and timely records are critical for the effective monitoring of the reproductive performance of both the individual dairy cow and the overall herd (Esslemont & Kossaibati, 2000). Key events that need to be recorded to be able to properly assess and analyse fertility for easy identification of problems and areas for improvement (Ghoribi et al., 2001) are shown in Table 2.1. On larger/modernised farms, computerised records can significantly aid fertility management, while on smaller farms, paper records can still be useful, especially when there is a person devoted to recording all the events required for fertility management.

Table 2.1. Events to be recorded in a dairy herd to facilitate effective monitoring of reproductive performance (Hudson et al., 2018)

Event	**Minimum Information**	**Additional Information**
Calving	Cow ID, Date	Level of intervention, calf outcome
Insemination	Cow ID, Date	AI/natural, sire, operator (for AI), Observed oestrus/FTAI
Pregnancy diagnosis	Cow ID, Date, Result	
Reproductive disease		Cow ID, Date
Oestrus but not inseminated		Cow ID, Date
Other veterinary examination		Cow ID, Date, result, Treatment
Culling	Cow ID, Date	

Interval-based measures (i.e. inter-calving interval (ICI), calving to conception interval (CCI) and calving to first service interval (CFSI)) have a few inherent limitations. One of these is the difficulty in selecting a denominator (or 'population at-risk') population for obtaining the interval data. In year-round calving herds, this is often done by selecting a cohort of cows that calved over a specified period. This is problematic in that not all cows in the cohort may yet have reached the end point for the interval: i.e. they may not have received a first insemination. Ideally, in the cohort selected, the outcome (or end point) should be known for every cow included (Morton, 2003; Hudson et al., 2012), but that means the analysis is delayed, so they may not (especially in non-seasonal herds) be currently relevant.

An alternative way of assessing fertility is the use of rate (risk)-based measurements, i.e. conception rate (CR), pregnancy rate (PR), oestrus detection rate (ODR), submission rate

(SR) and non-return rate (non-return to oestrus: NNR). Rate-based indices measure the proportion of cows in which a specified criterion is met in a specified time. Using rate-based indices, denominators in the population are usually more easily defined, and their calculation is not as retrospective as time-to-event indices. The key limitation of rate indices is that they may provide inadequate information about the population as a whole. For example, a low 21-day submission rate is less damaging if most cows not served within 21 days of becoming eligible receive a service within the next few days after this. Additionally, care must be taken that the denominator population does not become too small (Hudson et al., 2012; Jenkins et al., 2016).

Each measure of reproductive performance has its advantages and disadvantages; this is the reason why, when benchmarking fertility, a range of measures is normally used. For this review, the following fertility indices will be discussed: ICI, CCI, CFSI, CR, PR, ODR, SR and NNR. All of these indices are starting points to precipitate further examination and then identify the underlying parameters that are affecting them.

2.6.1. Inter-calving interval/index (ICI)

Customarily, the ideal reproductive performance of a pastoral dairy cow is characterised by its ability to produce one calf per year. Consequently, the inter-calving interval (ICI), the interval (usually recorded in days) between successive calvings for an individual cow, has been adopted as a standard measure of overall fertility performance during the lifetime of a dairy cow (Hudson et al., 2012; Cassandro, 2014) and has been used extensively to summarise the reproductive performance of a dairy herd. The mean inter-calving intervals of all cows in the herd at a specific time, calculated retrospectively from the most recent calving, are referred to as the calving index (Noakes, 1997). The optimal ICI is generally considered to be 365 days for animals managed at pasture, although Lehmann et al. (2016) suggested that extended intervals could have the same economic gain in animals with high peak yield and persistent lactations. Further, extended ICI as a result of extended lactation is becoming commonplace in non-seasonal herds of Holstein cows, which are capable of maintaining high yield for a longer time (Mellado et al., 2016) (also, because the primary market for milk is a liquid, sold to urban populations, where they catch a high price). Even though optimal values of ICI could be used as an indicator of reproductive performance (Schmidt, 1989; Plaizier et al., 1997). However, ICI might not be the most desirable direct measure of fertility (Cassandro, 2014), as it is an estimate of past rather than current reproductive performance. It also cannot be applied to cattle that have not yet calved twice (e.g. primiparous/nulliparous) (Upham, 1991).

To make the inter-calving interval more current and apply it to both cows and heifers, Fetrow et al. (1990) suggested the use of the projected/predicted inter-calving interval (PICI). The predicted inter-calving interval can be estimated once the cow has been confirmed to be pregnant (Fetrow et al., 1990; Upham, 1991; Noakes, 1997), while the predicted calving index is the mean predicted inter-calving interval of the herd.

Calving index can also be broken down into its components, e.g. calving to conception interval and conception to subsequent calving. These can also be summarised across the herd (Hudson et al., 2012), with the predicted inter-calving interval being obtained from the summation of two components: i.e. calving to conception interval and the interval from conception to subsequent calving (gestation length) (Fetrow et al., 1990; Hudson et al., 2012).

Hence, ICI = CCI + gestation length

If the CCI is 85 days and the gestation length is 280 days, the ICI is calculated as follows.

ICI = 85 days + 280 days = 365 days

The advantages and disadvantages of inter-calving interval and index are presented in Tables 2.2 and 2.3.

Table 2.2. Advantages and disadvantages of inter-calving interval/index

Advantages	Disadvantages
• The ICI indicates how closely the individual cow or herd approximates the accepted optimum of 365 days. • It is simple to evaluate and easy to understand.	• It is extremely historical/retrospective – it requires two consecutive calving dates, so on a herd calculation basis, events from as much as 2 years before are still used in the current calculation. It has substantial lag, because the outcome from reproductive management efforts can only be identified at the end of the next gestation period. • It introduces bias by excluding some populations, i.e. culled cows, first-lactation animals, animals pregnant but not yet calved and cows which are not to be bred for other reasons.

Table 2.3. Summarises the advantages and disadvantages of the predicted calving index

Advantages	Disadvantages
• The PCI indicates how closely the individual cow or herd approximates the accepted optimum of 365 days. • It is simple to evaluate and easy to understand. • It contains recent and prospective information. It includes first-lactation cows (primipara)	• It is highly affected by infertile cows, because infertile cows (cows that have had long intervals from calving but are not yet pregnant) are excluded from the calculation and artificially reduce the projected inter-calving interval (Meadows, 2005).

The average calving index in dairy cows is often much longer than the target 365 days, although there is significant variation between farms and in countries. For example, a survey of 500 Holstein herds in the UK identified a median calving index of 402 days, but the top 10% of herds had a calving index <380 days (Hanks & Kossaibati, 2012). In contrast, the median calving index in Ireland was reported as 387 days, with 10% of herds having a calving index of <365 days. There are only a few reports of the calving index of dairy cows kept in smallholder units and government farms in Tanzania. However, they all show that inter-calving intervals are far longer than the 365-day target: 477 days (Kanuya et al., 2000); 500 days (Swai et al., 2005b); 480 ± 2 days (Asimwe & Kifaro, 2007) and 476 ± 14 days (Swai et al., 2007).

2.6.2. Calving to conception interval (CCI)

Calving to conception interval is used as a more immediate measure of herd fertility than inter-calving interval. ICI is the sum of the calving to conception interval and gestation length. However, gestation length is not really a measure of reproductive efficiency, because it is hardly ever controlled by farm management, and variation around the mean is usually only of the order of a few days, even though gestation length is heritable and can thus potentially be manipulated by choice of bull (Jenkins et al., 2016). In contrast, calving to conception interval directly measures reproductive efficiency by measuring how quickly cows become pregnant after calving, and is directly influenced by farm management (Silva et al., 1992; Noakes, 1997; Aoxing et al., 2017).

Calving to conception interval provides similar information to that of calving index, but less retrospectively, as the endpoint of the interval is a successful service (usually confirmed by pregnancy diagnosis) (Noakes, 1997). Calving to conception interval is measured by counting the number of days from calving to the breeding that has resulted in pregnancy. i.e. usually the last recorded service (AI or natural) (Noakes, 1997; Hudson et al., 2012). Calving to conception interval is a useful measurement of reproductive performance, but it requires the following information:

i. Calving date
ii. Date of successful service / effective service
iii. A positive diagnosis of pregnancy

For the average ICI to be 365 days, the average CCI must be 85 days (assuming gestation length is 280 days) (Esslemont, 1992; Plaizier et al., 1997).

Calving to conception interval is, in turn, composed of the voluntary waiting period (VWP) and the interval between the end of the VWP and conception (Hudson et al., 2018). Voluntary waiting period is normally determined by farm management and is usually around 48-70 days after calving. At the herd level, CCI is normally expressed as an average. Since CCI data are usually right-skewed, median values are more representative and comparable than mean values (Hudson et al., 2012; 2018), especially if it is combined with a measurement of the spread of the distribution, such as the interquartile range. In seasonal-calving herds, the VWP is determined by the date of the start of breeding since all cows (usually regardless of calving date) are available for breeding after that date. In such herds, calculating the interval from the start of breeding to the first, or the successful, service is a useful measure of reproductive efficiency.

CCI can also be thought of as being composed of how soon after calving the cows are inseminated and how readily they become pregnant when they have been served (Laven, 2017).

Then, CCI can be expressed as:

CCI = calving to first service interval + interval from first service to conception

Thus, to achieve the 85-day CCI target, if the average calving to first service interval is 60 days, then the average interval from first service to conception needs to be <25 days.

The main limitation of CCI is that it only includes data from cows that have become pregnant and excludes cows that have failed to become pregnant or that are culled before becoming pregnant. An alternative to CCI, which does use such data, is 'days open'. Days Open is the same as CCI for cows that have conceived, but for non-pregnant cows, the number of Days Open is the interval between calving and culling for failure to get pregnant (Upham, 1991; Potgieter, 2012). Days Open are thus always longer than CCI, except if all cows get pregnant. Days Open is reported in the same way as CCI and is affected by the same factors (e.g. VWP, interval to first service, conception rate and oestrus detection), except that it is also influenced by the maximum interval between calving and mating or culling. A farm that allows cows to be served up to 400 days after calving will have longer Days Open than a farm that only allows 200 days.

Reports on CCI in dairy cows in Tanzania include those by Kanuya et al. (2000), who reported a median CCI of 221 days and a median days open of 267 days; and Lyimo et al. (2004), who reported a CCI of 123 ± 11 days. Table 2.4 below presents the advantages and disadvantages of calving to conception interval /days open.

Table 2.4. Advantages and disadvantages of calving to conception interval /days open

Advantage	Disadvantage
• It is an accurate measure of fertility because it is based on a positive diagnosis of pregnancy. • A simple figure that makes it easy to understand and fits into yearly planning. • DO only: includes data from cows that fail to become pregnant.	• The measure requires reasonable records and an accurate pregnancy diagnosis. • Management-related: A breeding policy to delay first service increases CCI and days open • CCI only: Does not include data from cows that fail to get pregnant

2.6.3. Calving to first service interval (CFSI)

Calving to first service interval is defined as the number of days from calving to the first service postpartum (Noakes, 1997). The two factors driving calving to the first service interval are the VWP and the interval between the end of that period and the first service.

The length of the latter period is determined by the cow's ability to display oestrus (or the interval between calving and the resumption of oestrous cycles), as well as the ability of farm management to detect the cows that are in oestrus (Hudson et al., 2018). Calving to first service interval is influenced by the following (Noakes, 1997):

i. The time taken to return to normal cyclical ovarian activity
ii. The detection of cows in oestrus after calving
iii. Type of cow –Primipara and high-yielding cows frequently have longer intervals to first service
iv. The need to alter or maintain the calving pattern of a herd, for example, changing calving time in pasture-based cows.

In seasonally calving herds, calving to first service interval is generally of less value as a fertility measure, as the critical measure in such herds is the proportion of cows bred after the start of the mating period (submission rate) (Laven, 2017).

For most cows, the interval to first service from the end of the VWP is shorter than the VWP. This is because cows will come into oestrus at a random interval after the VWP. On average, if all cows cycle and all cows are detected in oestrus, this will be ½ of the inter-oestrus interval (~11 days), so for a VWP of 60 days, the average calving to first service interval (CFSI) should be 71 days. However, as not all the cows in a cohort will cycle and not all cyclic cows will be detected in oestrus, then the herd average interval between the end of the VWP and first service will usually be longer than 11 days. As with the previous measures, data for calving to first service interval are right-skewed, which means that median values are more useful than mean values for assessing herd performance (Hudson et al., 2018). The same argument applies in seasonal herds regarding the interval from the start of mating to first service.

The main difference between CCI and CFSI is that the former requires successful insemination. The difference between CCI and CFSI is thus a reflection of the success of insemination. If the difference is small, then it means that most cows conceived after the first service, and when it is large, it indicates that many cows required subsequent inseminations. Moreover, CFSI can be used to evaluate the efficiency of oestrus detection, i.e. shorter intervals may imply good oestrus detection as more cows are submitted earlier for service, but this is dependent on oestrus detection being accurate.

The targeted average CFSI should be between 65 and 75 days, as when combined with effective service, this can still enable the farm to have one calf per year (Laven, 2017). Values of CFSI so far reported in Tanzania are greater than this target: 155 days (Kanuya et al., 2000) and 87 ± 9 days (Lyimo et al., 2004). Table 2.5 below presents the advantages and disadvantages of calving to the first service interval.

Table 2.5. A summary of the advantages and disadvantages of calving to the first service interval

Advantage	Disadvantages
• Prospective - target set for breeding that can be used for early identification of problems	• Management-related, as breeding policy is key. The set VWP directly affects the calving to first service interval, with VWP often being dependent on factors such as age and milk yield that are not directly related to fertility • Needs first insemination recorded – not directly measurable using pregnancy diagnosis, as opposed to calving to conception interval • Ignores conception rate – CCI can be long if CR is low, even if CFSI is short

2.6.4. Submission rate/risk (SR)

Submission rate/risk measures how quickly cows are served after the end of VWP, or, in seasonal breeding herds, after the start of the breeding period (Hudson et al., 2018). It is defined as the number of cows/heifers served within a specified period, i.e. 21- or 24-day period, expressed as a percentage of those eligible for service at the start of the period (Hudson et al., 2012). A good submission rate should be between 80 and 90% (Noakes, 1997), and it is best measured in cows that have not yet been inseminated (Table 2.6). High SR is obtained when there is good oestrus detection and a high proportion of cows have resumed oestrous cycles (especially immediately after the end of VWP or the beginning of the breeding period in seasonal calving herds) (Inchaisri et al., 2011; Ma et al., 2022). Factors like anoestrus and/or endometritis may markedly reduce submission rates, even if there is good oestrus detection. Therefore, identifying the cause of a low submission rate is important, particularly in determining the respective roles of poor oestrus detection and anovulatory anoestrus.

A relatively simple method of obtaining a fairly accurate measurement is to list all cows that are ready for service (at or beyond the VWP) at the start of each 21-day service period. At the end of the service period, the percentage submission risk/rate can be calculated as follows:

$$\text{Submission rate (\%)} = \frac{\text{No. of cows or heifers served within a 21-day period}}{\text{No. of cows or heifers eligible for service at the start of the period}} \times 100$$

Another method is to list all cows chronologically in order of the calving date. Then, add 21- or 24-days to the VWP, i.e. for a VWP of 45 days, every cow should be served before the target date of 66 or 69 days postpartum. The percentage SR can then be calculated as follows:

$$\text{Submission rate (\%)} = \frac{\text{No of cows served on or before the target date}}{\text{No. of cows that should have been served on or before the target date}} \times 100$$

Table 2.6. A summary of the advantages and disadvantages of the submission rate

Advantages	Disadvantage
• Submission rate is used to create an ongoing, updated rolling average. • It lacks bias (compared to calving to first service interval) as it includes all the eligible cows, not only those that have had first service. • Has less momentum - shows trends over time more effectively (compared to calving to first service interval).	• For cows that were not submitted during the observation period, submission does not provide information on how long these 'failures' take to be inseminated for the first time. • Does not differentiate between accurate and inaccurate oestrus detection (submission)

Submission rate can also be calculated for a specific service, i.e. first service submission rate. First service submission rate (usually defined as the proportion of cows inseminated within the first 24 days after the end of the cow's VWP) is the most widely used, particularly in seasonal systems. This submission rate shares one advantage with calving-to-first-service interval: it identifies how soon cows are served once they are eligible for insemination (Esslemont & Ellis, 1974; Esslemont, 1992; Ball & Peters, 2004). The submission rate for Tanzanian smallholder herds has not been reported.

2.6.5. Oestrus/heat detection (ODR)

In herds using AI, improving the detection of oestrus generally has a much greater influence upon reducing the calving-to-conception interval than improving the proportion of inseminations which produce a pregnancy. Effective oestrus detection enables herd managers to anticipate the time of a subsequent oestrus and thus improves the detection rate (Table 2.8). It also enables early detection of acyclic cows after the end of VWP or the beginning of the breeding period in seasonal calving herds (Ball & Peters, 2004; Roelofs et al., 2005; Layek et al., 2011). Oestrus detection has a direct influence on the number of cows/heifers that are presented for insemination/service (submission rate). Therefore, submission rate is commonly used as a primary measure of oestrus detection (LeBlanc, 2007; Walsh et al., 2011; Laven, 2017).

Oestrus detection depends on the ability of a cow to show oestrus, and once it does, the probability of it being detected. A comprehensive review of the factors affecting oestrous behaviour and its detection is beyond the scope of this chapter; however, both are influenced by a wide range of factors. Factors contributing to poor oestrus expression include nutrition, housing, milk yield, genetics, and disease (Dobson et al., 2008). Other factors, including poor building layout, insufficient time spent observing cows and limited staff training, can also lead to a reduced probability of cows in oestrus being detected (Van Eerdenburg et al., 2002; Kerbrat & Disenhaus, 2004; Machado et al., 2010).

When assessing the effectiveness of oestrus detection, two aspects are crucial: (i) the proportion of cows that are truly in oestrus and correctly detected (i.e. sensitivity) and (ii) the proportion of cows detected in oestrus that are not actually in oestrus (i.e. false positive or specificity error) (Upham, 1991; Fetrow et al., 2007; Fodor & Ózsvári, 2015). However, neither of these is simple to measure. Oestrus detection intensity (ODI) is the proportion of eligible cows/heifers that should be coming into oestrus that are detected in oestrus (Upham, 1991; Fetrow et al., 2007; LeBlanc, 2007; Fodor & Ózsvári, 2015). However, the degree to which oestrus detection intensity accurately reflects the true proportion of cows in oestrus that are detected depends on the population chosen, in particular, whether the eligible cows cycle within the observation period. For example, in seasonal calving systems, this issue can be recognised by identifying a cohort of cows (older cows that have calved at least 8 weeks before the start of the mating season) that have a very high likelihood of being in oestrus within 3 weeks of the start of the mating season and calculating the proportion of those observed in oestrus for 3 weeks (Diskin & Kenny, 2014; Laven, 2017).

Like submission rate, ODI is best measured in cows that have not yet been inseminated. ODI is very similar to the submission rate, unless a high proportion of eligible cows seen in oestrus are not inseminated. Ensuring that only cows in true oestrus are submitted for service (i.e. cows are not recorded as being in oestrus when they are not) requires additional testing, such as progesterone testing (Foulkes et al., 1982; Blavy et al., 2016). Cows in oestrus have very low milk progesterone concentrations, but if the cow is not actively cycling (i.e. it is in anoestrus), then milk progesterone concentrations can be low even though the cow is not in oestrus.

Measurement of inter-oestrus intervals allows oestrus detection efficiency (ODE) to be calculated. This is perhaps the best overall measure of the quality of oestrus detection. ODE is calculated from the percentage of all intervals within each category (see Table 2.10). A high proportion of intervals should be between 18 to 24 days (or integer multiples of that figure, e.g. 36-48 days (Noakes, 1997; Hartigan, 2004; Forde et al., 2011). Table 2.7 presents the categories of interservice/inter-oestrus interval.

Table 2.7. Categories of interservice/inter-oestrus interval (Hudson et al., 2012)

Category	Interval (days)	Remark
a	2-17/<18	1-day interval excluded (often indicates cows served when not truly in oestrus, can also be produced by cows with follicular cysts)
b	18-24	Normal interval length (likely to represent correctly detected heats with no missed oestrus in between)
c	25-35	Inaccurate interval/return at an extended interval (may represent late embryonic death, incorrectly identified/missed estruses, or the use of prostaglandin after an early negative pregnancy diagnosis)
d	36-48	Double normal interval length (likely to represent correctly identified heats with a missed oestrus in between)
e	>48	Could represent more than one missed heat, or fetal death/abortion (also difficult to interpret, except by reference to a threshold percentage)

Therefore, oestrus detection efficiency is expressed as follows:

$$\text{Oestrus detection efficiency (\%)} = \frac{b+d}{a+b+c+2(d+e)} \times 100$$

Table 2.8. A summary of the advantages and disadvantages of the oestrus detection rate (ODR)

Advantage	Disadvantages
• All eligible cows are included in the calculation	• It does not include oestrus detection accuracy (i.e. it includes false positives) and thus may overestimate the true detection rate if a large number of cows with short inter-service/interbreeding intervals are included in the calculation • It is inapplicable when hormonal synchronisation programs are carried out because the cows' oestrous cycle is manipulated

When interpreting oestrus detection rates, it is important to take care when interpreting values that are higher than is normal for the system, as this could mean that a large proportion of the cows being bred are not in true oestrus (Fodor & Ózsvári, 2015; Laven, 2017). If this is the case, then the proportion of inseminations that result in a pregnancy will be low. In contrast, if only cows with definitive signs of oestrus (true oestrus) are detected, then oestrus detection rates will be low, but the proportion of inseminations that result in pregnancy will be high (Fodor & Ózsvári, 2015). Poor oestrus detection can be inferred when a large percentage of cows that are not pregnant are presented for routine pregnancy diagnosis at 6-8 weeks post breeding (Noakes, 1997).

2.6.6. Non-return rate (NRR)

Non-return rate depends on the complete recording of subsequent inseminations (Rycroft & Bean, 1992; Miglior et al., 1998; Weigel & Rekaya, 2000). It is defined as the percentage of inseminated cows that are not re-presented for insemination within a set period of time, usually ranging between 30 to 60 days. It is thus an estimate of the proportion of cows that conceive to each insemination (LeBlanc, 2007; Santos et al., 2009; Laven, 2017). It is most useful as a measure of reproductive performance when the outcome of the insemination is not definitively known (Table 2.9). Thus, AI services use non-return as a proxy for conception rate, as the final outcome of the insemination is not known to them. As calculated in AI services, NRR is characteristically higher than CR or PR by a fixed proportion that varies between seasonal/non-seasonal calving systems (and the NRR interval). (Foulkes et al., 1982; Morton, 2010)

Table 2.9. Advantages and Disadvantages of Non-Return Rate

Advantages	Disadvantage
• It is cheap, i.e. only requires insemination records • It is quick, i.e. fertility data obtained within 30-60 days	• It is inaccurate as it does not take into account the final pregnancy rate

2.6.7. Conception rate (CR)

The risk of a cow becoming pregnant after insemination (usually after a single insemination) is usually referred to as the conception rate (Trimberger & Davis, 1943; Upham, 1991; Ferguson & Galligan, 1999; Laven, 2017). However, the proportion of cows that conceive (i.e. have a fertilised embryo), is much greater than the proportion of pregnant cows at the time of pregnancy diagnosis (Noakes, 1997; Ferguson & Galligan, 1999), so it has been suggested that it should be referred to as pregnancy rate (risk) (Noakes, 1997; Hudson et al., 2018). However, the term is used for the proportion of eligible cows becoming pregnant over a defined period (Section 2.6.8); the term conception rate is still used for the percentage of inseminations that result in pregnancy. The difference between conception rate and pregnancy rate is summarised in Table 2.10.

To determine the conception rate, dates of every service must be collected and documented. The date of conception for each pregnant cow must also be recorded, based on pregnancy diagnoses. This will usually, but not always, be the date of the last service, so ideally, pregnancies should be aged, not just confirmed. Conception rates at first service are often specifically recorded because such a measure will include all the eligible cows/heifers (every inseminated cow will get a first service). First service conception rate is defined as the number of first services resulting in a pregnancy as a percentage of the total number of first services given over a certain period (Upham, 1991; Noakes, 1997; Fodor & Ózsvári, 2015). First service conception rates tend to be higher than subsequent conception rates, as cows with inherently good fertility are more likely to conceive to their first service than cows with poor fertility, so for second and later inseminations, there is a higher proportion of cows with poor fertility or fertility problems. However, in the presence of high levels of untreated postpartum disease, first service CR can be low, whilst that of later services can be higher if the cows have recovered and properly established cycles. Conception rate (CR) is calculated as follows (with services per conception being the inverse of CR):

$$CR = \frac{\text{Number of cows or heifers that become pregnant}}{\text{Total number of cows or heifers inseminated}} * 100$$

Mean conception rate has been reported as 30% in the US (Norman et al., 2009), 32% in the UK (Hanks & Kossaibati, 2012), 38% in Australia (Brownlie et al., 2011), and 48% in New Zealand (Brownlie et al., 2014).There are no reports on the overall conception rate on smallholder dairy farms in Tanzania, but Kanuya et al. (2000) reported that the first service pregnancy rate was 25% and 67% under AI and natural service, respectively.

2.6.8. Pregnancy risk/rate (PR)

Pregnancy risk/rate is an important aggregate measure of reproductive performance (Fetrow et al., 2007; Stevenson & Britt, 2017). It is defined as the proportion of cows that are eligible for breeding and become pregnant during a specified period. The most commonly used period is 21 days (VanRaden et al., 2004; Fetrow et al., 2007; Stevenson & Britt, 2017), because the average oestrous cycle length of a dairy cow is 21 days, so a 21-day period represents one chance for a cow to become pregnant (VanRaden et al., 2004). The 21-day PR is the main determinant of the economic returns associated with reproduction (Ferguson & Galligan, 1999).

Irrespective of the period used, PR is dependent on the detection of oestrus and the proportion of cows that become pregnant after insemination (conception rate/risk). Failure to detect cows in oestrus results in few cows being submitted for AI, combined with a low CR, which results in very low PR and poor reproductive efficiency. Higher milk production has been associated with lower CR and with less pronounced oestrus behaviour and shorter expression of oestrus, and thus a decline in PR (Weigel, 2006; Mackey et al., 2007; LeBlanc, 2010).

Pregnancy rate is determined by taking the total number of cows that become pregnant during the stated period out of the total number of cows that were eligible to become pregnant during that period (Hudson et al., 2018).

$$PR21 = \frac{\text{Number of Cows became pregnant in a 21-day period}}{\text{Number of cows eligible to become pregnant at the start of that 21-day period}} * 100$$

Identifying the cows that become pregnant just requires regular pregnancy diagnosis of all inseminated cows. Identifying the eligible cows is more complex. According to Fetrow et al. (2007), the eligible cow should have the following features:

- Has passed her voluntary waiting period (VWP)
- Confirmed as being open (non-pregnant) at the start of the period of interest.
- Not flagged as a “do not breed” cow during or immediately before that period.

In smallholder dairy farming (where breeding is not synchronised), there is generally limited record keeping and few animals per household, so determining the proportion of adult pregnant cows at a regular interval could be the best way of evaluating the reproductive performance of cows in a particular area.

$$PR\ (\text{population}) = \frac{\text{Number of pregnant adult cows}}{\text{Number of adult cows eligible that could be pregnant}} \times 100$$

Table 2.10. Comparison of conception rate and pregnancy rate

Conception rate	Pregnancy rate
• The number of confirmed pregnant cows divided by the total number of cows inseminated/serviced (proportion that conceives per insemination). For example, if, in a herd of 120 eligible cows, 100 cows are bred and 35 become pregnant, the CR is 35 per cent. **NB:** For this calculation, the number of eligible cows is not considered; instead, only those that were inseminated/ served.	• The number of confirmed pregnant cows divided by the number of cows eligible to be inseminated/serviced in a specified period (proportion that conceive by the end of the breeding season). For example, if 35 pregnancies are confirmed and there are 120 eligible cows to be bred by the end of the breeding season/breeding period, then the PR is 20.8 per cent. **NB:** This calculation does not consider how many cows were inseminated/ served.

Table 2.11. Advantages and disadvantages of pregnancy rate/risk

Advantages	Disadvantages
• It is accurate as it is based on confirmed pregnancies. • It has a limited time lag between the start of the assessment period and the analysis of data, provided regular early pregnancy diagnosis is undertaken. • If eligible cows are accurately defined, then PR includes data from all relevant cows, not just those that become pregnant, but also those that have been inseminated or those that have remained in the herd	• It requires accurate recording, i.e. recording must include all services and not just the most recent one. • Requires regular early pregnancy testing. • Does not directly identify how soon cows become pregnant after calving, making it less informative in herds with wider variability in calving to breeding intervals. So it may be better suited to a herd using a high proportion of synchronisation where breeding timing is more standardised.

2.7. Body condition and fertility of dairy cattle

Dairy cows experience dynamic changes in their body weight and condition during the lactation period. These changes are caused by the imbalance between energy intake and the high physiological demands of milk production. Dairy cows enter a state of negative energy balance (NEB), which leads to loss in body condition during early lactation, followed by a gradual recovery in the mid to late lactation (Butler & Smith, 1989; Roche et al., 2009).

Because cows generally lose BCS after calving (although this can be mitigated by calving at the BCS that is optimal for the system, and by fully feeding in early lactation), cows that calve in low BCS will be at severe risk of impaired resumption of ovarian activity and lower conception rates, as well as increased risk of succumbing to reproductive disorders like metritis and anoestrus (Butler, 2000; Roche et al., 2007). There is also overwhelming evidence showing that the reproductive performance of dairy cattle has been impaired by genetic selection for high milk yield (Pryce & Veerkamp, 2001; Veerkamp et al., 2003; Dillon et al., 2006; Lucy, 2007). Single trait selection for high milk yield has resulted in the decline of fertility in dairy cows, with its negative effect being widely experienced across various management systems having different levels of nutrition (Royal et al., 2000; Lucy, 2001, 2007). The major genetic change that has driven this negative relationship has been the increased ability of the modern dairy cow to utilise body tissue stores to produce milk, which has led to a greater and more persistent negative energy balance (NEB) in early lactation (Butler & Smith, 1989; Roche et al., 2009). Investigation of this phenomenon has highlighted the importance of body condition score (BCS) in both production and fertility (Pryce et al., 2000; Roche, 2006). The NEB have also been shown to associate with the impaired growth and functions of ovarian follicles, in particular the dominant follicle by altering the endocrine environment: mostly by reducing the levels of circulating insulin, IGF1, and LH levels and finally delaying ovulation and reducing conception rate (Beam & Butler, 1999; Lucy, 2008; Sheehy et al., 2017).

2.7.1. Body condition score (BCS) and fertility of dairy cattle

Body condition was originally defined as the ratio of body fat to non-fat components in the body of a live animal (Murray, 1919). Body condition score (BCS) is an estimate of a cow's fat reserves, which categorises cows on a range from emaciated to obese (Jefferies, 1961; Edmonson et al., 1989; O' Leary et al., 2020). This is a semi-quantitative method for evaluating body fat in an animal and is used in dairy cow management as a tool for decision-making by dairy producers (Whay et al., 2003). Body condition score provides an indirect indication of likely fertility due to its strong relationship with the inter-calving interval (Pryce et al., 2000; Dal Zotto et al., 2007) and the duration of anovulatory anoestrus (Royal et al., 2002; Berry et al., 2003). Reports show that thinner cows are more likely to have longer inter-calving intervals, probably because they are more likely to be sustaining milk production at the cost of mobilising their body tissue and are, thus, yielding milk at the cost of reproduction (Pryce et al., 2000; Roche et al., 2007). For the same reason, low BCS at the time of calving or excess loss of BCS after calving are also associated with a prolonged postpartum anoestrous interval, thereby reducing the length of the effective breeding season and the chances of a cow becoming pregnant (Roche et al., 2007).

Intense transgenerational genetic selection for early lactation and total milk production has occurred in dairy cows (Dillon et al., 2006). This has brought about many physiological changes that enable more mobilisation of energetically important tissues in dairy cows (Chagas et al., 2007; Lucy et al., 2009). This implies that genetic selection for high milk yield in dairy has modified their key endocrine pathways, especially those involving growth hormone (GH), insulin and insulin-like growth factors (IGFs) (Lucy, 2001). The elevated GH and reduced circulating insulin cause excessive tissue mobilisation, which leads to hypoglycaemia (Chagas et al., 2007). The suppressed activities of insulin and IGFs impair follicular growth and the function of the corpus luteum, which further compromises the reproductive efficiency of a dairy cow (Lucy, 2001; Chagas et al., 2007).

Further, BCS is strongly associated with the health and performance of a cow: for example, metabolic disorders, lameness, and infertility rates increase when cow condition deviates from the recommended range (Bewley & Schutz, 2008; Somers et al., 2015). BCS is affected by cow-level factors, including parity (Berry et al., 2003; Roche et al., 2007), age within parity (Pryce & Harris, 2006), and season of calving (Pryce et al., 2001), as well as managemental (herd-level) factors, including stocking rate (McCarthy et al., 2007; Macdonald et al., 2008a), level of feeding (Roche et al., 2007), and the type of diet (McCarthy et al., 2007; Roche et al., 2007; Berry et al., 2008).

2.7.2. Measurement of BCS

There are several body condition scoring scales (scoring charts) available in the field, most of which were introduced in the 1970s and 1980s. Most scoring systems involve the palpation of the lumbar vertebrae and around the tail head (Lowman et al., 1973; Wright & Russel, 1984). Other body parts may also be included in the scoring systems to provide a broad picture of the energy reserve status of the cow. Commonly used parts include the thoracic and vertebral region of the spinal column (chine, loin, and rump), the ribs, the spinous processes of the lumbar vertebrae, the tuber sacrale (hip or hook bones), the tuber ischii (pin bones), the cranial coccygeal vertebrae (tail head), and the thigh region (Roche et al., 2004). A multiplicity of scoring systems has been proposed (Bewley et al., 2010), e.g. 1 to 5 in the UK (Mulvany, 1981); 1 to 8 in Australia (Earle, 1976); 1 to 5 in the USA (Edmonson et al., 1989); 1 to 9 in Slovenia (Klopčič et al., 2011) and 1 to 10 in New Zealand (Stockdale, 2001; Roche et al., 2004).

Irrespective of the scale that is used to score the body condition, the lower values in the scale reflect emaciation (thin cows, i.e. it has sharp bones and no palpable fat cover around the tail head, whilst higher values equate to obesity (fat cow), i.e. a cow that is excessively fat (Roche et al., 2004). Whichever scoring scale is chosen; it is best to identify the scale by referencing the highest number. For example, an animal with a BCS of 5 would be obese on a 1-5 scale (5/5) and ideal weight on a 1-9 scale (5/9), and a cow with a BCS of 3 would be ideal on a 1-5 scale and thin on a 1-9 scale.

Body condition scoring can be undertaken manually or by automated means using technologies such as infrared (Coffey et al., 2003) or digital cameras (Bewley & Schutz, 2008). In a manual system, the scorer either visually assesses the cow's body shape and/or palpates and feels a defined anatomical region (Roche et al., 2004). Potential disadvantages of the manual technique include subjectivity, the time needed for scoring many animals, and the requirement for trained personnel to perform it accurately. Even with highly trained scorers, variation between scorers and within an individual scorer may limit the ability to accurately detect small changes in body condition (Roche et al., 2009; Vasseur et al., 2013). For the scope of this review, a scale of 1-5 is summarised in Table 2.12, but a scale of 1-9 is added to provide more details during scoring.

Table 2.12. A summary of body condition scoring systems and their descriptions

(Wildman et al., 1982; Nicholson & Butterworth, 1986; Williams & Buzhardt, 2021)

Number Score		Nominal score	Description
1 to 5	1 to 9		
1	**1**	**Emaciated**	Ribs, backbone, and pelvic bones are highly prominent. No fat cover. Muscles are severely wasted. Deep hollow around the tailhead. Backbone sharply ridged; hip and pin bones angular.
	2	Very thin	All ribs, backbone, and pelvic bones are easily seen and felt. No fat deposits, slight muscle loss. Deep V-shaped hollow between the pin bones and the tailhead.
2	**3**	**Thin**	Ribs, hip bones, and backbone are easily palpated and somewhat visible. No fat cover. Pin bones are pointed. The thigh area shows a deep indentation.
	4	Borderline/underweight	Fore ribs are less noticeable but still palpable. Slight fat deposits over ribs and backbone. Pin and hip bones are still angular. The tailhead area shows a shallow V.
3	**5**	**Moderate/Ideal**	12th and 13th ribs no longer visible. Backbone ridge softens. Thin fat covers over ribs and hips. The thigh is more rounded. The area around the tailhead is slightly hollow but not deep.
	6	Good/overweight	Ribs and backbone are well covered with a spongy fat layer. Hip bones are rounded. Pin bones begin to round off. The tailhead area appears U-shaped. The thigh is flat to slightly rounded.
4	**7**	**Very good/heavy**	Ribs and pelvis are difficult to palpate. Fat cover is thicker and spongier, especially around the tailhead. Pin bones tap-like. The thigh is well-rounded.
	8	Fat/obese	Thick, spongy fat over ribs, pelvis, and backbone. These landmarks are hard to detect even with pressure. The area between the tailhead and the pins is filled. Thighs are very rounded.
5	**9**	**Obese/severely obese**	Very thick fat layer throughout the body. Ribs and backbone not palpable. The abdominal area distended outward and downward. Fat deposits over the hips, tailhead, face, and legs.

Ferguson et al. (1994) reported the accuracy of estimating fat reserves in dairy cows by using BCS. They showed that accuracy is high if the cow falls in the middle range of the scale, i.e. on a 0-5 scale, BCS can be scored with an accuracy of 0.25 points if the score is between 2.5 and 4.0, but outside of this range, the accuracy is 0.5. This highlights the weakness of the association between subjective BCS assessment and total fat stores in thin cows (it could also reflect that people rarely see BCS 1, 2, 8, 9, 10 on the 1-10 scale) and, probably, the inability to accurately assess total reserves (intra-abdominal as well as subcutaneous) in very fat cows. Similar findings were reported by Roche et al. (2004) for the 1-10 scoring system used in New Zealand. The other factor influencing the accuracy of BCS assessment is whether the score given was based on tactile or visual appraisal of the cow, with the former being more accurate (Roche et al., 2004).

2.7.3. BCS in Tanzanian dairy cattle

In Tanzania, the monthly mean BCS of lactating high-producing dairy cows (cross-breeds) was reported by Lyimo et al. (2004) as 3.1 ± 1.3 (1-9 scale: Nicholson & Butterworth (1986)). This was satisfactory but below the average (4.5, on a 1-9 scale) and the optimal score of ≥5. Lyimo et al. (2004) also reported large fluctuations in cow condition throughout the year, with the lowest BCS being recorded in the dry season when cows are often poorly fed (i.e. low-quantity and poor-quality feeds). In contrast, Phiri et al. (2007) reported that optimal body condition scores were much more commonly seen in crossbred dairy cows when measured prepartum. Phiri et al. (2007) reported that BCS ranged from 2.5-3.4 (using a 1 to 5 scale, with slight modifications from Wildman et al. (1982)).

2.8. The Knowledge, Attitude and Practices (KAP) research in smallholder dairy systems

The Knowledge, Attitude and Practices (KAP) model (also called knowledge, attitude, behaviour and practice – KABP survey) (Nichter, 1993; Green, 2001; Nichter, 2008) has been widely used as a framework in agriculture, i.e., livestock studies, especially in understanding how what farmers *know*, *believe* and *do* influences the adoption of effective management and technologies (WHO, 2008; Launiala, 2009; Gemeda et al., 2020; Mulugeta et al., 2024). In smallholder dairy systems, KAP evaluation helps obtain information on farmers' awareness of a specific concept (Knowledge), their perceptions and values toward certain practices (Attitudes), and the routine actions they perform on their farms (Practices). This tripartite structure enables researchers to identify barriers to adoption and design targeted interventions that improve farmers' decision-making, ultimately leading to enhanced animal performance outcomes. Nevertheless, KAP studies are easy to create and conduct, cost-effective and easy to interpret the results (Launiala, 2009; Bhattacharyya, 2013).

Being the key dairy production system in Tanzania, smallholder dairying plays a great role in the improvement of not only household income but also family nutrition (Leslie et al., 1999; Paris, 2002; McDermott et al., 2010). This is because the majority of the milk produced in the country origination from the smallholder dairy farming (NBS&OCGS, 2021). There have been some studies in the region employing the KAP model: milk quality and hygiene in Kenya (Nyokabi et al., 2021; Chilambula, 2025); in Ethiopia (Sewunet et al., 2024); in Rwanda, antimicrobial use (Hirwa et al., 2024) and zoonoses (Munyaneza et al., 2025); use and disposal of veterinary antibiotics (Muwonge et al., 2024), safety standards in beef farming (Okello et al., 2025) in Uganda. Similarly, there are studies employing the KAP model in Tanzania: livestock diseases (Mwaseba & Kigoda, 2017; Mengele et al., 2018; Makoga et al., 2023; Maruchu et al., 2023; Mramba & Mohamed, 2024); milk hygiene (Nonga & Mtambo, 2015; Andrew et al., 2021; Kimambo et al., 2025). Currently, there is no specific study that applies the KAP model to examine cattle infertility under smallholder dairy farming in Tanzania, a gap that this study aims to address.

2.9. Summary and conclusion

In conclusion, the present review on smallholder dairy cattle farming in Tanzania has highlighted the key demographics along with their importance, fundamental constraints and the reproductive challenges which are typical of the low-input systems. It has also outlined the various factors influencing dairy cattle fertility, including management practices, nutrition, farmers' knowledge and the available indicators of reproductive performance. It has also identified some challenges associated with measures of herd reproductive performance in smallholder dairy cattle farms, such as those that characterise dairy farming in Tanzania.

Building on these insights, this thesis aims to investigate the underlying causes of cattle infertility, focusing on the impacts of farmers' demographic characteristics, their understanding of issues related to cattle infertility and the evaluation of the key reproductive performance indicators in their herds. All these are important in planning for practical interventions for the improvement of reproductive efficiency. By linking the reviewed concepts to the Tanzanian smallholder context, the present study will offer evidence-based guidance to support more effective fertility management among farmers and other stakeholders in the sector.

2.10. References

Aerts, J. M. J., & Bols, P. E. J. (2010). Ovarian Follicular Dynamics. A review with Emphasis on the Bovine Species. Part II: Antral Development, Exogenous Influence and Future Prospects. *Reproduction in Domestic Animals*, *45*(1), 180-187. https://doi.org/10.1111/j.1439-0531.2008.01298.x

Ahammed, R., Tasnim, M., Halim, M. A., Sarkar, M., Islam, M. S., & Morshed, M. (2018). A comparative study on reproductive hormones of repeat breeding and synchronized repeat breeding dairy cows under Bathan rearing system at Baghabari milk shed areas in Bangladesh. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, *11*(11), 55-60.

Alonso, S., Toye, P. G., Msalya, G., Grace, D., & Unger, F. (2014). Smallholder dairy farming in Tanzania: Farming practices, animal health and public health challenges and opportunities.

Andrew, R., Chusi, T., & Mwembezi, G. (2021). Milking hygiene and handling practices among smallholder dairy farmers in Zanzibar.

Aoxing, L., Lund, M. S., Yachun, W., Gang, G., Ganghui, D., Madsen, P., & Guosheng, S. (2017). Variance components and correlations of female fertility traits in Chinese Holstein population. *Journal of Animal Science & Biotechnology*, *8*, 1-9. https://doi.org/10.1186/s40104-017-0189-x

Asimwe, L., & Kifaro, G. (2007). Effect of breed, season, year and parity on reproductive performance of dairy cattle under smallholder production system in Bukoba district, Tanzania. *Livestock Research for Rural Development*, *19*(10), 1-9.

Asrat, A., Feleke, A., & Ermias, B. (2016). Characterization of dairy cattle production systems in and around Wolaita Sodo Town, Southern Ethiopia. *Scholarly Journal of Agricultural Science*, *6*(3), 62-70.

Atashi, H., Asaadi, A., & Hostens, M. (2021). Association between age at first calving and lactation performance, lactation curve, calving interval, calf birth weight, and dystocia in Holstein dairy cows. *PLoS One*, *16*(1), e0244825. https://doi.org/10.1371/journal.pone.0244825

Ball, P. J. H., & Peters, A. R. (2004). Reproductive Efficiency in Cattle Production. In *Reproduction in Cattle* (pp. 1-12). https://doi.org/https://doi.org/10.1002/9780470751091.ch1

Beam, S., & Butler, W. (1999). Effects of energy balance on follicular development and first ovulation in postpartum. *Reprod Fertil. Suppl*, *54*, 411-424.

Bee, J., Msanga, Y., & Kavana, P. (2006). Lactation yield of crossbred dairy cattle under farmer management in Eastern coast of Tanzania. Retrieved February 2, 2025, from http://www.lrrd.org/lrrd18/2/bee18023.htm. *Management*, *18*(2), 5.

Berry, D., Roche, J., & Coffey, M. (2008). Body condition score and fertility–more than just a feeling. *Proceedings of Fertility in Dairy Cows–bridging the gaps. Liverpool Hope University, Liverpool, UK*.

Berry, D. P., Buckley, F., Dillon, P., Evans, R., Rath, M., & Veerkamp, R. (2003). Genetic parameters for body condition score, body weight, milk yield, and fertility estimated using random regression models. *Journal of Dairy Science*, *86*(11), 3704-3717.

Berry, D. P., Wall, E., & Pryce, J. E. (2014). Genetics and genomics of reproductive performance in dairy and beef cattle. *Animal*, *8 Suppl 1*, 105-121. https://doi.org/10.1017/S1751731114000743

Bewley, J. M., Boyce, R. E., Hockin, J., Munksgaard, L., Eicher, S. D., Einstein, M. E., & Schutz, M. M. (2010). Influence of milk yield, stage of lactation, and body condition on dairy cattle lying behaviour measured using an automated activity monitoring sensor. *Journal of Dairy Research*, *77*(1), 1-6. https://doi.org/10.1017/S0022029909990227

Bewley, J. M., & Schutz, M. M. (2008). An Interdisciplinary Review of Body Condition Scoring for Dairy Cattle. *The Professional Animal Scientist*, *24*(6), 507-529. https://doi.org/10.15232/s1080-7446(15)30901-3

Bhattacharyya, K. (2013). Key informants, pile sorts, or surveys? Comparing behavioral research methods for the study of acute respiratory infections in West Bengal. In *The Anthropology of Infectious Disease* (pp. 211-238). Routledge.

Blavy, P., Derks, M., Martin, O., Hoglund, J. K., & Friggens, N. C. (2016). Overview of progesterone profiles in dairy cows. *Theriogenology*, *86*(4), 1061-1071. https://doi.org/10.1016/j.theriogenology.2016.03.037

Britt, J. H., Scott, R. G., Armstrong, J. D., & Whitacre, M. D. (1986). Determinants of Estrous Behavior in Lactating Holstein Cows. *JOURNAL OF DAIRY SCIENCE*, *69*(8), 2195-2202. https://doi.org/10.3168/jds.S0022-0302(86)80653-1

Brownlie, T. S., Morton, J. M., Heuer, C., Hunnam, J., & McDougall, S. (2014). Reproductive performance of seasonal-calving, pasture-based dairy herds in four regions of New Zealand. *N Z Vet J*, *62*(2), 77-86. https://doi.org/10.1080/00480169.2013.848499

Brownlie, T. S., Weir, A. M., Tarbotton, I., Morton, J. M., Heuer, C., & McDougall, S. (2011). Reproductive management of dairy herds in New Zealand: attitudes, priorities and constraints perceived by farmers managing seasonal-calving, pasture-based herds in four regions. *N Z Vet J*, *59*(1), 28-39. https://doi.org/10.1080/00480169.2011.547167

Burgers, E. E. A., Kok, A., Goselink, R. M. A., Hogeveen, H., Kemp, B., & van Knegsel, A. T. M. (2021a). Effects of extended voluntary waiting period from calving until first insemination on body condition, milk yield, and lactation persistency. *J Dairy Sci*, *104*(7), 8009-8022. https://doi.org/10.3168/jds.2020-19914

Burgers, E. E. A., Kok, A., Goselink, R. M. A., Hogeveen, H., Kemp, B., & van Knegsel, A. T. M. (2021b). Fertility and milk production on commercial dairy farms with customized lactation lengths. *J Dairy Sci*, *104*(1), 443-458. https://doi.org/10.3168/jds.2019-17947

Butler, W. (2000). Nutritional interactions with reproductive performance in dairy cattle. *Animal Reproduction Science*, *60*, 449-457.

Butler, W. R., & Smith, R. D. (1989). Interrelationships Between Energy Balance and Postpartum Reproductive Function in Dairy Cattle. *Journal of Dairy Science*, *72*(3), 767-783. https://doi.org/10.3168/jds.S0022-0302(89)79169-4

Cassandro, M. (2014). Genetic aspects of fertility traits in dairy cattle–review. *Acta agraria kaposváriensis*, *18*(1), 11-23.

Chagas, L. M., Bass, J. J., Blache, D., Burke, C. R., Kay, J. K., Lindsay, D. R., Lucy, M. C., Martin, G. B., Meier, S., Rhodes, F. M., Roche, J. R., Thatcher, W. W., & Webb, R. (2007). Invited review:

New perspectives on the roles of nutrition and metabolic priorities in the subfertility of high-producing dairy cows. *Journal of Dairy Science*, *90*(9), 4022-4032. https://doi.org/10.3168/jds.2006-852

Chilambula, E. (2025). *Evaluation of smallholder dairy farmers' knowledge, aattitudes, practices (KAP) and factors contributing to hygienic production of raw milk in Malawi's Blantyre agriculture development division* The University of Zambia].

Coffey, M. P., Simm, G., Hill, W. G., & Brotherstone, S. (2003). Genetic Evaluations of Dairy Bulls for Daughter Energy Balance Profiles Using Linear Type Scores and Body Condition Score Analyzed Using Random Regression. *Journal of Dairy Science*, *86*(6), 2205-2212. https://doi.org/10.3168/jds.S0022-0302(03)73810-7

Crowe, M. A., Hostens, M., & Opsomer, G. (2018). Reproductive management in dairy cows - the future. *Ir Vet J*, *71*, 1. https://doi.org/10.1186/s13620-017-0112-y

CSIRO. (2020). *Dairy production in Tanzania* (90% of milk in Tanzania is produced by cattle. The majority of this is produced in low input, low yielding systems and consumed by the producer's household - *CSIRO Research*, Issue. Retrived July 2024, from: https://research.csiro.au/livegaps/wp-content/uploads/sites/37/2020/01/Tanzania-dairy-factsheet-Jan-2020.pdf

DairyNZ. (2023). *Detecting heats*. DairyNZ. Retrieved April 19 from https://www.dairynz.co.nz/animal/reproduction-and-mating/detect-heats/#:~:text=Every%20detected%20heat%20and%20successful,in%20calf%20the%20following%20season.

Dal Zotto, R., De Marchi, M., Dalvit, C., Cassandro, M., Gallo, L., Carnier, P., & Bittante, G. (2007). Heritabilities and genetic correlations of body condition score and calving interval with yield, somatic cell score, and linear type traits in Brown Swiss cattle. *J Dairy Sci*, *90*(12), 5737-5743. https://doi.org/10.3168/jds.2007-0280

Dekkers, J. C. M., Ten Hag, J. H., & Weersink, A. (1998). Economic aspects of persistency of lactation in dairy cattle. *Livestock Production Science*, *53*(3), 237-252. https://doi.org/10.1016/S0301-6226(97)00124-3

Dillon, P., Berry, D. P., Evans, R. D., Buckley, F., & Horan, B. (2006). Consequences of genetic selection for increased milk production in European seasonal pasture based systems of milk production. *Livestock Science*, *99*(2-3), 141-158. https://doi.org/10.1016/j.livprodsci.2005.06.011

Diskin, M. G. (2018). Review: Semen handling, time of insemination and insemination technique in cattle. *Animal*, *12*(s1), s75-s84. https://doi.org/10.1017/S1751731118000952

Diskin, M. G., & Kenny, D. A. (2014). Optimising reproductive performance of beef cows and replacement heifers. *Animal*, *8*, 27-39. https://doi.org/10.1017/S175173111400086X

Diskin, M. G., & Sreenan, J. M. (2000). Expression and detection of oestrus in cattle. *Reproduction Nutrition Development*, *40*(5), 481-491.

Dismas Said, S., Okeyo, A. M., Julie, M. K. O., Daniel, M. K., & Bockline Omedo, B. (2022). Assessing Lactation Curve Characteristics of Dairy Cows Managed under Contrasting Husbandry Practices and Stressful Environments in Tanzania. In *World* (Vol. 3, pp. 1032-1052): MDPI AG.

Dobson, H., Smith, R., Royal, M., Knight, C., & Sheldon, I. (2007). The high-producing dairy cow and its reproductive performance. *Reproduction in Domestic Animals*, *42*, 17-23. https://doi.org/https://doi.org/10.1111/j.1439-0531.2007.00906.x

Dobson, H., Walker, S. L., Morris, M. J., Routly, J. E., & Smith, R. F. (2008). Why is it getting more difficult to successfully artificially inseminate dairy cows? *Animal*, *2*(8), 1104-1111. https://doi.org/10.1017/S175173110800236X

Dolecheck, K. A. (2015). Assessment of the technical and economic potential of automated estrus detection technologies for dairy cattle. Dolecheck, K. A. (2015). Assessment of the technical and economic potential of automated estrus detection technologies for dairy cattle. Theses and Dissertations--Animal and Food Sciences. 44. https://uknowledge.uky.edu/animalsci_etds/44.

Donofrio, G., Herath, S., Sartori, C., Cavirani, S., Flammini, C. F., & Sheldon, I. M. (2007). Bovine herpesvirus 4 is tropic for bovine endometrial cells and modulates endocrine function. *Reproduction*, *134*(1), 183-197. https://doi.org/10.1530/REP-07-0065

Earle, D. (1976). A guide to scoring dairy cow condition. *Dairyfarming digest*.

Edmonson, A. J., Lean, I. J., Weaver, L. D., Farver, T., & Webster, G. (1989). A Body Condition Scoring Chart for Holstein Dairy Cows. *Journal of Dairy Science*, *72*(1), 68-78. https://doi.org/10.3168/jds.S0022-0302(89)79081-0

Esslemont, R., & Kossaibati, M. (2000). The use of databases to manage fertility. *Animal Reproduction Science*, *60*, 725-741.

Esslemont, R. J. (1992). Measuring dairy herd fertility. *Veterinary Record: Journal of the British Veterinary Association*, *131*(10), 209-212. https://doi.org/https://doi.org/10.1136/vr.131.10.209

Esslemont, R. J., & Ellis, P. R. (1974). Components of a herd calving interval. *The Veterinary record*, *95*(14), 319-320. https://doi.org/10.1136/vr.95.14.319

Evans, A. C., & Fortune, J. E. (1997). Selection of the dominant follicle in cattle occurs in the absence of differences in the expression of messenger ribonucleic acid for gonadotropin receptors. *Endocrinology*, *138*(7), 2963-2971. https://doi.org/10.1210/endo.138.7.5245

Fahey, J., O'Sullivan, K., Crilly, J., & Mee, J. (2002). The effect of feeding and management practices on calving rate in dairy herds. *Animal Reproduction Science*, *74*(3-4), 133-150. https://doi.org/https://doi.org/10.1016/S0378-4320(02)00192-6

Faramade, I. A., Alabi, P. I., Oladele, G. M., & Okewole, P. A. (2016). Factors limiting effective veterinary practice in Oyo State. *Vom Journal of Veterinary Science*, *11*, 136-144.

Ferguson, J. D., & Galligan, D. T. (1999). Veterinary reproductive programs. American Association of Bovine Practitioners Proceedings of the Annual Conference,

Ferguson, J. D., Galligan, D. T., & Thomsen, N. (1994). Principal Descriptors of Body Condition Score in Holstein Cows. *Journal of Dairy Science*, *77*(9), 2695-2703. https://doi.org/10.3168/jds.S0022-0302(94)77212-X

Fernandes, E. C., Oktingati, A., & Maghembe, J. (1984). The Chagga homegardens: a multistoried agroforestry cropping system on Mt. Kilimanjaro (Northern Tanzania). *Agroforestry systems*, *2*(2), 73-86.

Fesseha, H., & Degu, T. (2020). Estrus detection, Estrus synchronization in cattle and it's economic importance. *Int. J. Vet. Res*, *3*(1), 1001.

Fetrow, J., McClary, D., Harman, R., Butcher, K., Weaver, L., Studer, E., Ehrlich, J., Etherington, W., Guterbock, W., Klingborg, D., Reneau, J., & Williamson, N. (1990). Calculating selected reproductive indices: recommendations of the American Association of Bovine Practitioners. *Journal of Dairy Science*, *73*(1), 78-90.

Fetrow, J., Stewart, S., Eicker, S., & Rapnicki, P. (2007). Reproductive health programs for dairy herds: analysis of records for assessment of reproductive performance. In *Current therapy in large animal theriogenology* (pp. 473-489). Elsevier Inc.

Firk, R., Stamer, E., Junge, W., & Krieter, J. (2002). Automation of oestrus detection in dairy cows: a review. *Livestock Production Science*, *75*(3), 219-232. https://doi.org/10.1016/S0301-6226(01)00323-2

Fodor, I., & Ózsvári, L. (2015). *The evaluation of reproductive performance in dairy herds* 5th International Conference on Management, leadership and strategy for SMEs' competitiveness, http://dx.doi.org/10.17626/dBEM.ICoM.P00.2015.p085

Forde, N., Beltman, M. E., Lonergan, P., Diskin, M., Roche, J. F., & Crowe, M. A. (2011). Oestrous cycles in Bos taurus cattle. *Animal Reproduction Science*, *124*(3-4), 163-169. https://doi.org/10.1016/j.anireprosci.2010.08.025

Foulkes, J. A., Cookson, A. D., & Sauer, M. J. (1982). AI in cattle based on daily microtitre plate enzymeimmunoassay of progesterone in whole milk. *British Veterinary Journal*, *138*(6), 515-521.

Fuller, F. H., Huang, J., Ma, H., & Rozelle, S. (2005). The rapid rise of China's dairy sector: Factors behind the growth in demand and supply.

Galina, C. S., & Orihuela, A. (2007). The detection of estrus in cattle raised under tropical conditions: what we know and what we need to know. *Horm Behav*, *52*(1), 32-38. https://doi.org/10.1016/j.yhbeh.2007.03.025

Gemeda, B. A., Amenu, K., Magnusson, U., Dohoo, I., Hallenberg, G. S., Alemayehu, G., Desta, H., & Wieland, B. (2020). Antimicrobial use in extensive smallholder livestock farming systems in Ethiopia: knowledge, attitudes, and practices of livestock keepers. *Frontiers in Veterinary Science*, *6*(February). https://doi.org/10.3389/fvets.2020.00055

Ghoribi, L., Hireche, S., & Chibat, M. (2001). Study of some reproductive parameters in bovine dairy farms in the east of Algeria. *Age*, *2002*.

Giannone, C., Bovo, M., Ceccarelli, M., Torreggiani, D., & Tassinari, P. (2023). Review of the Heat Stress-Induced Responses in Dairy Cattle. *Animals (2076-2615)*, *13*(22), 3451. https://doi.org/10.3390/ani13223451

Gillah, K., Kifaro, G., & Madsen, J. (2012). Urban and peri urban dairy farming in East Africa: A review on production levels, constraints and opportunities. *Livestock Research for Rural Development*, *24*(11), 198.

Gillah, K., Kifaro, G., & Madsen, J. (2013a). Management and production levels of cross-bred dairy cattle in Dar es Salaam and Morogoro urban and peri urban areas. *Livest. Res. Rural Dev*, *25*(9), Article 165.

Gillah, K., Kifaro, G., & Madsen, J. (2013b). Management and production levels of cross-bred dairy cattle in Dar es Salaam and Morogoro urban and peri urban areas. *Livestock Research for Rural Development*, *25*(9), Article 165.

Green, E. C. (2001). Can qualitative research produce reliable quantitative findings? *Field Methods*, *13*(1), 3-19. https://doi.org/10.1177/1525822X0101300101

Gutierrez, C., Gong, J., Bramley, T., & Webb, R. (1999). Effects of genetic selection for milk yield on metabolic hormones and follicular development in postpartum dairy cattle. *J. Reprod. Fertil*, *24*, 16.

Habimana, V., Ekine-Dzivenu, C. C., Nguluma, A. S., Nziku, Z. C., Morota, G., Chenyambuga, S. W., & Mrode, R. (2023). Genes and models for estimating genetic parameters for heat tolerance in dairy cattle. *Frontiers in Genetics*, *14*(Febuary). https://doi.org/10.3389/fgene.2023.1127175

Hadley, G., Harsh, S., & Wolf, C. (2002). Managerial and financial implications of major dairy farm expansions in Michigan and Wisconsin. *Journal of Dairy Science*, *85*(8), 2053-2064.

Hanks, J., & Kossaibati, M. (2012). Key Performance Indicators for the UK national dairy herd. *A study of herd performance in*, *500*, 1-26.

Hansel, W., & Dowd, J. P. (1986). New concepts of the control of corpus luteum function. *Journal of Reproduction and Fertility*, *78*(2), 755-768-768.

Hansel, W., & Echternkamp, S. E. (1972). Control of Ovarian Function in Domestic Animals. *American Zoologist*, *12*(2), 225-225. https://doi.org/10.1093/icb/12.2.225

Hartigan, P. (2004). Reproductive physiology in cattle. In *Bovine Medicine: Diseases and Husbandry of Cattle* (pp. 471-505). Blackwell Science Ltd., Oxford, UK.

Hemme, T., & Otte, J. (2010). Status and prospects for smallholder milk production. Accessed on 15th July 2024 from: https://openknowledge.fao.org/handle/20.500.14283/I1522E

http://www.fao.org/3/i1522e/i1522e.pdf. 186.

Herlihy, M. M., Giordano, J. O., Souza, A. H., Ayres, H., Ferreira, R. M., Keskin, A., Nascimento, A. B., Guenther, J. N., Gaska, J. M., Kacuba, S. J., Crowe, M. A., Butler, S. T., & Wiltbank, M. C. (2012). Presynchronization with Double-Ovsynch improves fertility at first postpartum artificial insemination in lactating dairy cows. *J Dairy Sci*, *95*(12), 7003-7014. https://doi.org/10.3168/jds.2011-5260

Higgins, H. M., Ferguson, E., Smith, R. F., & Green, M. J. (2013a). Using hormones to manage dairy cow fertility: the clinical and ethical beliefs of veterinary practitioners. *PLoS One*, *8*(4), e62993. https://doi.org/10.1371/journal.pone.0062993

Higgins, H. M., Huxley, J. N., Wapenaar, W., & Green, M. J. (2013b). Proactive dairy cattle disease control in the UK: veterinary surgeons' involvement and associated characteristics. *Vet Rec*, *173*(10), 246. https://doi.org/10.1136/vr.101692

Hirwa, E. M., Mujawamariya, G., Shimelash, N., & Shyaka, A. (2024). Evaluation of cattle farmers' knowledge, attitudes, and practices regarding antimicrobial use and antimicrobial resistance in Rwanda. *PLoS One*, *19*(4), e0300742.

Horst, E. A., Kvidera, S. K., & Baumgard, L. H. (2021). Invited review: The influence of immune activation on transition cow health and performance-A critical evaluation of traditional dogmas. *J Dairy Sci*, *104*(8), 8380-8410. https://doi.org/10.3168/jds.2021-20330

Hudson, C., Cook, J. G., & Laven, R. (2018). Veterinary control of herd fertility in intensively managed dairy herds. In D. Noakes, T. Parkinson, & G. England (Eds.), *Veterinary Reproduction and Obstetrics* (10th ed., pp. 467-484). Elsevier.

Hudson, C., Kerby, M., Statham, J., & Wapenaar, W. (2012). Managing herd reproduction. In *Dairy herd health* (pp. 73-116). CABI Wallingford UK. https://doi.org/https://doi.org/10.1079/9781845939977.0073

Ilukor, J. (2017). Improving the delivery of veterinary services in Africa: Insights from the empirical application of transaction costs theory in Uganda and Kenya. *Rev Sci Tech*, *36*(1), 279-289.

Inchaisri, C., Jorritsma, R., Vos, P. L. A. M., van der Weijden, G. C., & Hogeveen, H. (2011). Analysis of the economically optimal voluntary waiting period for first insemination. *Journal of Dairy Science*, *94*(8), 3811-3823. https://doi.org/10.3168/jds.2010-3790

Jaime, G., Hobeika, A., & Figuié, M. (2022). Access to veterinary drugs in sub-saharan Africa: Roadblocks and current solutions. *Frontiers in Veterinary Science*, *8*, 558973.

Jefferies, B. (1961). Body condition scoring and its use in management. *Tasmanian journal of agriculture*, *32*, 19-21.

Jenkins, G. M., Amer, P., Stachowicz, K., & Meier, S. (2016). Phenotypic associations between gestation length and production, fertility, survival, and calf traits. *J Dairy Sci*, *99*(1), 418-426. https://doi.org/10.3168/jds.2015-9934

Kanuya, N., Kessy, B., Bittegeko, S., Mdoe, N., & Aboud, A. (2000). Suboptimal reproductive performance of dairy cattle kept in smallholder herds in a rural highland area of northern Tanzania. *Preventive Veterinary Medicine*, *45*(3-4), 183-192. https://doi.org/https://doi.org/10.1016/S0167-5877(00)00134-3

Kanuya, N. L., Matiko, M. K., Nkya, R., Bittegeko, S. B., Mgasa, M. N., Reksen, O., & Ropstad, E. (2006). Seasonal changes in nutritional status and reproductive performance of Zebu cows kept under a traditional agro-pastoral system in Tanzania. *Trop Anim Health Prod*, *38*(6), 511-519. https://doi.org/10.1007/s11250-006-4419-z

Kashoma, I., & Ngou, A. (2021). Retained fetal membrane in Tanzanian dairy cows: economic impacts and subsequent reproductive performances. *J. Vet. Med. Sci*, *4*, 1059.

Kathambi, E. K., Sonstegard, T. S., & Larsen, P. A. (2025). Review: Cross-breeding, advanced reproductive technologies, and genetic selection in twelve dairy production systems in Africa. *Animal*, *19*(3). https://doi.org/10.1016/j.animal.2025.101424

Kavana, P., & Msangi, B. (2005). On farm dairy cattle feeding experience in eastern zone of Tanzania. *Livestock Research for Rural Development*, *17*(6).

Kearney, J. F., Wall, E., Villanueva, B., & Coffey, M. P. (2004). Inbreeding Trends and Application of Optimized Selection in the UK Holstein Population. *JOURNAL OF DAIRY SCIENCE*, *87*(10), 3503-3509. https://doi.org/10.3168/jds.S0022-0302(04)73485-2

Kerbrat, S., & Disenhaus, C. (2004). A proposition for an updated behavioural characterisation of the oestrus period in dairy cows. *Applied Animal Behaviour Science*, *87*(3-4), 223-238. https://doi.org/10.1016/j.applanim.2003.12.001

Kilgour, R., Skarsholt, B., Smith, J., Bremner, K., & Morrison, M. (1977). Observations on the behaviour and factors influencing the sexually-active group in cattle.

Kim, I., & Francisco, N. (2010). Programmed reproductive management including Presynch-Ovsynch-Resynch protocol in dairy cows. *Journal of Veterinary Clinics*, *27*(4), 397-401.

Kimambo, J., Kimera, Z. I., Niccodem, E., Kunambi, P., Mgaya, F. X., & Matee, M. I. (2025). Antibiotic Use in Small-Scale Dairy Farming and Residue Levels of Tetracyclines and Sulphonamides in Milk from Eastern Tanzania.

Kivaria, F., Noordhuizen, J., & Kapaga, A. (2006). Prospects and constraints of smallholder dairy husbandry in the Dar es Salaam region, Tanzania. *Outlook on Agriculture*, *35*(3), 209-215. https://doi.org/https://doi.org/10.5367/000000006778536819

Klopčič, M., Hamoen, A., & Bewley, J. (2011). *Body condition scoring of dairy cows*. Biotechnical Faculty, Department of Animal Science Ljubljana, Slovenia.

Knight, C. H., Beever, D. E., & Sorensen, A. (1999). Metabolic loads to be expected from different genotypes under different systems. *BSAP Occasional Publication*, *24*, 27-35. https://doi.org/10.1017/s1463981500043053

Kurwijila, L. R., Omore, A. O., & Grace, D. (2012). Tanzania dairy industry overview 2012.

Kurwiljila, R. (2010). Overview of Dairy Development in Tanzania. *Smallholder dairy production and marketing—Opportunities and constraints*, 174.

Landaeta-Hernández, A., Palomares-Naveda, R., Soto-Castillo, G., Atencio, A., Chase Jr, C., & Chenoweth, P. J. (2004). Social and breed effects on the expression of a PGF2α induced oestrus in beef cows. *Reproduction in Domestic Animals*, *39*(5), 315-320. https://doi.org/https://doi.org/10.1111/j.1439-0531.2004.00515.x

Larson, L., & Ball, P. (1992). Regulation of estrous cycles in dairy cattle: a review. *Theriogenology*, *38*(2), 255-267.

Launiala, A. (2009). How much can a KAP survey tell us about people's knowledge, attitudes and practices? Some observations from medical anthropology research on malaria in pregnancy in Malawi. *Anthropology Matters*, *11*(1).

Laven, R. (2017). Measuring fertility -benchmarking your farm.

Layek, S. S., Mohanty, T. K., Kumaresan, A., Behera, K., & Chand, S. (2011). Behavioural signs of estrus and their relationship to time of ovulation in Zebu (Sahiwal) cattle. *Animal Reproduction Science*, *129*(3/4), 140-145. https://doi.org/10.1016/j.anireprosci.2011.11.006

LeBlanc, S. (2007). Economics of improving reproductive performance in dairy herds. *Adv. Dairy Technol*, *19*, 201-214.

LeBlanc, S. (2010). Assessing the association of the level of milk production with reproductive performance in dairy cattle. *The Journal of reproduction and development*, *56 Suppl*, S1-S7. https://doi.org/10.1262/jrd.1056s01

Lehmann, J. O., Fadel, J. G., Mogensen, L., Kristensen, T., Gaillard, C., & Kebreab, E. (2016). Effect of calving interval and parity on milk yield per feeding day in Danish commercial dairy herds. *J Dairy Sci*, *99*(1), 621-633. https://doi.org/10.3168/jds.2015-9583

Leslie, J., Swai, E., Karimuribo, E., & Bell, C. (1999). *Tanga and Southern Highland dairy development programmes: Socio-economic aspects and farmer perception of dairy cattle keeping and animal diseases* (DFID/NRRD Animal Health Research Programme, Issue.

Louca, A., & Legates, J. (1968). Production losses in dairy cattle due to days open. *Journal of Dairy Science*, *51*(4), 573-583.

Lowman, B., Scott, N., & Somerville, S. (1973). Condition scoring of cattle. *Edinburgh*: East of Scotland College of Agriculture, 8.

Lucy, M. (2001). Reproductive loss in high-producing dairy cattle: where will it end? *Journal of dairy science*, *84*(6), 1277-1293. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(01)70158-0
Lucy, M. (2007). Fertility in high-producing dairy cows: reasons for decline and corrective strategies for sustainable improvement. *Society of Reproduction and Fertility supplement*, *64*, 237-254.
Lucy, M., Verkerk, G., Whyte, B., Macdonald, K., Burton, L., Cursons, R., Roche, J., & Holmes, C. (2009). Somatotropic axis components and nutrient partitioning in genetically diverse dairy cows managed under different feed allowances in a pasture system. *Journal of Dairy Science*, *92*(2), 526-539.
Lucy, M. C. (2008). Functional differences in the growth hormone and insulin-like growth factor axis in cattle and pigs: implications for post-partum nutrition and reproduction. *Reprod Domest Anim*, *43 Suppl 2*, 31-39. https://doi.org/10.1111/j.1439-0531.2008.01140.x
Lyimo, Z., Nielen, M., Ouweltjes, W., Kruip, T., & Van Eerdenburg, F. (2000). Relationship among estradiol, cortisol and intensity of estrous behavior in dairy cattle. *Theriogenology*, *53*(9), 1783-1795.
Lyimo, Z., Nkya, R., Schoonman, L., & Van Eerdenburg, F. (2004). Post-partum reproductive performance of crossbred dairy cattle on smallholder farms in sub-humid coastal Tanzania. *Tropical Animal Health and Production*, *36*(3), 269-279.
Ma, J., Burgers, E. E. A., Kok, A., Goselink, R. M. A., Lam, T. J. G. M., Kemp, B., & van Knegsel, A. T. M. (2022). Consequences of extending the voluntary waiting period for insemination on reproductive performance in dairy cows. *Animal Reproduction Science*, *244*, N.PAG-N.PAG. https://doi.org/10.1016/j.anireprosci.2022.107046
MacDonald, J. M., McBride, W. D., O'Donoghue, E., Nehring, R. F., Sandretto, C., & Mosheim, R. (2007). Profits, costs, and the changing structure of dairy farming. *USDA-ERS Economic Research Report*(47).
Macdonald, K. A., Verkerk, G. A., Thorrold, B. S., Pryce, J. E., Penno, J. W., McNaughton, L. R., Burton, L. J., Lancaster, J. A., Williamson, J. H., & Holmes, C. W. (2008a). A comparison of three strains of holstein-friesian grazed on pasture and managed under different feed allowances. *J Dairy Sci*, *91*(4), 1693-1707. https://doi.org/10.3168/jds.2007-0441
Machado, V., Caixeta, L., McArt, J., & Bicalho, R. (2010). The effect of claw horn disruption lesions and body condition score at dry-off on survivability, reproductive performance, and milk production in the subsequent lactation. *Journal of Dairy Science*, *93*(9), 4071-4078. https://doi.org/https://doi.org/10.3168/jds.2010-3177
Mackey, D. R., Gordon, A. W., McCoy, M. A., Verner, M., & Mayne, C. S. (2007). Associations between genetic merit for milk production and animal parameters and the fertility performance of dairy cows. *Animal*, *1*(1), 29-43. https://doi.org/10.1017/S1751731107257921
Macmillan, K. L., Lean, I. J., & Westwood, C. T. (1996). The effects of lactation on the fertility of dairy cows. *Australian veterinary journal*, *73*(4), 141-147. https://doi.org/10.1111/j.1751-0813.1996.tb10007.x
Makoga, F., Geda, G. G., Mark, M. J., Malugu, P. J., Njau, E. P., & Chengula, A. (2023). Assessment of community knowledge, attitude and practice (KAP) towards lumpy skin disease (LSD) in Tanga and Pwani Region-Tanzania. *East African Journal of Science, Technology and Innovation*, *5*(1).
Maleko, D., Msalya, G., Mwilawa, A., Pasape, L., Owiro, N., Ochuodho, J., Rachuonyo, H., Gohole, L., Tarus, J., & Ooko, L. (2016). Overview of feed resources condition and feeding practices among the smallholder dairy farmers in Tanzania. Fifth African Higher Education Week and RUFORUM Biennial Conference 2016," Linking agricultural universities with civil society, the private sector, governments and other stakeholders in support of agricultural development in Africa, Cape Town", South Africa, 17-21 October 2016,

Marchitelli, C., Signorelli, F., Napolitano, F., Buttazzoni, L., Grelet, C., Vanlierde, A., Dehareng, F., Soyeurt, H., Crowe, M., & Consortium, G. (2017). Expression profiles of immune genes in milk somatic cells and MIR predicted mineral contents in milk as indicators of mastitis. 36th International Society for Animal Genetics conference,

Maruchu, U., Chang'a, E., Mpemba, C., Mwaipopo, L., Masola, S., Guni, F., Kabululu, M., Mdetele, D., Makungu, S., & Komba, E. (2023). Knowledge, attitudes and practices on bovine brucellosis among smallholder livestock keepers in Rungwe district, Tanzania. *Applied Veterinary Research*, *2*(3), 2023012-2023012.

Mbwambo, N., Nigussie, K., & Stapleton, J. (2019). Dairy development in the Tanzanian livestock master plan. *Gates Open Res*, *3*(628), 628. https://doi.org/https://doi.org/10.21955/gatesopenres.1115533.1

McCarthy, S., Berry, D. P., Dillon, P., Rath, M., & Horan, B. (2007). Influence of Holstein-Friesian Strain and Feed System on Body Weight and Body Condition Score Lactation Profiles. *Journal of Dairy Science*, *90*(4), 1859-1869. https://doi.org/10.3168/jds.2006-501

McDermott, Staal, S., Freeman, H., Herrero, M., & Van de Steeg, J. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science*, *130*(1-3), 95-109. https://doi.org/https://doi.org/10.1016/j.livsci.2010.02.014

McDougall, S. (2010). Effects of treatment of anestrous dairy cows with gonadotropin-releasing hormone, prostaglandin, and progesterone. *J Dairy Sci*, *93*(5), 1944-1959. https://doi.org/10.3168/jds.2009-2305

McLeod, B. J., Foulkes, J. A., Williams, M. E., & Weller, R. F. (1991). Predicting the time of ovulation in dairy cows using on-farm progesterone kits. *Animal Production*, *52*(1), 1-9. https://doi.org/10.1017/S0003356100005638

Meadows, C. (2005). Reproductive record analysis. *Vet Clin North Am Food Anim Pract*, *21*(2), 305-323. https://doi.org/10.1016/j.cvfa.2005.02.001

Mee, J. F. (2007). The role of the veterinarian in bovine fertility management on modern dairy farms. *Theriogenology*, *68 Suppl 1*, S257-265. https://doi.org/10.1016/j.theriogenology.2007.04.030

Mekonnen, T., & Gebremariam, T. (2024). Cattle Artificial Insemination Service in Developing Countries: Efficiency, Major Challenges and Economic Loss: A Review. *Biotechnology Journal International*, *28*(4), 18-40.

Mellado, M., Flores, J. M., de Santiago, A., Veliz, F. G., Macías-Cruz, U., Avendaño-Reyes, L., & García, J. E. (2016). Extended lactation in high-yielding Holstein cows: Characterization of milk yield and risk factors for lactations >450 days. *Livestock Science*, *189*, 50-55. https://doi.org/10.1016/j.livsci.2016.05.004

Mellau, L., Sarimbo, A., Kimera, S., & Phiri, E. (2009). Recumbence syndrome around calving in cattle: a study of risk factors of milk fever in dairy units in Dar es Salaam, Tanzania. *Tanzania Veterinary Journal*, *26*(2), 52.

Mengele, I., Garcia-Gonzalez, D., Mekonnen, G., & Arenas-Gamboa, A. (2018). Bovine brucellosis seroprevalence, farmers' awareness, practices and animal health extension services inputs in Mpwapwa district, Tanzania. *Tanzania Veterinary Journal*, *36*, 135-144.

Mgongo, F., Mujuni, P., & Kitambi, A. (2009). Pregnancy rates of crossbred dairy cattle synchronized using GnRH and one injection of PGF2alpha versus two injections of PGF2alpha prior to insemination. *Livest. Res. Rural. Dev*.

Michaelis, I., Burfeind, O., & Heuwieser, W. (2014). Evaluation of Oestrous Detection in Dairy Cattle Comparing an Automated Activity Monitoring System to Visual Observation. *Reproduction in Domestic Animals*, *49*(4), 621-628. https://doi.org/10.1111/rda.12337

Miglior, F., Pizzi, F., & Guaita, N. (1998). Effect of environmental factors on non return rate in Italian Holstein-Friesians. *Interbull Bulletin*(18), 106-106.

MLFD. (2010). *Livestock sector development_strategy-2010.pdf*. DSM, Tanzania: MLFD

Moore, K., & Thatcher, W. (2006). Major advances associated with reproduction in dairy cattle. *Journal of Dairy Science*, *89*(4), 1254-1266. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(06)72194-4

Morton, J. M. (2003). The InCalf Project - Identifying Risk Factors for Reproductive Performance in Australian Dairy Herds. *Cattle Practice*, *11*, 201-208.

Morton, J. M. (2010). Interrelationships between herd-level reproductive performance measures based on intervals from initiation of the breeding program in year-round and seasonal calving dairy herds. *Journal of Dairy Science*, *93*(3), 901-910. https://doi.org/10.3168/jds.2009-2045

Mossie, T., & Wondmnew, T. (2016). Review on estrous synchronization in Ethiopia dairy cattle, its principles, methods, and purpose. *Int. J. Vet. Sci. Anim. Husb*, *1*(6), 24-29.

Mramba, R. P., & Mohamed, M. A. (2024). The prevalence and factors associated with mastitis in dairy cows kept by small-scale farmers in Dodoma, Tanzania. *Heliyon*, *10*(13).

Msalya, G. (2017b). Possibilities of Utilizing Biotechnology to Improve Animal and Animal Feeds Productivity in Tanzania – Review of Past Efforts and Available Opportunities. *Journal of Dairy, Veterinary & Animal Research*, *5*(5). https://doi.org/10.15406/jdvar.2017.05.00155

Msangi, B., Bryant, M., & Thorne, P. (2005). Some factors affecting variation in milk yield in crossbred dairy cows on smallholder farms in North-east Tanzania. *Tropical Animal Health and Production*, *37*(5), 403-412.

Msangya, M., Urassa, J., & Mahonge, C. (2015). Contribution of Heifer In-Trust schemes to smallholder households' well-being in Highland area of Njombe Region, Tanzania. *Livestock and rural research and development*, *26*(12), Article 233.

Muhairwa, A., Barnabas, E., & Nonga, H. (2014). A retrospective study of production and reproductive conditions in crossbred dairy cows attended at Sokoine University of Agriculture Animal Hospital, Tanzania.

Mulligan, F. J., O'Grady, L., Rice, D. A., & Doherty, M. L. (2006). A herd health approach to dairy cow nutrition and production diseases of the transition cow. *Anim Reprod Sci*, *96*(3-4), 331-353. https://doi.org/10.1016/j.anireprosci.2006.08.011

Mulugeta, T., Ilomo, M., Mueke, A., Onyango, C., Matsaunyane, L., Kritzinger, Q., & Alexandersson, E. (2024). Smallholder farmers' knowledge, attitudes, and practices (KAP) regarding agricultural inputs with a focus on agricultural biologicals. *Heliyon*, *10*(4). https://doi.org/10.1016/j.heliyon.2024.e26719

Mulvany, P. (1981). 6.5 Dairy cow condition scoring. *BSAP Occasional Publication*, *4*, 349-353. https://doi.org/https://doi.org/10.1017/S0263967X00000690

Munyaneza, C., Bizimana, F., Mukumbo, F., Gatesi, S., Sibomana, E., Munyampuhwe, S., & Dutuze, M. F. (2025). Knowledge, attitudes, practices (KAP), and risk factors toward zoonotic diseases among smallholder livestock farmers in Bugesera district of Rwanda. *Frontiers in Public Health*, *13*, 1569682.

Murray, J. A. (1919). Meat production. *Journal of agricultural science*, *9*(2), 174-181. https://doi.org/10.1017/S0021859600004767

Muwonge, K. M., Ndagire, H., & Twesigye, C. K. (2024). Smallholder farmers' knowledge, attitude and practices towards use and disposal of veterinary antibiotics in Kassanda District, Uganda-A cross sectional survey. *54*(1).

Mwaseba, D. L., & Kigoda, K. J. (2017). Knowledge, attitude, and practices about tsetse control among communities neighbouring Serengeti National Park, Tanzania. *Heliyon*, *3*(6).

NBS&OCGS. (2021). *National Sample Census of Agriculture 2019/20*. Tanzania: National Bureau of Statistics (NBS) and Office of the Chief Government Statistician (OCGS) Retrieved from https://www.nbs.go.tz/nbs/takwimu/Agriculture/2019-20_Agri_Census_%20Main_Report.pdf

Nebel, R., Dransfield, M., Jobst, S., & Bame, J. (2000). Automated electronic systems for the detection of oestrus and timing of AI in cattle. *Animal Reproduction Science*, *60*, 713-723.

Nell, A. J., Schiere, H., & Bol, S. (2014). *Quick scan dairy sector Tanzania*. Dutch Ministry of Economic Affairs. Accessed on 10th August 2024, from https://www.best-dialogue.org/wp-content/uploads/TanzDairyScanReport-14Jan14-Final1.pdf.

Ngigi, M., Ahmed, M. A., Ehui, S., Assefa, Y., Haggblade, S., & Hazell, P. B. R. (2010). Smallholder Dairying in Eastern Africa. In *Successes in African Agriculture: Lessons for the Future* (pp. 209-261). Published for the International Food Policy Research Institute. Baltimore: Johns Hopkins University Press.

Nicholson, M., & Butterworth, M. H. (1986). *A guide to condition scoring of zebu cattle*. ILRI (aka ILCA and ILRAD). Retrieved from https://delavidaboran.co.za/temp/article_A%20Guide%20to%20Condition%20Score%20of%20Zebu%20Cattle%20Pg1.pdf.

Nichter, M. (1993). Social science lessons from diarrhea research and their application to ARI. *Human Organization*, *52*(1), 53-67.

Nichter, M. (2008). *Global health: Why cultural perceptions, social representations, and biopolitics matter*. University of Arizona Press.

Njombe, A., Msanga, Y., Mbwambo, N., & Makembe, N. (2011, 25-27 May). The Tanzania dairy industry: Status, opportunities and prospects. 7th African Dairy Conference and Exhibition held at Moven Pick Palm Hotel,

Noakes, D. E. (1997). *Fertility and obstetrics in cattle* (2nd ed ed.). Blackwell Science.

Nonga, H., & Mtambo, M. (2015). Assessment of raw milk quality and stakeholders' awareness on milk-borne health risks in Arusha City and Meru District, Tanzania. *Tropical Animal Health & Production*, *47*(5).

Nyokabi, S., Luning, P. A., de Boer, I. J., Korir, L., Muunda, E., Bebe, B. O., Lindahl, J., Bett, B., & Oosting, S. J. (2021). Milk quality and hygiene: Knowledge, attitudes and practices of smallholder dairy farmers in central Kenya. *Food Control*, *130*, 108303.

O' Leary, N. O., Leso, L., Buckley, F., Kenneally, J., McSweeney, D., & Shalloo, L. (2020). Validation of an Automated Body Condition Scoring System Using 3D Imaging. *Agriculture*, *10*(6). https://doi.org/10.3390/agriculture10060246

Ojango, J. M. K., Wasike, C. B., Enahoro, D. K., & Okeyo, A. M. (2016). Dairy production systems and the adoption of genetic and breeding technologies in Tanzania, Kenya, India and Nicaragua. *Animal Genetic Resources/Ressources génétiques animales/Recursos genéticos animales*, *59*, 81-95. https://doi.org/10.1017/s2078633616000096

Ojo, T. O., Vandenplas, J., Mulder, H. A., van Pelt, M. L., & Calus, M. P. L. (2025). Genetic analysis of the impact of heat stress on fertility traits in dairy cows in the Netherlands. *Journal of Dairy Science*, *108*(2), 1699-1713. https://doi.org/10.3168/jds.2024-25316

Okello, P., Ilukor, J., Kamatara, K., & Turyahabwe, N. (2025). Farmers knowledge, attitude, and practices towards compliance with beef safety standard practices in Uganda. *Pastoralism: Research, Policy and Practice*, *15*, 13991.

Oltenacu, P. A., & Algers, B. (2005). Selection for increased production and the welfare of dairy cows: are new breeding goals needed? *AMBIO: A Journal of the Human Environment*, *34*(4), 311-315.

Orpin, P., & Esslemont, R. (2010). Culling and wastage in dairy herds: an update on incidence and economic impact in dairy herds in the UK. *Cattle Practice*, *18*(3), 163-172.

Otte, J., Pica-Ciamarra, U., & Morzaria, S. (2019). A comparative overview of the livestock-environment interactions in Asia and Sub-Saharan Africa. *Frontiers in Veterinary Science*, *6*, 37.

Otwinowska-Mindur, A., & Ptak, E. (2016). Factors affecting the shape of lactation curves in Polish Holstein-Friesian cows. *Animal Science Papers & Reports*, *34*(4).

Paris, T. R. (2002). Crop–animal systems in Asia: Socio-economic benefits and impacts on rural livelihoods. *Agricultural systems*, *71*(1-2), 147-168. https://doi.org/https://doi.org/10.1016/S0308-521X(01)00041-5

Phiri, E. C., Nkya, R., Pereka, A. E., Mgasa, M. N., & Larsen, T. (2007). The effects of calcium, phosphorus and zinc supplementation on reproductive performance of crossbred dairy cows in Tanzania. *Trop Anim Health Prod*, *39*(5), 317-323. https://doi.org/10.1007/s11250-007-9016-2

Plaizier, J., King, G., Dekkers, J., & Lissemore, K. (1997). Estimation of economic values of indices for reproductive performance in dairy herds using computer simulation. *Journal of Dairy Science*, *80*(11), 2775-2783.

Potgieter, J. P. (2012). *Estimation of genetic parameters for fertility traits and the effect of milk production on reproduction performance in South African Holstein cows* Stellenbosch: Stellenbosch University].

Pryce, J., Coffey, M., & Brotherstone, S. (2000). The genetic relationship between calving interval, body condition score and linear type and management traits in registered Holsteins. *Journal of Dairy Science*, *83*(11), 2664-2671.

Pryce, J., & Veerkamp, R. (2001). The incorporation of fertility indices in genetic improvement programmes. *BSAP Occasional Publication*, *26*(1), 237-249.

Pryce, J. E., Coffey, M. P., & Simm, G. (2001). The Relationship Between Body Condition Score and Reproductive Performance. *Journal of Dairy Science*, *84*(6), 1508-1515. https://doi.org/10.3168/jds.S0022-0302(01)70184-1

Pryce, J. E., & Harris, B. L. (2006). Genetics of body condition score in New Zealand dairy cows. *Journal of Dairy Science*, *89*(11), 4424-4432. https://doi.org/10.3168/jds.S0022-0302(06)72490-0

Pursley, J., Mee, M., & Wiltbank, M. (1995). Synchronization of ovulation in dairy cows using PGF2α and GnRH. *Theriogenology*, *44*(7), 915-923.

Roche, J., Dillon, P., Stockdale, C., Baumgard, L., & VanBaale, M. (2004). Relationships among international body condition scoring systems. *Journal of Dairy Science*, *87*(9), 3076-3079.

Roche, J. F. (2006). The effect of nutritional management of the dairy cow on reproductive efficiency. *Anim Reprod Sci*, *96*(3-4), 282-296. https://doi.org/10.1016/j.anireprosci.2006.08.007

Roche, J. R., Friggens, N. C., Kay, J. K., Fisher, M. W., Stafford, K. J., & Berry, D. P. (2009). Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. *J Dairy Sci*, *92*(12), 5769-5801. https://doi.org/10.3168/jds.2009-2431

Roche, J. R., Lee, J. M., Macdonald, K. A., & Berry, D. P. (2007). Relationships among body condition score, body weight, and milk production variables in pasture-based dairy cows. *J Dairy Sci*, *90*(8), 3802-3815. https://doi.org/10.3168/jds.2006-740

Roelofs, J., Lopez-Gatius, F., Hunter, R., Van Eerdenburg, F., & Hanzen, C. (2010). When is a cow in estrus? Clinical and practical aspects. *Theriogenology*, *74*(3), 327-344.

Roelofs, J. B., van Eerdenburg, F., Soede, N. M., & Kemp, B. (2005). Various behavioral signs of estrous and their relationship with time of ovulation in dairy cattle. *Theriogenology*, *63*(5), 1366-1377. https://doi.org/10.1016/j.theriogenology.2004.07.009

Royal, M., Mann, G. E., & Flint, A. P. (2000). Strategies for reversing the trend towards subfertility in dairy cattle. *Vet J*, *160*(1), 53-60. https://doi.org/10.1053/tvjl.1999.0450

Royal, M., Pryce, J., Woolliams, J., & Flint, A. (2002). The genetic relationship between commencement of luteal activity and calving interval, body condition score, production, and linear type traits in Holstein-Friesian dairy cattle. *Journal of Dairy Science*, *85*(11), 3071-3080.

Rycroft, H., & Bean, B. (1992). Factors influencing non-return data. Proceedings of the 14th Technical Conference on Artificial Insemination and Reproduction, National Association of Animal Breeders,

Saint-Dizier, M., & Chastant-Maillard, S. (2012). Towards an automated detection of oestrus in dairy cattle. *Reprod Domest Anim*, *47*(6), 1056-1061. https://doi.org/10.1111/j.1439-0531.2011.01971.x

Sakaguchi, M. (2011). Practical aspects of the fertility of dairy cattle. *Journal of Reproduction and Development*, *57*(1), 17-33. https://doi.org/https://doi.org/10.1262/jrd.10-197E

Santos, J. E. P., Rutigliano, H. M., & Filho, M. F. S. (2009). Risk factors for resumption of postpartum estrous cycles and embryonic survival in lactating dairy cows. *Animal Reproduction Science*, *110*(3/4), 207-221. https://doi.org/10.1016/j.anireprosci.2008.01.014

Schmidt, G. H. (1989). Effect of Length of Calving Intervals on Income Over Feed and Variable Costs. *Journal of Dairy Science*, *72*(6), 1605-1611. https://doi.org/10.3168/jds.S0022-0302(89)79272-9

Sewunet, S. D., Kebede, E., Melaku, A., Yirga Assefa, A., Alebie, A., Assefa, A., Ayalew, H., Birhan, G., & Kenubih, A. W. (2024). Dairy Farmers' Knowledge, Attitudes, and Practices (KAP) Towards Aflatoxin Contamination in Milk and Feeds in Bahir Dar, Ethiopia. *International Journal of Microbiology*, *2024*(1), 5568286.

Shanks, R. D., Freeman, A. E., Berger, P. J., & Kelley, D. H. (1978). Effect of Selection for Milk Production and General Health of the Dairy Cow. *Journal of Dairy Science*, *61*(12), 1765-1772. https://doi.org/10.3168/jds.S0022-0302(78)83800-4

Sheehy, M. R., Fahey, A. G., Aungier, S. P. M., Carter, F., Crowe, M. A., & Mulligan, F. J. (2017). A comparison of serum metabolic and production profiles of dairy cows that maintained or lost body condition 15 days before calving. *J Dairy Sci*, *100*(1), 536-547. https://doi.org/10.3168/jds.2016-11206

Shehab-El-Deen, M. A., Leroy, J. L., Fadel, M. S., Saleh, S. Y., Maes, D., & Van Soom, A. (2010). Biochemical changes in the follicular fluid of the dominant follicle of high producing dairy cows exposed to heat stress early post-partum. *Anim Reprod Sci*, *117*(3-4), 189-200. https://doi.org/10.1016/j.anireprosci.2009.04.013

Silva, H. M., Wilcox, C. J., Thatcher, W. W., Becker, R. B., & Morse, D. (1992). Factors Affecting Days Open, Gestation Length, and Calving Interval in Florida Dairy Cattle. *Journal of Dairy Science*, *75*(1), 288-293. https://doi.org/10.3168/jds.S0022-0302(92)77764-9

Somers, J. R., Huxley, J., Lorenz, I., Doherty, M. L., & O'Grady, L. (2015, 2015/01/01/2015). The effect of lameness before and during the breeding season on fertility in 10 pasture-based Irish dairy herds. Proceedings of the 18th International Symposium & 10th Conference on Lameness in Ruminants, November 22-25, 2015, Valdivia, Chile, Valdivia, Chile.

Spear, T. T. (1997). *Mountain farmers: Moral economies of land & agricultural development in Arusha & Meru*. Univ of California Press.

Stevenson, J., Lucy, M., & Call, E. (1987). Failure of timed inseminations and associated luteal function in dairy cattle after two injections of prostaglandin F2-alpha. *Theriogenology*, *28*(6), 937-946.

Stevenson, J. S., & Britt, J. H. (2017). A 100-Year Review: Practical female reproductive management. *J Dairy Sci*, *100*(12), 10292-10313. https://doi.org/10.3168/jds.2017-12959

Stockdale, C. R. (2001). Body condition at calving and the performance of dairy cows in early lactation under Australian conditions: a review. *Australian Journal of Experimental Agriculture*, *41*(6), 823-839. https://doi.org/https://doi.org/10.1071/EA01023

Strandberg, E., & Oltenacu, P. A. (1989). Economic Consequences of Different Calving Intervals. *Acta Agriculturae Scandinavica*, *39*(4), 407-420. https://doi.org/10.1080/00015128909438534

Suleiman, T., Mdegela, R., & Karimuribo, E. (2016). Characteristics of dairy farming and its effect on milk production: a case study of Unguja island of Zanzibar, Tanzania. *Livestock Research for Rural Development*, *28*(10), 174.

Sveberg, G., Refsdal, A. O., Erhard, H. W., Kommisrud, E., Aldrin, M., Tvete, I. F., Buckley, F., Waldmann, A., & Ropstad, E. (2013). Sexually active groups in cattle-a novel estrus sign. *J Dairy Sci*, *96*(7), 4375-4386. https://doi.org/10.3168/jds.2012-6407

Sveberg, G., Rogers, G. W., Cooper, J., Refsdal, A. O., Erhard, H. W., Kommisrud, E., Buckley, F., Waldmann, A., & Ropstad, E. (2015). Comparison of Holstein-Friesian and Norwegian Red dairy cattle for estrus length and estrous signs. *J Dairy Sci*, *98*(4), 2450-2461. https://doi.org/10.3168/jds.2014-8905

Swai, E., Bryant, M., Karimuribo, E., French, N., Ogden, N., Fitzpatrick, J., & Kambarage, D. (2005b). A cross-sectional study of reproductive performance of smallholder dairy cows in coastal Tanzania. *Tropical Animal Health and Production*, *37*(6), 513-525.

Swai, E., Karimuribo, E., Schoonman, L., French, N., Fitzpatrick, J., Kambarage, D., & Bryant, M. (2005a). Description, socio-economic characteristics, disease managements and mortality dynamics in smallholder's dairy production system in coastal humid region of Tanga, Tanzania. *Livestock Research for Rural Development*, *17*(4), Article 41.

Swai, E., Kyakaisho, P., & Ole-Kawanara, M. (2007). Studies on the reproductive performance of crossbred dairy cows raised on smallholder farms in eastern Usambara mountains, Tanzania. *Livestock Research for Rural Development*, *19*(5), Article 61. https://doi.org/http://www.lrrd.org/lrrd19/5/swai19061.htm

Swai, E. S., & Karimuribo, E. D. (2011). Smallholder Dairy Farming in Tanzania. *Outlook on Agriculture*, *40*(1), 21-27. https://doi.org/10.5367/oa.2011.0034

Talukder, S. (2015). Oestrus and ovulation detection in pasture-based dairy herds: the role of new technologies. PhD thesis; University of Sydney. https://doi.org/https://core.ac.uk/download/pdf/41240908.pdf

Tamminga, S., Luteijn, P., & Meijer, R. (1997). Changes in composition and energy content of liveweight loss in dairy cows with time after parturition. *Livestock Production Science*, *52*(1), 31-38.

Thatcher, W., Bilby, T., Bartolome, J., Silvestre, F., Staples, C., & Santos, J. (2006). Strategies for improving fertility in the modern dairy cow. *Theriogenology*, *65*(1), 30-44. https://doi.org/https://doi.org/10.1016/j.theriogenology.2005.10.004

The_cow_vets. (2000). *Heat Detection*. The Cow Vets. Retrieved April 19 from https://www.thecowvets.co.nz/heat-detection/#:~:text=This%20new%20tech%20is%20rapidly,Other

Trimberger, G. W., & Davis, H. (1943). Conception rate in dairy cattle by artificial insemination at various stages of estrus.

Upham, G. (1991). Measuring dairy herd reproductive performance. *The Bovine Practitioner*, 49-56. https://doi.org/https://doi.org/10.21423/bovine-vol1991no26p49-56

Van-Eerdenburg, C. M., Karthaus, D., Taverne, M. A. M., Mercis, I., & Szenci, O. (2002). The Relationship between Estrous Behavioral Score and Time of Ovulation in Dairy Cattle. *Journal of Dairy Science*, *85*(5), 1150-1156. https://doi.org/10.3168/jds.S0022-0302(02)74177-5

van Belzen, D. N. (2017). *Achieving sustainable production of milk*. Burleigh Dodds Science Publishing.

Van Eerdenburg, F., Karthaus, D., Taverne, M., Mercis, I., & Szenci, O. (2002). The relationship between estrous behavioral score and time of ovulation in dairy cattle. *Journal of Dairy Science*, *85*(5), 1150-1156.

VanRaden, P., Sanders, A., Tooker, M., Miller, R., Norman, H., Kuhn, M., & Wiggans, G. (2004). Development of a national genetic evaluation for cow fertility. *Journal of Dairy Science*, *87*(7), 2285-2292. https://doi.org/10.3168/jds.S0022-0302(04)70049-1

Vasseur, E., Gibbons, J., Rushen, J., & de Passille, A. M. (2013). Development and implementation of a training program to ensure high repeatability of body condition scoring of dairy cows. *J Dairy Sci*, *96*(7), 4725-4737. https://doi.org/10.3168/jds.2012-6359

Veerkamp, R. F., Beerda, B., & van der Lende, T. (2003). Effects of genetic selection for milk yield on energy balance, levels of hormones, and metabolites in lactating cattle, and possible links to reduced fertility. *Livestock Production Science*, *83*(2), 257-275. https://doi.org/10.1016/S0301-6226(03)00108-8

Waiblinger, S., & Menke, C. (1999). Influence of herd size on human—cow relationships. *Anthrozoös*, *12*(4), 240-247. https://doi.org/https://doi.org/10.2752/089279399787000156

Walsh, S. W., Williams, E. J., & Evans, A. C. (2011). A review of the causes of poor fertility in high milk producing dairy cows. *Anim Reprod Sci*, *123*(3-4), 127-138. https://doi.org/10.1016/j.anireprosci.2010.12.001

Weigel, K. A. (2006). Prospects for improving reproductive performance through genetic selection. *Anim Reprod Sci*, *96*(3-4), 323-330. https://doi.org/10.1016/j.anireprosci.2006.08.010

Weigel, K. A., & Rekaya, R. (2000). Genetic Parameters for Reproductive Traits of Holstein Cattle in California and Minnesota. *Journal of Dairy Science*, *83*(5), 1072-1080. https://doi.org/10.3168/jds.S0022-0302(00)74971-X

Whay, H. R., Main, D. C. J., Green, L. E., & Webster, A. J. F. (2003). Assessment of the welfare of dairy cattle using animal-based measurements: direct observations and investigation of farm records. *Veterinary Record: Journal of the British Veterinary Association*, *153*(7), 197-202. https://doi.org/10.1136/vr.153.7.197

WHO. (2008). *Advocacy, communication and social mobilization for TB control: a guide to developing knowledge, attitude and practice surveys* (9241596171).

Wildman, E. E., Jones, G. M., Wagner, P. E., Boman, R. L., Troutt, H. F., Jr., & Lesch, T. N. (1982). A Dairy Cow Body Condition Scoring System and Its Relationship to Selected Production Characteristics. *Journal of Dairy Science*, *65*(3), 495-501. https://doi.org/10.3168/jds.S0022-0302(82)82223-6

Williams, K., & Buzhardt, L. (2021). *Body Condition Scores*. Retrieved May from https://vcahospitals.com/know-your-pet/body-condition-scores

Williamson, N., Morris, R., Blood, D., Cannon, C., & Wright, P. (1972). A study of oestrous behaviour and oestrus detection methods in a large commercial dairy herd. u. Oestrous signs and behaviour patterns. https://doi.org/https://doi.org/10.1136/vr.91.3.58

Wright, I. A., & Russel, A. J. F. (1984). Partition of fat, body composition and body condition score in mature cows. *Animal Production*, *38*(1), 23-32. https://doi.org/10.1017/S0003356100041313

Xu, Z. Z. (2017). Effect of time of artificial insemination after oestrus detection on non-return rate of lactating dairy cows on pasture. *N Z Vet J*, *65*(3), 119-123. https://doi.org/https://doi.org/10.1080/00480169.2016.1256238

Yoshida, C., & Nakao, T. (2005). Some characteristics of primary and secondary oestrous signs in high-producing dairy cows. *Reproduction in Domestic Animals*, *40*(2), 150-155.

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Chapter Three: Understanding Smallholder Dairy Farming in Tanzania: A Cross-Sectional Survey of Farmer Demographics and Management Constraints

Foreword: This chapter covers the demographics of the smallholder dairy cattle farms and farmers alongside their farm attendants. Additionally, the chapter addresses the general constraints in dairy farming and management perceived by 301 smallholder dairy cattle farmers across the thirteen districts of the six key dairy farming regions on the Tanzanian mainland. This study has been submitted for publication in the Veterinary Medicine and Science Journal. In this thesis, the manuscript has been presented in the journal format and style.

Title: Understanding Smallholder Dairy Farming in Tanzania: A Cross-Sectional Survey of Farmer Demographics and Management Constraints

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Abstract

There has been a significant shift in the population of smallholder dairy cattle farmers in Tanzania, yet we lack current demographic data and information on key productivity constraints. This cross-sectional survey of 301 smallholder dairy cattle farmers across six regions aimed to gather demographic data and identify key farming constraints. Of the 301 households surveyed, 74% were headed by men; however, in Njombe, there was an equal number of women and men. Most respondents had primary education(55%); however, in Morogoro, 68% of farmers had secondary/university education. Across four regions (Njombe, Mbeya, Kilimanjaro and Arusha), herd size of 3-4 animals was most common (32-50%); however, in Morogoro and Tanga most herds had >4 animals (66% and 78%, respectively). Zero-grazing was the most common grazing system (75%), but tethering was predominant (68%) in Mbeya. Cash purchase was the most common means of obtaining the first cattle beast (66%), although a gift from a relative/friend (49%) was the most common source in Mbeya. High input costs (93%), unavailability of feed (71%), lack of land (68%) and diseases (62%) were the key identified constraints, while high breeding costs (96%), poor oestrus detection (89%), cows not displaying oestrus (79%) and lack of AI services (51%) were the key constraints to successful breeding. Widespread challenges related to management, feed and reproduction face smallholder dairy systems in Tanzania, and they vary regionally. Addressing these through region-tailored interventions could substantially improve productivity and sustainability. **Keywords**

Smallholder dairy cattle farmer, household, demographic, farming constraints

1. Introduction

Historically, the initiatives to improve the dairy cattle industry in Tanzania started in 1921 when the colonial government of the time introduced the first Holstein and Ayrshire cattle into Temeke, Dar es Salaam (Sumberg, 1997). The establishment of a few medium-to-large-scale settler dairy farms in the country's Northern and Southern highland regions followed this move. However, most of these farms were nationalised after independence, following the Arusha Declaration in 1967. This resulted in the dairy sector in the 1970s being dominated by governmental parastatal and state-owned farms, especially following the formation in 1975 of the Tanzanian Dairy Farming Company and Tanzania Dairies Ltd. The latter was responsible for processing and selling milk to consumers (Kurwijila et al., 1995; Mdoe & Wiggins, 1997). However, subsequent challenges, such as political interference with the milk price and the generally low productivity of the cattle, led to poor economic performance and the collapse of these governmental parastatal and state-owned farms in the early 1980s (Kurwijila et al., 1995; Mdoe & Wiggins, 1997).

After this collapse, efforts to bridge the gap between Tanzanian milk production and demand for dairy products within Tanzania began. These efforts were led by private, religious and non-governmental organisations, all of which promoted smallholder dairy cattle farming (Kurwijila & Boki, 2003). Smallholder dairy cattle farming refers to a type of dairy farming practised on a small scale, with a mean herd size of approximately 4 animals, ranging from 1 to 12 cattle, often involving unimproved genetics and rudimentary management by individual farmers or households (Chagunda et al., 2004; McDermott et al., 2010; Njombe et al., 2011; Alonso et al., 2014; Nell et al., 2014; Suleiman et al., 2016) . These efforts were supported, at the government level, by the Tanzania Livestock Policy, which emphasised the promotion of smallholder dairy cattle farming (Mdoe & Wiggins, 1997).

Initially, most smallholder dairy farms were owned by high and mid-ranking civil servants, with cows being kept in their owners' place of residence ("backyard production"), with milk production being a supplementary, rather than a primary income source (Mdoe & Wiggins, 1997; Swai & Karimuribo, 2011). However, beginning in the 1990s, smallholder dairy cattle farming started experiencing rapid growth across Tanzania, with a change in the demographics of farmers, from producers for whom milk was a supplementary income, to producers for whom milk was the primary source of income (Limbu, 1999). The smallholder dairy sector thus currently provides significant income and employment across rural, peri-urban and urban areas of Tanzania, as well as being a valuable source of human nutrition in those areas (Gillah et al., 2012; Limbu, 1999; NBS&OCGS, 2021).

Of the 33.9. million cattle in Tanzania, 33.8. million (99.6%) are kept by smallholder farmers, with only 142,000 (0.4%) in large-scale farms (i.e. farms that have more than 100 cattle) (Mbwambo et al., 2019; NBS&OCGS, 2021). Around 80% of the milk produced in Tanzania is from Indigenous cattle (Brett, 2019). For smallholders, improved dairy cattle are generally crosses of European dairy breeds (e.g. Friesian, Ayrshire, and Jersey) with indigenous cattle, especially the Tanzanian Shorthorn Zebu, Boran, and Sahiwal. These improved dairy cattle are concentrated in the rural areas of Tanga, Arusha, Kilimanjaro and Manyara (Northern Highland regions), Mbeya, Iringa and Njombe (Southern Highland regions), as well as in the Morogoro, Kagera and Dar es Salaam regions (Swai & Karimuribo, 2011).

Initiatives to improve the productivity of the Tanzanian dairy industry, particularly smallholder farms, are ongoing (Chawala et al., 2019). These initiatives are a mixture of government-led and external stakeholder-led programmes. They include long-running programmes such as the Dairy Development Programme, and the Heifer Project International in Tanzania (HPI) Scheme (Msangya et al., 2015). Community Action Research Programme (Pasape, 2022), AgResults Tanzania Dairy Productivity Challenge Project (2019-2024), and the newer countrywide programme for the transformation of the livestock sector titled 'Livestock Sector Transformation Plan (MoLF, 2022).

However, despite the significant change in the population of smallholder dairy cattle farmers across Tanzania since the 1980s, there is limited information regarding the demographics of such farmers. Some localised surveys of smallholder dairy cattle farming have been undertaken, but these have generally been limited to one or two regions: Dar es Salaam (Kivaria et al., 2006b), Morogoro (Gillah et al., 2013; Gillah et al., 2014), Tanga (Alonso et al., 2014), and Kilimanjaro and Arusha (Swai et al., 2014). Larger scale surveys have been undertaken, but they did not report demographic data (Chawala et al., 2019) or had a limited analysis of such data (Mwambene et al., 2014). Further, these studies were largely conducted in urban and peri-urban areas, so they provided limited information about farmers at the regional/rural level. Nor did they well characterise the demographics of smallholder dairy farmers. Such information is needed to inform farm advisers, the government, and development agencies to better understand the smallholder dairy farmer population, as well as their goals and challenges. Such understanding could be useful in targeting support for dairy farmers based on individual requirements (especially if structured at the regional level) rather than using a “one-size-fits-all” programme across Tanzania. Thus, as part of a larger study looking at the reproductive performance of cows on Tanzanian smallholder dairy farms, data on the demographic characteristics of smallholder dairy cattle farmers from thirteen districts across six different regions of Tanzania were collected. Alongside this, information on the constraints that the farmers perceived to be affecting their productivity was also collected.

This paper, therefore, aims to investigate the demographics of smallholder/small-scale dairy cattle farmers in the main dairying regions of Tanzania, and to investigate their views on the constraints that they presently experience in their dairy-farming enterprises. Understanding these demographics and constraints could help in the identification of farmers involved in the dairying, their capacity, along with the challenges limiting their productivity. Consequently, assist in planning and implementation of appropriate dairy strategies. Secondarily, it aims to identify whether there are significant differences between regions in demographics of, and constraints to smallholder dairy farmers across these six key dairying regions in Tanzania.

2. Methodology

2.1. Ethical considerations and approval

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007) of the United Republic of Tanzania. Permission letters were first provided by the office of the Regional Administrative Secretary from the six study regions, and then, from the Executive Directors of the respective District Councils (DC), Town Council (TC), Municipal Council (MC) or City Council (CC) of the thirteen study districts of Tanzania mainland. A local veterinarian or livestock officer first introduced the interviewer (the first author did all interviews) to the farmer/respondent (usually the family head). The interviewer explained the reason for the visit. Thereafter, each respondent/farmer was given a written informed consent form for them to sign before participating in the questionnaire interview. If the interviewee was unable to read and write, another family member was called to approve and sign on their behalf. Results were anonymised and personal data were kept confidential. The specific consent of the relevant participants was obtained for any photographs used to illustrate this study.

2.2. Study area and study farm selection

Six regions of the Tanzania mainland were purposely selected, principally based on the proportion of improved dairy cattle (NBS&OCGS, 2021; Nyange & Mdoe, 1995). Three of these regions were in the Northern Highlands (Arusha, Kilimanjaro and Tanga), two in the Southern Highlands (Mbeya and Njombe) and one (Morogoro) in the Eastern zone. . Within each region, district(s) were selected using a convenience sampling process with the help of local veterinarians/livestock officers (Figure 1). Within each district, convenience sampling was employed to identify study villages and the first study farm in each village (whose suitability was decided by the local veterinarian/livestock officer and interviewer). Snowball sampling was then employed to select other study farms in a particular village. Subjects could nominate as many further subjects as they wished, with non-discriminative sampling being used until >50 respondents had been identified per region. No sample size calculations were undertaken; the number of farms visited was based on the number of farms the authors believed could be visited within a district over 2 weeks. If a selected farm owner or someone who could respond to the questionnaire was not available, then the interviewer moved to the next one on the list.

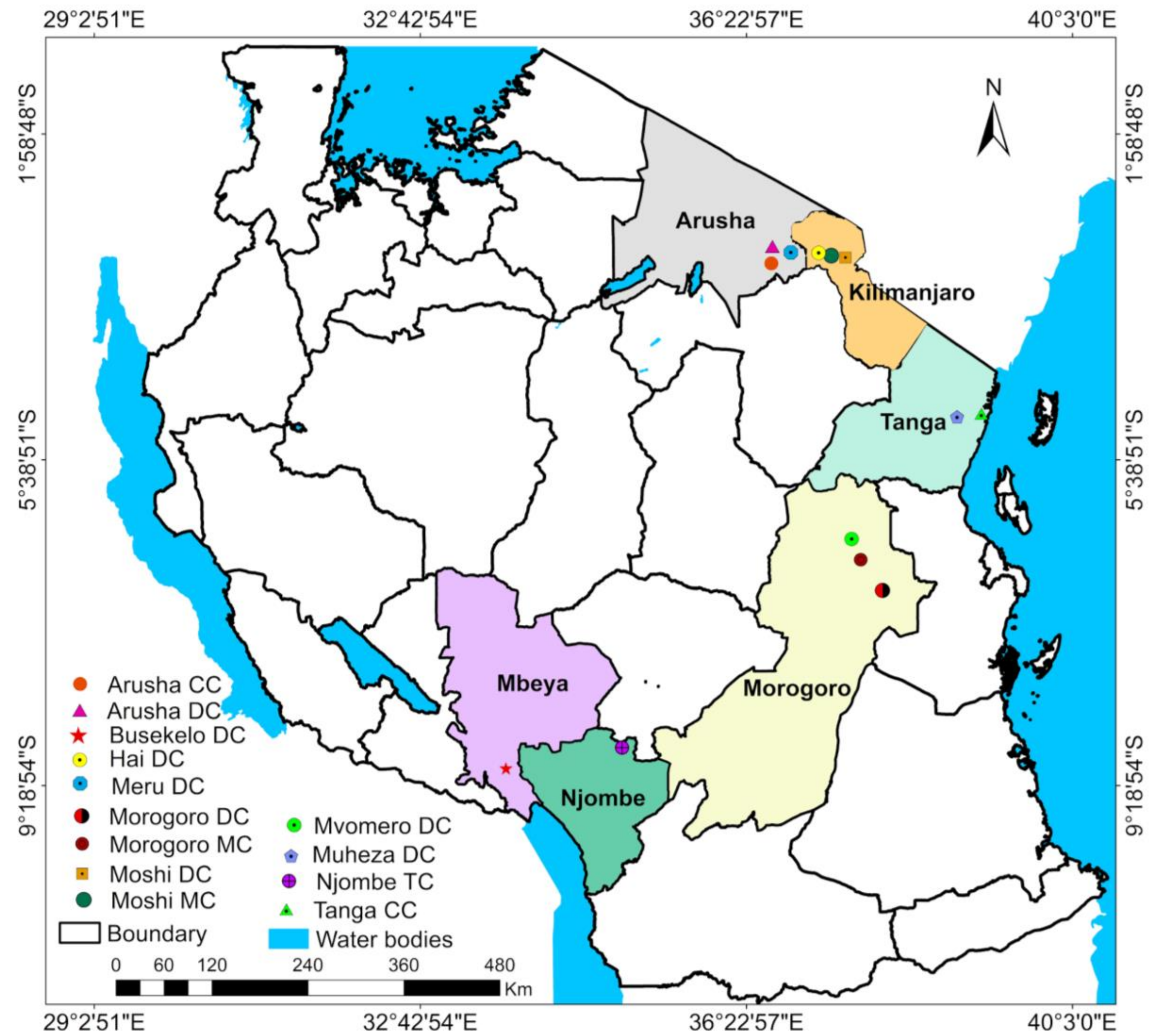

Figure 1. Map of Tanzania showing study regions: Southern Highland regions (Mbeya, Iringa and Njombe), Northern Highland regions (Arusha, Kilimanjaro, and Tanga), and Morogoro. (**Key:** DC - District council, TC - Town council, MC - Municipal council and CC - City council).

2.3. Field data collection

Information from smallholder dairy cattle farmers was gathered using a cross-sectional study design from May 2022 to February 2023. Research data were collected using a structured and pre-tested questionnaire-guided interview, supplemented by on-farm observations for verification. Pre-testing was conducted in the Morogoro municipality, involving twenty-four smallholder farmers (who were not included in the final questionnaire) and eleven experts, including veterinarians, livestock officers, and researchers. The feedback obtained from both groups was considered during the adjustments on clarity, relevance, and comprehensiveness to improve its validity and reliability. The questionnaire was formulated so that all the questions were closed, and responses were entered into KoboToolbox (Cambridge, USA) for subsequent data collation.

Initial information collected from farmers included age, gender, dairy farming experience, involvement (full or part-time), education level, dependence on dairy farming (plus other household/farm income-generating activities) and decision-making process on the farm. Respondents were also asked about farm-related issues, such as the source of their first dairy animals, herd size, herd composition, as well as breeding practices and preferences. The last section asked the respondents for their opinions regarding the key constraints that affected their farm, capturing information related to cattle health and reproduction, availability of veterinary and breeding services, availability of land and feed, and access to markets for their product. Data collection was performed on the farmers' premises, so that statements about their livestock (etc.) could be readily verified by concurrent observation.

2.4. Data management and analysis

Data from the questionnaire were downloaded from KoboToolbox to Excel spreadsheets (Microsoft, Seattle, USA) before analysis using SPSS version 25 (IBM, Seattle, USA). Results were tabulated and are presented as overall results and by region.

The effect of region on responses was assessed using logistic regression, with response as the outcome variable and region as the sole predictor variable. Categories were combined for all analyses where totals across all regions were less than 10. For most responses, multinomial logistic regression was utilised:

$$Pr(y_i = j / Region_i) = \frac{\exp(\beta_{0j} + \beta_{1j}.Region_i)}{\sum^{J}_{m=1} \exp(\beta_{0m} + \beta_{1m}.Region_i)}$$

This calculates the probability of the multinomial outcome (y_i) being a specific category (j), conditioned on the given region ($Region_i$).

For outcomes where the responses were clearly ordered (e.g. questions around importance, ordinal logistic regression was used:

$$Pr(y_i > k / Region_i) = \frac{1}{1 + \exp(-(\beta_0 + \beta_1.Region_i) - K_k}$$

This calculates the probability of the multinomial outcome (y_i) being higher than a particular category (j), conditional on the specific region ($Region_i$). In this model, K_k is the threshold parameter for category *k.*

For all ordinal models, the proportional odds assumption was tested. If this assumption was not met, then a multinomial regression was utilised. For all analyses, except where otherwise stated, Tanga was used as the reference region, and the category with the highest frequency in the outcome was designated as the reference category.

3. Results

At least 50 smallholder dairy cattle farmers were interviewed per region, except Arusha, where only 16 farmers were interviewed. Fewer farmers in Arusha participated following the unavailability of local veterinarians and livestock officers, who were participating in the national livestock identification programme, resulting in reluctance among farmers to participate. Overall, across the six regions, 301 farmers were recruited for the survey (Table 1).

Table 1. The number of regions, districts and smallholder dairy cattle farmers visited during a survey on smallholder dairy cattle farming, demographics, and constraints in Tanzania.

S/No	Regions visited	Districts visited	Farmers	
			Per District	Per Region (n (%))
1	Njombe	Njombe TC	54	54 (17.9)
2	Mbeya	Busokelo DC	55	55 (18.3)
3	Tanga	Tanga CC	12	53 (17.6)
		Muheza DC	41	
4	Kilimanjaro	Moshi MC	8	66 (21.9)
		Moshi DC	18	
		Hai DC	40	
5	Arusha	Arusha CC	6	16 (5.3)
		Arusha DC	1	
		Meru DC	9	
6	Morogoro	Morogoro MC	47	57 (18.9)
		Morogoro DC	5	
		Mvomero DC	5	
Total		**13**	**301**	**301 (100)**

Key: DC - District council, TC - Town council, MC - Municipal council and CC -City council

3.1. Smallholder dairy farmers' household, family, and farm demographics

Of the 301 households that participated in this study, 224 (74%) were headed by a father(Table 2). For the analysis of the effect of region, two categories were created (father and mother), with respondents who were recorded as 'other' combined with father or mother, depending on their gender (male or female). There were differences between regions in who was the head of the household (Figure 2), with households in Njombe having much higher odds of having a female head of the household than households in Tanga (odds ratio (OR): 5.2, 95%CI: 2.8-13.1).

Table 2. Smallholder dairy cattle farmers' household and herd characteristics across the study regions in Tanzania mainland. Data are shown as the number of respondents and percentage of responses within each region n (%).

Character	Category	Region						
		Njombe	**Mbeya**	**Tanga**	**Kilimanjaro**	**Arusha**	**Morogoro**	**Total**
Total respondents		n=54 (18)	n=55 (18)	n=53 (18)	n=66 (22)	n=16 (5)	n=57 (19)	n=301 (100)
Head of the family								
	Father	**26 (48)**	**48 (87)**	**45 (85)**	**52 (79)**	**12 (75)**	**41 (72)**	**224 (74)**
	Mother	**26 (48)**	2 (4)	8 (15)	14 (21)	4 (25)	15 (26)	69 (23)
	Other[a]	2 (4)	5 (9)				1 (2)	8 (3)
Type of family								
	monogamy	**41 (76)**	**43 (78)**	**43 (81)**	**46 (70)**	**14 (88)**	**49 (86)**	**236 (78)**
	polygamy	5 (9)	4 (7)	4 (8)	2 (3)		2 (4)	17 (6)
	widow	6 (11)		4 (8)	11 (17)	2 (13)	4 (7)	27 (9)
	widower			1 (2)	5 (8)			6 (2)
	Single parents & unmarried	2 (4)	8 (15)	1 (2)	2 (3)		2 (4)	15 (5)
Participatory decision-making in the family								
	yes	**39 (72)**	**49 (89)**	**46 (87)**	**51 (77)**	**15 (94)**	**48 (84)**	**248 (82)**
	no	15 (28)	6 (11)	7 (13)	15 (23)	1 (6)	9 (16)	53 (18)
People taking care of animals								
	1, 2	**40 (74)**	**38 (69)**	23 (43)	**44 (67)**	**14 (88)**	**42 (74)**	**201 (67)**
	3, 4	13 (24)	17 (31)	**30 (57)**	22 (33)	2 (13)	14 (25)	98 (33)
	≥5	1 (2)					1 (2)	2 (1)
Source of the first dairy cattle/cow								
	Cash purchase	**37 (69)**	25 (45)	**27 (51)**	**48 (73)**	**13 (81)**	**50 (88)**	**200 (66)**
	Gift (relatives or friends)	3 (6)	**27 (49)**	11 (21)	17 (26)	3 (19)	6 (11)	67 (22)
	NGO[b]	14 (26)		14 (26)			1 (2)	29 (10)
	Home-bred and bank		3 (5)	1 (2)	1 (2)			5 (2)
Total herd size (all cattle)								
	1, 2	14 (26)	15 (27)	6 (11)	15 (23)	1 (6)	9 (16)	60 (20)

	3, 4	**25 (46)**	**20 (36)**	6 (11)	**21 (32)**	**8 (50)**	10 (18)	**90 (30)**
	5, 6	12 (22)	13 (24)	11 (21)	15 (23)	2 (13)	9 (16)	62 (21)
	7, 8	2 (4)	5 (9)	**13 (25)**	8 (12)	1 (6)	11 (19)	40 (13)
	9, 10		1 (2)	11 (21)	5 (8)	4 (25)	3 (5)	24 (8)
	≥11	1 (2)	1 (2)	6 (11)	2 (3)		**15 (26)**	25 (8)
Number of cows								
Respondents with adult cows		n=52 (96)	n=48 (87)	n=53 (100)	n=60 (91)	n=15 (94)	n=54 (95)	n=282 (94)
	1, 2	**32 (62)**	**26 (54)**	18 (34)	**33 (55)**	**10 (67)**	18 (33)	**137 (49)**
	3, 4	18 (34)	20 (42)	**22 (42)**	22 (37)	5 (33)	**19 (35)**	106 (38)
	5, 6	1 (2)	1 (2)	9 (17)	3 (5)		5 (9)	19 (7)
	7, 8	1 (2)		1 (2)			6 (11)	8 (3)
	≥9		1 (2)	3 (6)	2 (3)		6 (11)	12 (4)
Number of heifers								
Respondents with heifers		n=23 (46)	n=37 (67)	n=36 (68)	n=43 (65)	n=13 (65)	n=37 (65)	n=189 (63)
	1, 2	**22 (96)**	**33 (89)**	**32 (89)**	**41 (95)**	**9 (69)**	**25 (68)**	**162 (86)**
	3, 4	1 (4)	4 (11)	3 (8)	2 (5)	4 (31)	11 (30)	25 (13)
Number of calves								
Respondents with calves		n=30 (56)	n=31 (56)	n=48 (91)	n=43 (65)	n=13 (65)	n=43 (75)	n=208 (69)
	1, 2	**25 (83)**	**29 (94)**	**23 (48)**	**26 (61)**	**10 (77)**	**20 (47)**	**133 (64)**
	3, 4	5 (17)	2 (6)	18 (38)	14 (33)	2 (15)	13 (30)	54 (26)
	≥5			7 (15)	3 (6)	1 ()	10 (23)	21 (10)
Number of bulls								
Respondents with bulls		n=2 (4)	n=2 (4)	n=8 (15)	n=16 (24)	n=6 (38)	n=18 (32)	n=52 (17)
	1, 2	**2 (100)**	**2 (100)**	**8 (100)**	**15 (94)**	**6 (100)**	**15 (83)**	**48 (92)**
	≥3				1 (6)		3 (17)	4 (8)

For each region, results in bold indicate the category with the highest frequency for that question; [a] child or relative [b]; non-governmental organisation, e.g. Heifer-in-Trust Scheme

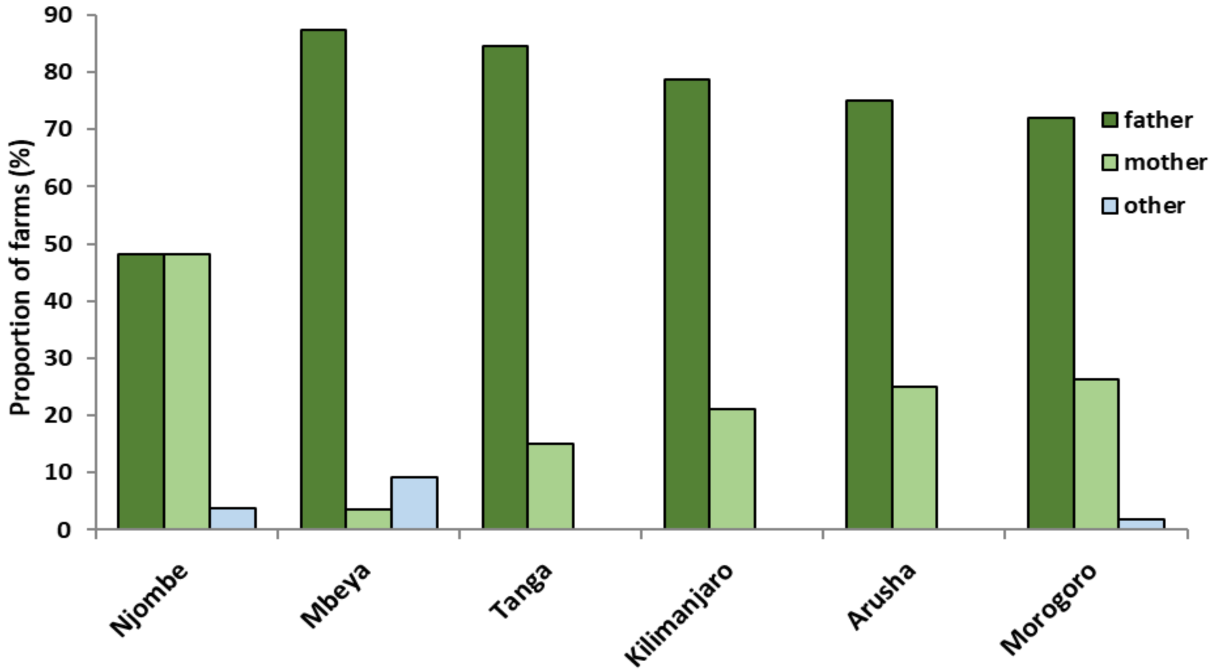

Figure 2. Gender of the head of the household of Tanzania smallholder dairy farms.

Most households (236/301; 78%) were monogamous, with the lowest proportion recorded in Njombe (41/54; 76%), and the highest in Arusha (14/16; 88%) (Figure 3). Additionally, in most households (248/301; 82%), the entire family was involved in the decision-making process, not just the head of the household.

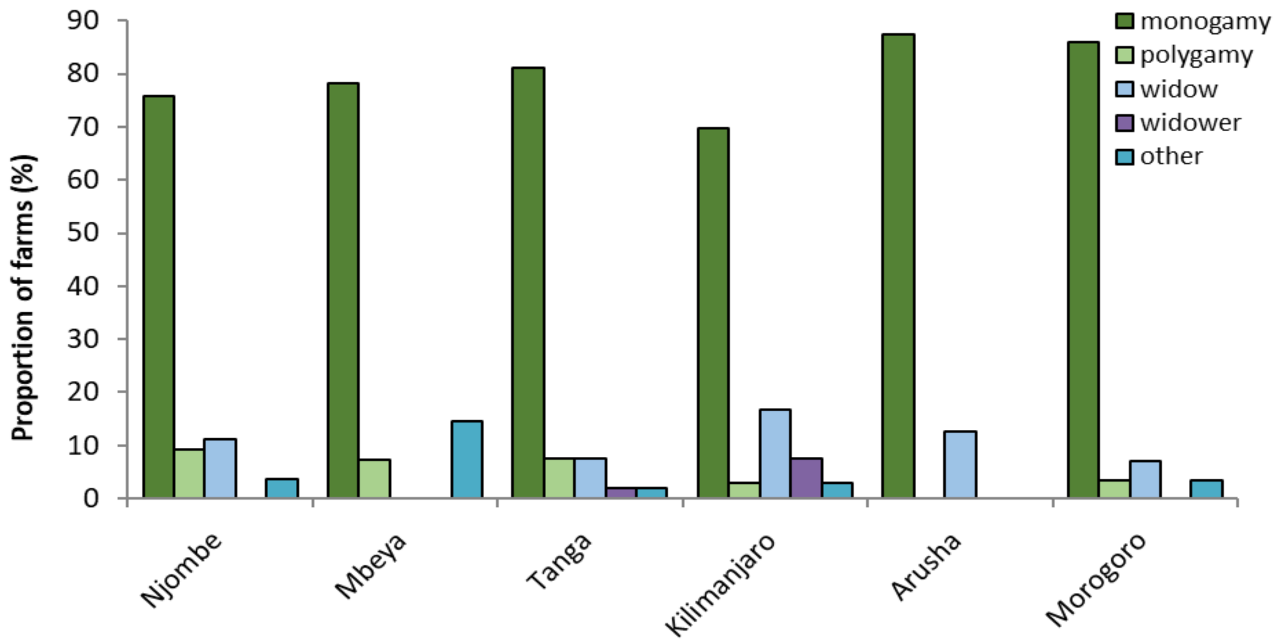

Figure 3. Comparison across six regions of Tanzania on family type in smallholder dairy farmers' households.

Total herd size ranged from 1 to 35 cattle, with the '3-4' category being the mode herd size (90/301; 30%) (Table 2 and Figure 4). For the analysis of the effect of region, five categories of herd size were used: 1-2, 3-4, 5-6, 7-8 and ≥9. Ordinal logistic regression identified differences across regions in the proportion of farms in one of the higher herd size categories. Compared to Tanga, the odds of farms being in the higher herd size category were notably less in Kilimanjaro (OR: 0.3, 95%CI: 0.1-0.5), Mbeya (OR: 0.2, 95%CI: 0.08-0.3) and Njombe (OR: 0.1, 95%CI: 0.07-0.3).

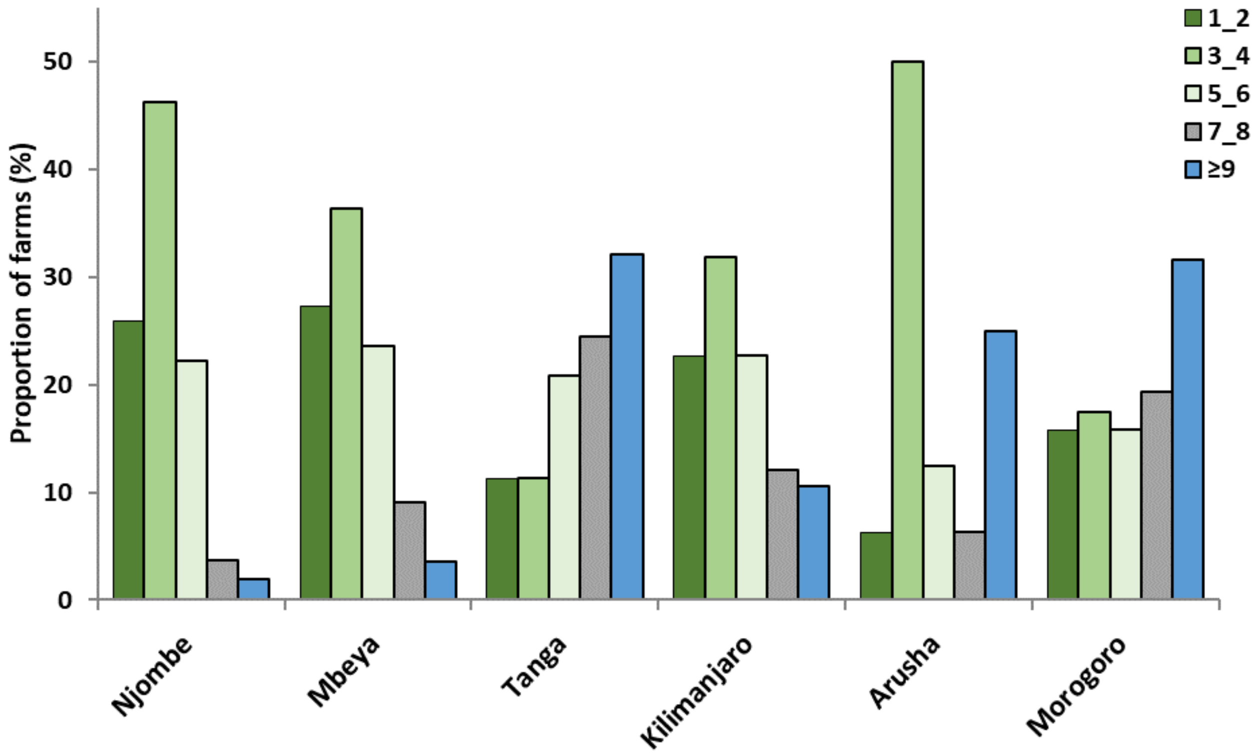

Figure 4. Number of cattle per smallholder dairy farms across the study regions in Tanzania.

Of the 301 farms, 19 had no adult cows, 112 had no heifers, 98 had no calves and 249 farms had no breeding bulls. No effect of region on the proportion of farms with milking cows was found but compared to Tanga, farms in Njombe were less likely to have heifers (OR: 0.4, 95%CI: 0.2-0.8), and farms in Morogoro more likely to have bulls (OR: 2.6, 95%CI: 1.02-6.6). The proportion of farms with calves in Tanga was the highest of any region, with farms in Tanga having higher odds of having calves than farms in Njombe (OR: 0.1, 95%CI: 0.1-0.4), Mbeya (OR: 0.1, 95%CI: 0.1-0.4), Kilimanjaro (OR: 0.2, 95%CI: 0.1-0.6) and Morogoro (OR: 0.3, 95%CI: 0.1-1).

Most respondents (201; 67%) reported having fewer than three people who took care of the dairy cattle on their farm (Table 2). As with herd size, there was an effect of region such that, with reference to Tanga, the odds of having more than two people actively participating on the farm was lower than in all other regions: Kilimanjaro (OR: 0.4, 95%CI: 0.2-0.8), Mbeya (OR: 0.3, 95%CI: 0.2-0.8), Morogoro (OR: 0.3, 95%CI: 0.1-0.6) and Njombe (OR: 0.3, 95%CI: 0.1-0.6).

Cash purchase was the dominant (200; 66%) source of obtaining the first dairy cattle beast (Table 2). Regionally, this was true for all regions except for Mbeya, where a gift from a relative or friend was the most common source (Figure 5). For analysis of regional differences, data were merged into three groups: cash, gift and other (merging non-governmental organisation (NGO), bank and home-bred). Arusha was excluded from this analysis as there were no farms in the 'other' category. Relative to cash purchase, three regions had different odds of a gift being the source of their first cattle beast than respondents in Tanga: the odds were higher in Mbeya (OR: 2.7, 95%CI: 1.1-6.4) and were lower in Morogoro (OR: 0.3, 95%CI: 0.1-0.9) and Njombe (OR: 0.2, 95%CI: 0.05-0.8). For the 'other' category, the odds were lower in Kilimanjaro (OR: 0.04, 95%CI: 0.01-0.3), Mbeya (OR: 0.2, 95%CI: 0.1-0.8) and Morogoro (OR: 0.04, 95%CI: 0.01-0.3) relative to cash purchase than in Tanga.

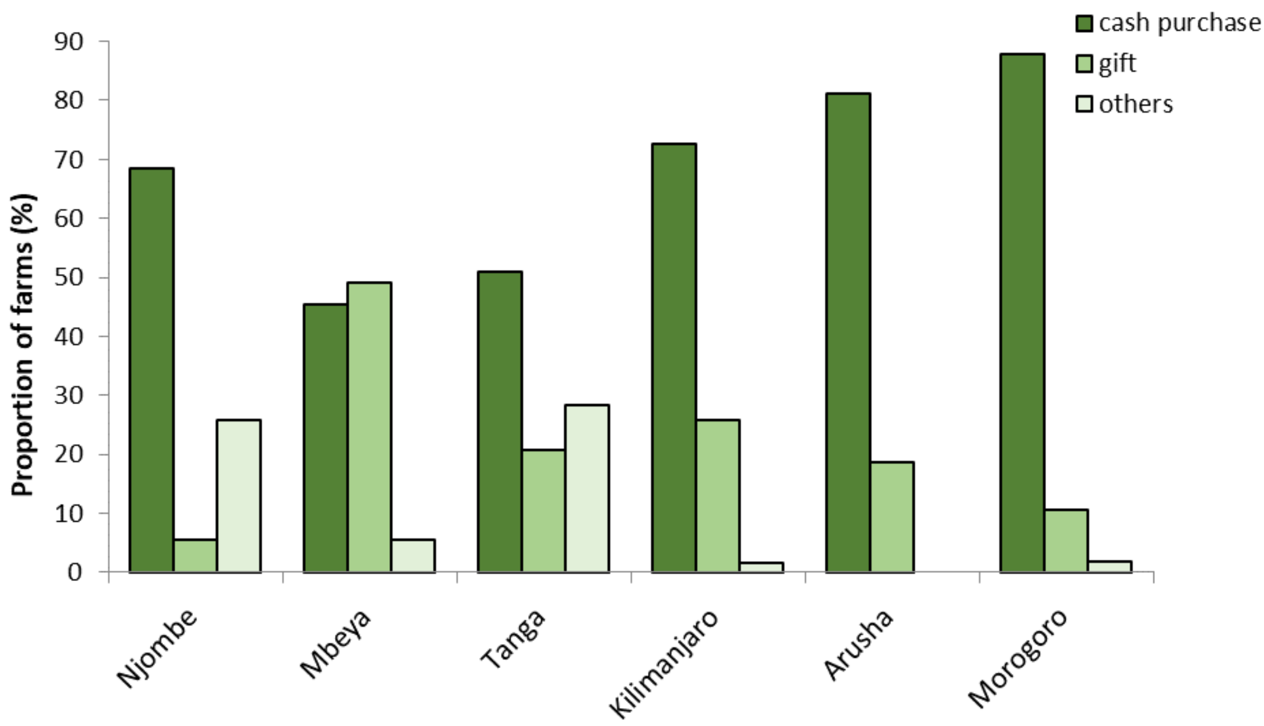

Figure 5. Source of first dairy animal across smallholder cattle farms/households in Tanzania.

3.2. Farmers/respondents and assistants/worker's demographic characteristics

Most respondents were over 40 years of age (238/301; 79%), with the majority (155/301; 52%), being between 41 and 60 years. This was consistent across all regions (Figure 6 and Table 3). Using ordinal logistic regression with four age categories (i.e. ≤20, 21-40, 41-60 and ≥61), the odds of a farmer being in a higher age category were lower in Mbeya (OR: 0.4, 95%CI: 0.2-0.7) compared to Tanga.

Experience in dairy farming was classified into 10-year blocks (≤10, 11-21, etc.). The highest proportion of respondents (118/301; 39%) had ≤10 years of experience. There was little difference between regions, except that ordinal logistic regression showed that the odds of being in a higher experience category were lower in Morogoro (OR: 0.49, 95%CI: 0.24-0.97) compared with Tanga.

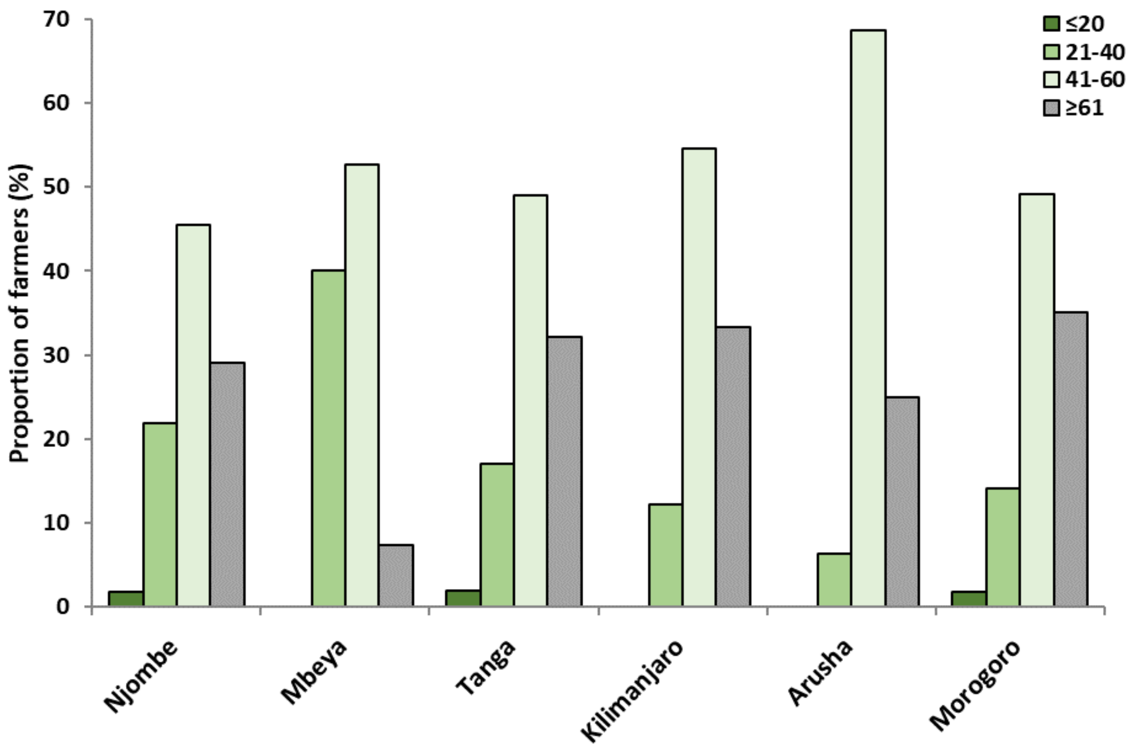

Figure 6. Distribution of ages of smallholder dairy cattle farmers across the study regions of Tanzania.

Most respondents (231/301; 77%) were involved full-time in dairy cattle farming (Table 3). The proportion was highest in Tanga (46/53; 87%) and lowest in Morogoro (41/57; 58%), with the odds of being a part-time farmer being higher in Morogoro (OR: 4.8, 95%CI: 1.8-12.4) than in Tanga.

The most common level of education in respondents was primary level (7-14 years) (166/301; 55%) (Table 3 and Figure 7). For analysis of the effect of region, respondents who had not had a formal education were excluded. Compared to respondents from Tanga, the proportion in each education category was similar across all regions except for Morogoro, where respondents were more likely to have had a higher category of education (OR: 6.5, 95%CI: 3-13.9).

Table 3. Demographics of smallholder dairy cattle farmers and assistants/workers across the study regions in Tanzania mainland. Data are shown as number of respondents and percentage of responses within each region n (%).

Character	Category	Region						
		Njombe	Mbeya	Tanga	Kilimanjaro	Arusha	Morogoro	Total
Demographics of dairy farmers								
Total respondents		n=54 (18)	n=55 (18)	n=53 (18)	n=66 (22)	n=16 (5)	n=57 (19)	n=301 (100)
Age								
	≤20	1(2)		1(2)			1(2)	3(1)
	21-40	12(22)	22(40)	9(17)	8(12)	1(6)	8(14)	60(20)
	41-60	**25(46)**	**29(53)**	**26(49)**	**36(55)**	**11(69)**	**28(49)**	**155(51)**
	≥61	16(30)	4(7)	17(32)	22(33)	4(25)	20(35)	83(28)
Experience in dairy cattle farming (years)								
	≤10	**27(50)**	**21(38)**	16(30)	**20(30)**	3(19)	**31(54)**	**118(39)**
	11 to 20	16(30)	19(35)	**18(34)**	14(21)	**6(38)**	11(19)	84(28)
	21 to 30	7(13)	10(18)	12(23)	**20(30)**	4(25)	12(21)	65(22)
	31 to 40	4(7)	3(5)	7(13)	10(15)	2(13)	2(4)	28(9)
	≥41		2(4)		2(3)	1(6)	1(2)	6(2)
Involvement in dairy cattle farming								
	Full time	**41(76)**	**42(76)**	**46(87)**	**50(76)**	**11(69)**	**41(58)**	**231(77)**
	Part-time	13(24)	13(24)	7(13)	16(24)	5(31)	16(42)	70(23)
Education level								
	No formal education	2(4)	2(4)	1(2)	2(3)		1(2)	8(3)
	Primary	**32(59)**	**34(62)**	**35(57)**	**38(52)**	**10(63)**	17(30)	**166(55)**
	Secondary	10(19)	9(17)	8(23)	8(12)	1(6)	7(12)	43(14)
	College	5(9)	5(9)	6(11)	15(26)	3(19)	9(16)	43(14)
	University	5(9)	5(9)	3(8)	3(8)	2(13)	**23(40)**	41(14)
Demographics of farm assistants								

Total respondents		n=31(15)	n=25(12)	n=43(21)	n=46(23)	n=6(3)	n=52(26)	n=203(%)
Age								
	≤20	**16(52)**	7(28)	7(16)	14(31)	**3(50)**	**24(46)**	71(35)
	21-30	8(26)	**17(68)**	**17(40)**	**19(41)**	2(33)	23(44)	**86(42)**
	31-40	3(10)	1(4)	14(33)	7(15)	1(17)	4(8)	30(15)
	≥41	4(13)		5(12)	6(13)		1(2)	16(8)
Experience in dairy cattle farming (years)								
	<1	6(19)	2(8)	3(7)	8(17)		17(33)	36(18)
	1 to 5	**21(68)**	**16(64)**	**27(63)**	**32(70)**	**6(100)**	**30(58)**	**132(65)**
	6 to 10	2(6)	5(20)	10(23)	5(11)		5(10)	27(13)
	11 to 15	1(3)	2(8)	1(2)				4(2)
	≥16	1(3)		2(5)	1(2)			4(2)
Involvement in dairy cattle farming								
	Full time	**26(84)**	**18(72)**	**35(81)**	**40(87)**	**6(100)**	**51(98)**	**176(87)**
	Part time	5(16)	7(28)	8(19)	6(13)		1(2)	27(13)
Education level								
	No formal education	6(19)	1(4)	4(9)	6(13)		4(8)	21(10)
	Primary	**16(52)**	**15(60)**	**28(65)**	**30(63)**	**3(50)**	**42(81)**	**134(66)**
	Secondary	4(13)	4(16)	8(19)	6(13)	2(33)	4(8)	28(14)
	College	3(10)	5(20)	1(2)	2(4)			11(5)
	University	2(7)		2(5)	2(7)	1(17)	2(4)	9(4)

For each region, results in bold indicate the category with the highest frequency for that question

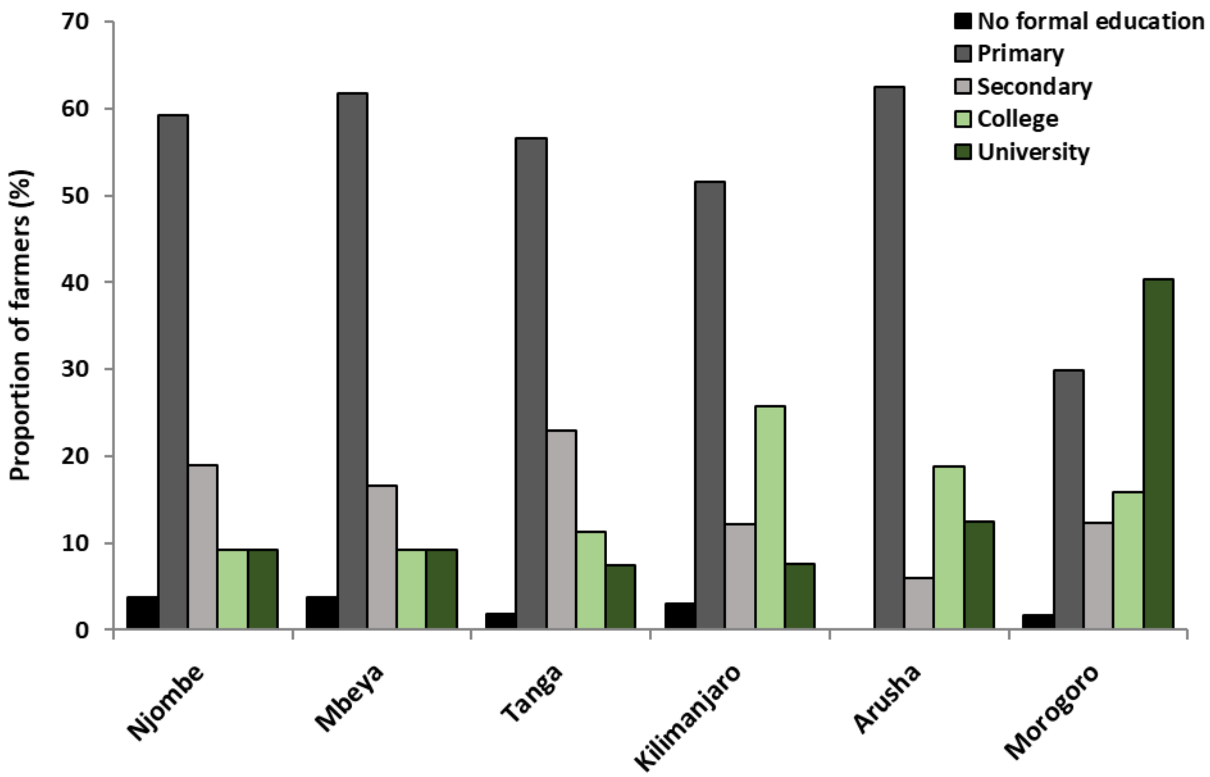

Figure 7. The maximum education level of smallholder dairy cattle farmers across the study regions in Tanzania.

For the farm workers/assistants, the majority (157/203; 77%) were aged ≤30 years and had ≤5 years of experience (168/203: 83%), making them generally younger and less experienced than the main respondents (Table 3). Analysis of assistant demographics excluded data from Arusha, as there were only 6 responses from that region. Compared to workers in Tanga, assistants from Mbeya (OR: 0.3, 95%CI: 0.12-0.77), Morogoro (OR: 0.2, 95%CI: 0.093-0.45), and Njombe (OR: 0.32, 95%CI: 0.09-0.56) all had lower odds of being in a higher age category. For experience, data were merged into four categories: <1 year, 1 to 5 years, 6 to years and ≥ 11 years. This analysis showed that assistants from Morogoro had lower odds of being in a higher experience category (OR: 0.18, 95%CI: 0.08-0.44) compared to those in Tanga, as did assistants in Kilimanjaro (OR: 0.37, 95%CI: 0.16-0.88). Most assistants were full-time workers (176/203; 87%), and most (182/203; 90%) had had only primary education. The education level of farm workers was similar across the study regions.

3.3. Smallholder dairy farmers' sources of household income

Although 77% of respondents reported full-time involvement with dairy farming, almost all households reported having other sources of income (282/301; 94%) (Table 4). Crop farming was the most common alternative, with 180/282 (64%) gaining at least some income from it. Conversely, only 37% (104/282) and 29% (81/282) of respondents were involved in employment or business, respectively. For analysis of regional differences in other income sources, two categories were created, i.e., 'Yes' (representing major, moderate and minor) and 'Not at all'. Excluding Mbeya and Arusha, where there are no respondents for the 'Not at all' category, the odds for a farmer participating in crop farming were lower in Njombe (OR: 0.1, 95%CI: 0.01-0.9) than in Tanga. Further, the odds of a farmer relying on employment as the source of income were highest in Morogoro (OR: 5.2, 95%CI: 2.2-12.4) and lowest in Njombe (OR: 0.1, 95%CI: 0.04-0.4). Lastly, Mbeya had lower odds (OR: 0.2, 95%CI: 0.07-0.6) for its farmers depending on business as an income source compared to Tanga.

Furthermore, farmers' responses (major, moderate and minor, excluding 'not at all') for their involvement in other income-generation activities (i.e., crop farming, employment and business) apart from dairying, were further evaluated to determine their contribution to the household income. For that, responses were given score values i.e., 3=major, 2=moderate and 1=minor; where the total score was ≥6, then dairying was defined as not being the major source of income and defined as being the major source of income when the total score was ≤5. Based on this score, dairying was the major income source for 238/282 (84%) households. Logistic regression was used to evaluate the regional differences (excluding the Arusha region due to fewer respondents) of household dependence on other income sources. Concerning Tanga, only farmers from the Njombe had higher odds (OR: 4.9, 95%CI: 1.7-13.9) of non-dairying income being their major source of income.

3.4. Smallholder farmers' dairy cattle management system and feed sources

Across the 301 farms, 225 (75%) of respondents kept their dairy cattle under a zero-grazing/intensive system, in which forages were harvested daily and brought to the cattle in their shelter (Figures 8, 9, 10a, 10b and Table 5). This system dominated across all regions except Mbeya, where tethering at pasture (Figures 10a and 10b) was predominant (37/55; 68%). Across the different regions, the odds of semi-intensive farming (compared to intensive/zero grazing) were higher in Mbeya (OR: 12, 95%CI: 3.03-47.5) and Morogoro (OR: 6, 95%CI: 1.9-19.1) than in Tanga.

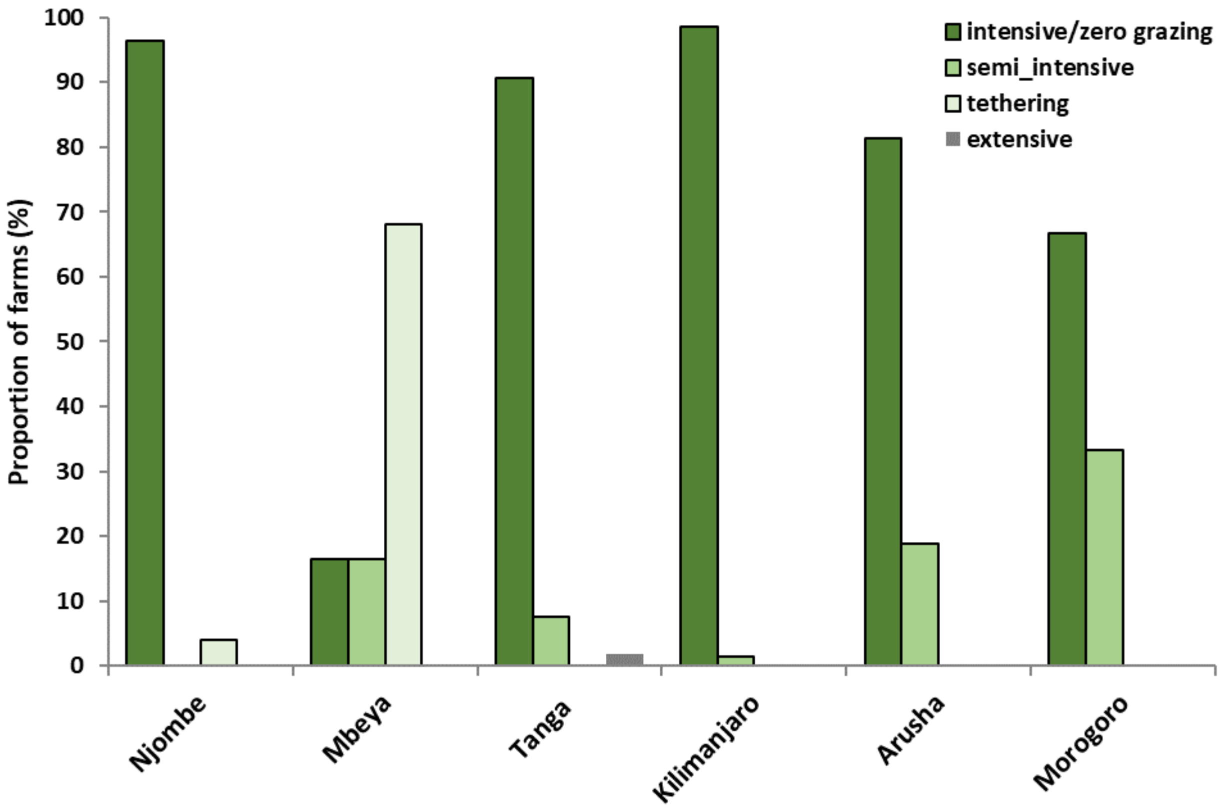

Figure 8. Dairy cattle management systems among the smallholder dairy farms across the study regions of Tanzania mainland.

Figure 9 Dairy cow tethered for grazing by a smallholder dairy farmer.

(a) b)

Figure 10 Smallholder dairy cattle farmers undertaking cut and carry farming: a) carrying the cut forages, b) spreading cut forages in the feeding trough.

Sources of feed are shown in Table 5 and Figure 11. Natural pastures (i.e. naturally occurring grasses, legumes, and other species) ranked as the most used source of feed, with 294/301 (98%) respondents using at least some natural pasture, and 241 (80%) using it as the major source of feed. Most respondents gave at least some supplementary concentrate feeds to their cattle; only 10/301(3%) stated that they did not do so at all.

Table 4. Income generation activities in the smallholder dairy cattle household across the study regions in Tanzania mainland. Data are shown as number of respondents and percentage of responses within each region n (%).

Character	Category	Region						
		Njombe	Mbeya	Tanga	Kilimanjaro	Arusha	Morogoro	Total
Total respondents		n=54(18)	n=55(18)	n=53(18)	n=66(22)	n=16(5)	n=57(19)	n=301(100)
Dependency on dairy cattle farming								
	yes	8(15)		5(9)	2(3)		4(7)	19(6)
	no	**46(85)**	**55(100)**	**48(91)**	**64(97)**	**16(100)**	**53(93)**	**282(94)**
Other income sources								
Total respondents		n=46(16)	n=55(20)	n=48(17)	n=64(23)	n=16(6)	n=53(19)	n=282(100)
Employment								
	Major	12(26)	3(5)	3(6)	7(11)		**17(32)**	42(15)
	Moderate	4(9)		11(23)	8(13)	1(6)	**17(32)**	41(15)
	Minor	2(4)	1(2)	5(10)	5(8)	1(6)	7(13)	21(7)
	Not at all	**28(61)**	**51(93)**	**29(60)**	**44(69)**	**14(88)**	12(23)	**178(63)**
Crop farming								
	Major	**24(52)**	20(36)	3(6)	15(23)	3(19)	3(6)	68(24)
	Moderate	17(37)	**34(62)**	**16(33)**	**31(48)**	**9(56)**	5(9)	**112(40)**
	Minor	4(9)	1(2)	21(44)	14(22)	4(25)	**34(64)**	78(28)
	Not at all	1(2)		8(17)	4(6)		11(21)	24(9)
Business								
	Major	6(13)		6(13)	7(11)	3(19)	4(8)	26(9)
	Moderate	3(7)	4(7)	7(15)	6(9)	1(6)	4(8)	25(9)
	Minor	2(4)	2(4)	5(10)	12(19)	4(25)	5(9)	30(11)
	Not at all	**35(76)**	**49(89)**	**30(63)**	**39(61)**	**8(50)**	**40(75)**	**201(71)**

For each region, results in bold indicate the category with the highest frequency for that question

Table 5. Dairy cattle management systems and feed sources utilized by the smallholder dairy cattle farms across the study regions of mainland Tanzania. Data are shown as number of respondents and percentage of responses within each region n (%).

Character	Category	Region						
		Njombe	**Mbeya**	**Tanga**	**Kilimanjaro**	**Arusha**	**Morogoro**	**Total**
Total respondents		n=54 (18)	n=55 (18)	n=53 (18)	n=66 (22)	n=16 (5)	n=57 (19)	n=301 (100)
Cattle rearing system								
	intensive/zero grazing	**52(96)**	9(16)	**48(91)**	**65(99)**	**13(81)**	**38(67)**	**225(75)**
	semi-intensive		9(16)	4(8)	1(2)	3(19)	19(33)	36(12)
	tethering	2(4)	**37(68)**					39(13)
	extensive			1(2)				1(0.3)
Feed sources								
Fodder plot at farm								
	major	10(19)	**19(35)**				3(5)	32(11)
	moderate	**16(30)**	11(20)	10(19)	8(12)		2(4)	47(16)
	minor	15(28)	18(18)	14(26)	**31(47)**	3(19)	7(12)	88(29)
	not at all	13(24)	7(13)	**29(55)**	27(41)	**13(81)**	**45(79)**	**134(45)**
Crop residuals								
	major	**41(76)**	5(9)	1(2)	12(18)	6(38)		65(22)
	moderate	12(22)	**28(51)**	2(4)	**46(70)**	**10(63)**	9(16)	107(36)
	minor		22(40)	**48(91)**	8(12)		**47(83)**	**125(42)**
	not at all	1(2)		2(4)			1(2)	4(1)
Natural pastures (roadside and swamp areas)								
	major	**49(91)**	**37(67)**	**49(93)**	**51(77)**	**11(69)**	**44(77)**	**241(80)**
	moderate	5(9)	16(29)	1(2)	10(15)	5(31)	6(11)	43(14)
	minor		1(2)	2(4)	3(5)		4(7)	10(3)
	not at all		1(2)	1(2)	2(3)		3(5)	7(2)
Conserved feeds (hay + silage)								
	major	8(15)						8(6)

	moderate	12(22)		3(6)		1(6)	3(5)	19(6)
	minor	4(7)	3(6)	11(21)	10(15)	6(38)	5(9)	39(13)
	not at all	**30(56)**	**52(95)**	**39(74)**	**56(85)**	**9(56)**	**49(86)**	**235(78)**
Bought fodder								
	major	2(4)	2(4)					4(1)
	moderate	3(6)	1(2)					4(1)
	minor	5(9)	21(38)		2(3)	1(6)	3(5)	32(11)
	not at all	**44(82)**	**31(56)**	**53(100)**	**64(97)**	**15(94)**	**54(95)**	**261(87)**
Grazing								
	major	1(2)		4(8)			16(28)	21(7)
	moderate		2(4)	1(2)			1(2)	4(1)
	minor		33(60)					33(11)
	not at all	**53(98)**	**20(36)**	**48(91)**	**66(100)**	**16(100)**	**40(70)**	**243(81)**
Cut fodder from outside								
	major	**51(94)**						51(17)
	moderate	3(6)	9(16)					12(4)
	minor		20(36)	3(6)	1(2)		10(18)	34(11)
	not at all		**26(47)**	**50(94)**	**65(98)**	**16(100)**	**47(83)**	**204(68)**
Supplementary feeding (concentrates)								
	Yes	**54(100)**	**55(100)**	**52(98)**	**61(92)**	**15(94)**	**54(95)**	**291(97)**
	No			1(2)	5(8)	1(6)	3(5)	10(3)

For each region, results in bold indicate the category with the highest frequency for that question

Some feeds were used to a very limited extent, including conserved forage, bought fodder and actual grazing; all of which were used by <25% of respondents. Across all regions, not at all was the most common response for those feeds (Table 5). Other, more commonly used feed sources had regional variations. Cut forage was used by 32% of respondents. Of those, 54/97 (55%) were in Njombe, with most of those (51) reporting that it was a major source of feed (a category only used in Njombe). Fodder plots were used by 55% of respondents, but this varied appreciably by region, with respondents in Njombe and Mbeya having higher odds of reporting that they used fodder plots (at any level) than respondents in Tanga (OR: 3.8, 95%CI: 1.7–8.7, and OR: 8.3, 95%CI: 3.2–21.7, respectively), while respondents in Morogoro were less likely to report that they used fodder plots than those in Tanga (OR: 0.3, 95%CI: 0.1–0.7).

Most respondents used crop residuals (only 4% did not) but the level of use varied markedly by region. Compared to Tanga, the odds of a respondent reporting moderate/major use of crop residuals (as opposed to minor/not at all) were much higher in Njombe and Mbeya (OR: 883, 95%CI: 88.9-8770 and OR: 25, 95%CI: 6.9-90.3, respectively).

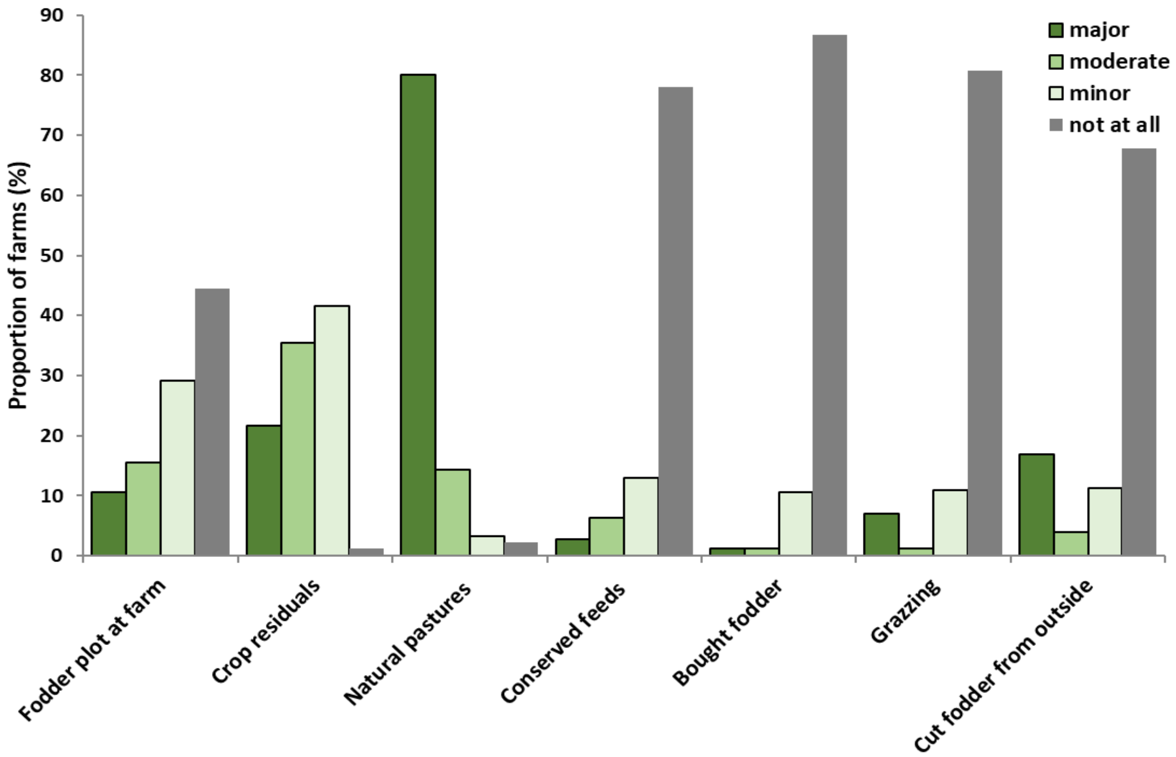

Figure 11. Dairy cattle feed sources for smallholder dairy farmers in different regions of Tanzania.

3.5. Smallholder dairy farming constraints

Farmers were asked to rank the important farming constraints (Table 6 and Figure 12), with high costs of inputs ranked as very highly significant by 229/301 (76%) respondents and by most farmers in all six study regions. Lack of enough land (150/301; 50%) was the second most important constraint, while unavailability of feed (24/301; 41%) was the third.

For the assessment of regional variations, three ordinal categories were created i.e., High (encompassing 'very highly significant' and 'important'), Moderate and Low (encompassing little importance and minor) and not at all (data from Arusha were excluded from this analysis because of the absence of data in one or more categories). Insufficient land was reported to be an important constraint by farmers in Kilimanjaro (OR: 3.2, 95%CI: 1.5–6.8), Morogoro (3.1, 95%CI: 1.4–7) and Njombe (2.1; 95%CI 1-4.5) than in Tanga. Availability of feed was regarded as of greater importance by farmers from Kilimanjaro (OR: 11.7, 95%CI: 4.6–29.8), Mbeya (OR: 3.4, 95%CI: 1.6–7.3), Morogoro (OR: 3.6, 95%CI: 1.6–7.8) and Njombe (OR: 2.7, 95%CI: 5.9–1.3) than those from Tanga.

Lack of money to buy inputs was regarded as of greater importance in both Mbeya and Njombe (OR 7.32, 95%CI: 3.2–16.6 and 3, 95%CI: 1.4–6.2, respectively) than in Tanga, while the unpredictability of the milk market was regarded as of greater importance in Njombe (OR: 11.4, 95%CI: 0.2–0.7), Kilimanjaro (OR: 4.8, 95%CI: 2.2–10.4) and Mbeya (OR: 2.3, 95%CI: 1–5.2) than in Tanga. Concerning constraints for successful breeding, farmers in Njombe regarded the lack of a breeding service as more important than farmers in Tanga (OR: 9.5, 95%CI: 4.1–22.2).

The importance of disease as a constraint was analysed using a multinomial regression, as the proportional odds assumption was not met ($P<0.001$). The odds of being in the low category compared to the higher category were consistent across regions. For the Moderate category, farmers in Kilimanjaro and Morogoro had lower odds of being in the Moderate rather than the High category when compared to farmers in Tanga (OR: 0.2, 95%CI: 0.1–0.1 and OR: 0.2, 95%CI: 0.1–0.7, respectively).

Table 6. General constraints in smallholder dairy cattle farming across the study regions in Tanzania mainland. Data are shown as number of respondents and percentage of responses within each region n (%).

Character	Category	Regions						Total
		Njombe	Mbeya	Tanga	Kilimanjaro	Arusha	Morogoro	
Total respondents		n=54 (18)	n=55 (18)	n=53 (18)	n=66 (22)	n=16 (5)	n=57 (19)	n=301 (100)
Lack of enough land								
	Very highly significant	**31(57)**	**30(55)**	11(21)	**32(48)**	**15(94)**	**31(54)**	**150(50)**
	Important	4(7)	3(5)	15(28)	18(27)	1(6)	12(21)	53(18)
	Moderate	9(17)	8(15)	6(11)	3(5)		3(5)	29(10)
	Minor	4(7)	9(16)	**20(38)**	11(17)		9(16)	53(18)
	Of little importance	6(11)	5(9)	1(2)	2(3)		2(4)	16(5)
Unavailability of feeds								
	Very highly significant	**26(48)**	**25(46)**	5(9)	13(20)	7(44)	14(25)	90(30)
	Important	10(17)	14(26)	17(32)	**46(70)**	**9(56)**	**28(49)**	**124(41)**
	Moderate	7(13)	7(13)	9(17)	4(6)		3(5)	30(10)
	Minor	5(9)	7(13)	**19(36)**	3(5)		11(19)	45(15)
	Of little importance	6(11)	2(4)	3(6)			1(2)	12(4)
High costs of inputs								
	Very highly significant	**42(78)**	**52(95)**	**35(66)**	**50(76)**	**13(81)**	**37(65)**	**229(76)**
	Important	4(7)	1(2)	13(25)	15(23)	3(19)	15(26)	51(17)
	Moderate	5(9)		5(9)			2(4)	12(4)
	Minor	1(2)	2(4)		1(2)		3(5)	7(2)
	Of little importance	2(4)						2(1)
Lack of money to buy inputs								
	Very highly significant	**17(32)**	**23(42)**	4(8)	4(6)	1(6)	1(2)	50(17)
	Important	13(24)	20(36)	12(23)	20(30)	**11(69)**	12(21)	88(29)
	Moderate	11(20)	3(6)	9(17)	9(14)		3(5)	35(12)
	Minor	8(15)	3(6)	**25(47)**	**30(46)**	4(25)	**38(67)**	**108(36)**
	Of little importance	5(9)	6(11)	3(6)	3(5)		3(5)	20(7)

Unpredictable milk market							
Very highly significant	**33(61)**	6(11)	4(8)	**20(30)**	**11(69)**	4(7)	78(26)
Important	8(15)	16(29)	10(19)	18(27)	4(25)	7(12)	63(21)
Moderate	4(7)	4(7)		5(8)		5(9)	18(6)
Minor	3(6)	**17(31)**	**23(43)**	18(27)	1(6)	19(33)	**81(27)**
Of little importance	6()	12(22)	16(30)	5(8)		**22(39)**	61(20)
Unavailability of breeding service							
Very highly significant	**17(32)**	3(6)		2(3)		1(2)	23(8)
Important	14(26)	10(18)	8(15)	3(5)	1(6)	9(16)	45(15)
Moderate	10(19)	6(11)	3(6)	5(8)		1(2)	25(8)
Minor	9(17)	**27(49)**	**26(49)**	**37(56)**	**9(56)**	20(35)	**128(43)**
Of little importance	4(8)	9(16)	16(30)	19(29)	6(38)	**26(46)**	80(27)
Diseases							
Very highly significant	**20(37)**	8(15)	2(4)				30(10)
Important	13(24)	19(35)	**24(45)**	**47(71)**	**15(94)**	**39(68)**	**157(52)**
Moderate	10(19)	**21(38)**	15(28)	5(8)		5(9)	56(19)
Minor	9(17)	5(9)	10(19)	11(17)	1(6)	8(14)	44(15)
Of little importance	2(4)	2(4)	2(4)	3(5)		5(9)	14(5)

For each region, results in bold indicate the category with the highest frequency for that question

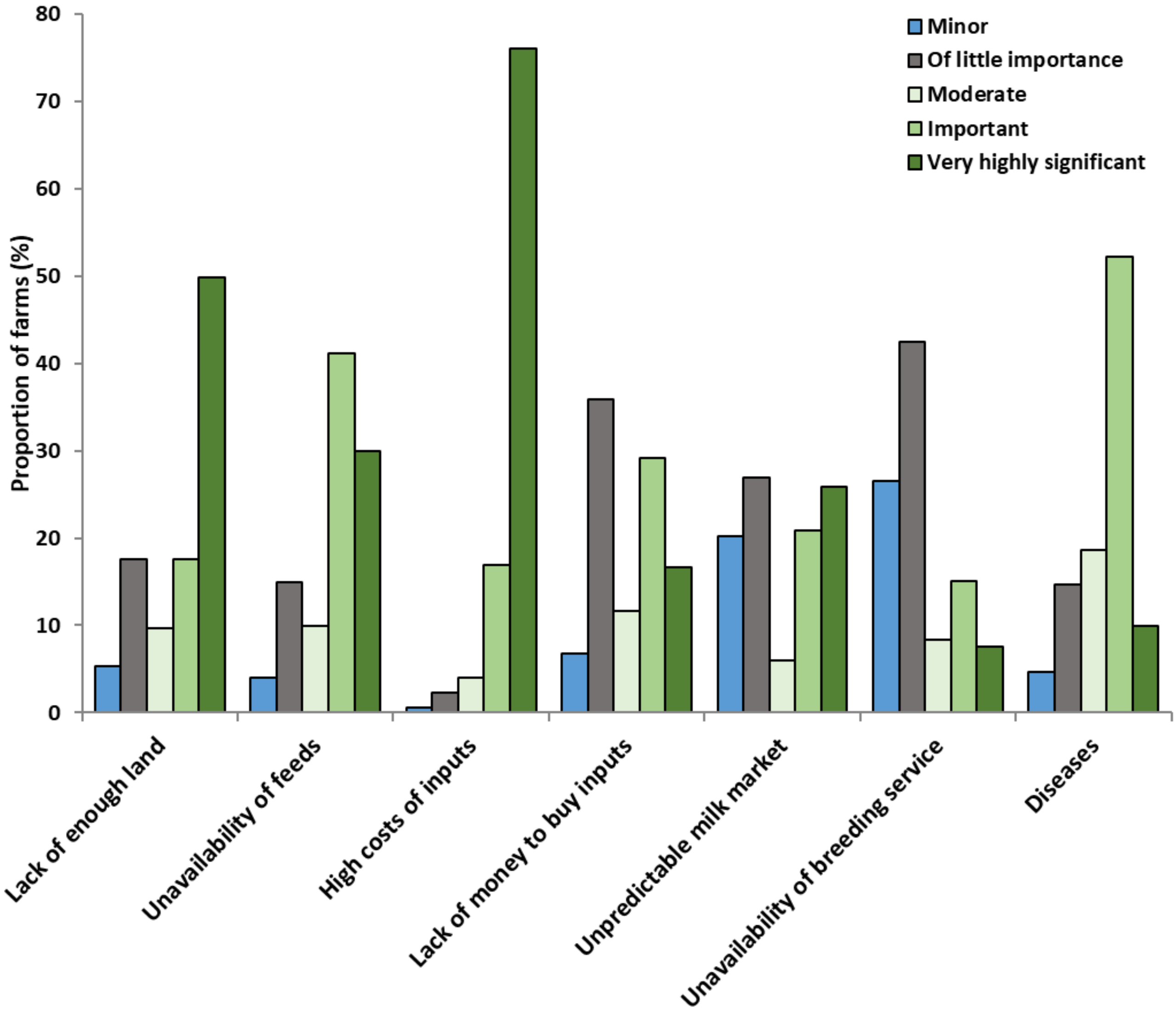

Figure 12. General constraints for successful smallholder dairy cattle farming in Tanzania.

3.6. Dairy breed selection criteria and breeding practice

Preference for one or more breeds (Figure 13) was expressed by 160 (53%) respondents, whereas 59 (20%) had no specific preference (Table 7). Farmers in Njombe were more likely to report having a breed preference than farmers in Tanga (OR: 21.5, 95%CI: 4.7 - 97.6). Of those who expressed a breed preference, the focus was milk production (146/160: 91%), followed by easy handling (108/160: 68%), large body size (100/160: 63%) and ease of getting pregnant (37/160: 60%).

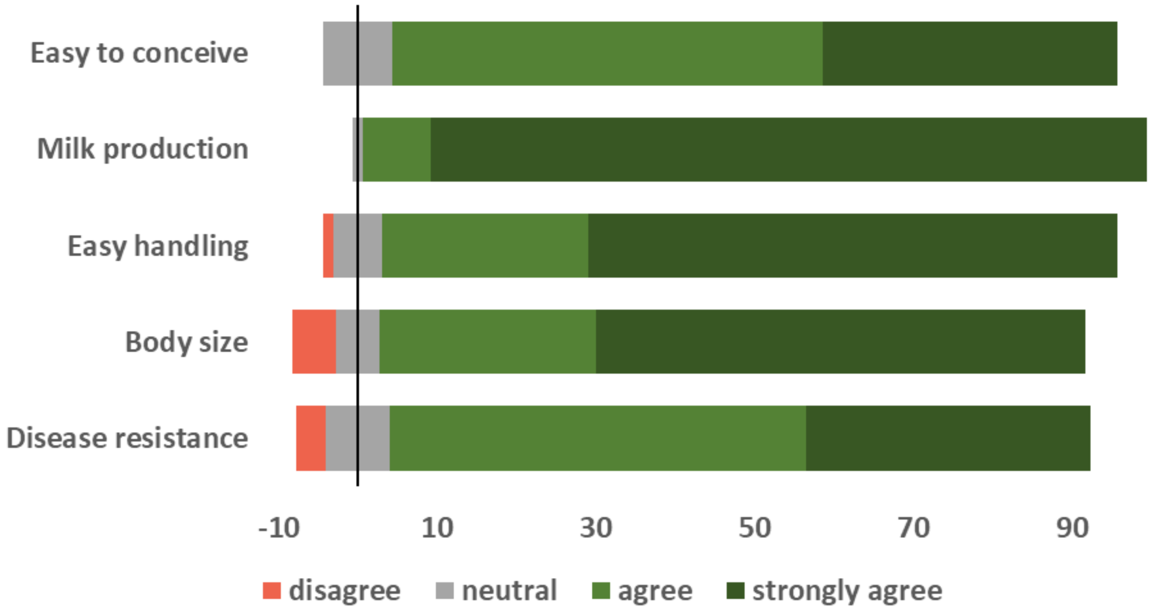

Figure 13. General criteria expressed by smallholder dairy cattle farmers in Tanzania when selecting their preferred dairy cattle breed.

Breeding methods are summarised in Table 8 and Figure 14. In general, the most frequently applied breeding method involved a mix of natural service and artificial insemination (AI) (138/301; 46%). At the regional level, AI alone was the most common method in Arusha (10/16; 63%), Kilimanjaro (34/66; 52%) and Tanga (29/53; 55%), while most farmers used a mix of AI and natural service in Morogoro (42/57; 74%) and Njombe (33/64; 61%), and natural service only predominated in Mbeya (53/55; 96%). Relative to Tanga, farmers were less likely to report using AI alone in Morogoro (OR: 0.2, 95%CI: 0.1-0.5) and Njombe (OR: 0.4, 95%CI: 0.2-0.9) (this analysis excluded Mbeya as no farmers in that region reported using AI alone).

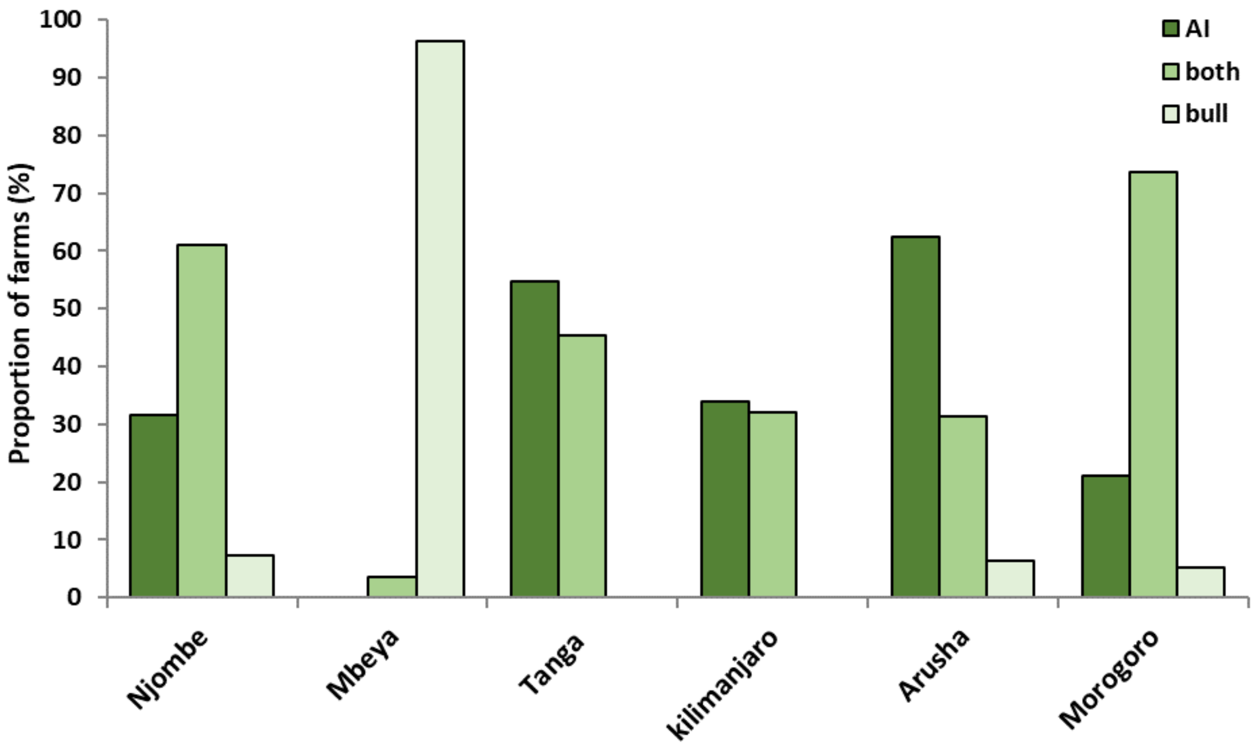

Figure 14. Breeding methods applied by smallholder dairy farmers across the study regions in Tanzania; the use of artificial insemination (AI), just natural breeding (bull only), or a combination (both).

Of the 200 farmers who used natural service on some occasions, 180 answered the question about where they sourced bulls from. Overall, they largely (113/180; 63%) opted to hire bulls from nearby farms, with most of the rest using a combination of their own and their neighbours' bulls (46/180, 26%). Only 17 (9%) reported exclusively using their bulls.

Of the 240 farmers who used AI for at least some inseminations, 221 answered questions about AI use. Across all regions, most farmers reported receiving the service regularly (131/221; 59%) and most (179/221; 80%) reported that waiting time from informing the AI technician to the actual insemination ranged between seven and nine hours.

Table 7. Breed preference and dairy cattle selection criteria were used, among smallholder dairy cattle farmers across the study regions in Tanzania mainland. Data are shown as number of respondents and percentage of responses within each region n (%).

Character	Category	Regions						Total
		Njombe	Mbeya	Tanga	Kilimanjaro	Arusha	Morogoro	
Total respondents		n=54 (18)	n=55 (18)	n=53 (18)	n=66 (22)	n=16 (5)	n=57 (19)	n=301 (100)
Do you have a breed preference?								
	yes	**52(96)**	**34(62)**	**29(55)**	20(30)	4(25)	**21(37)**	**160(53)**
	no	1(2)	6(11)	9(17)	18(27)	**8(50)**	17(30)	59(20)
	I do not know	1(2)	15(27)	15(28)	**28(42)**	4(25)	19(33)	82(27)
Total respondents		n=52(33)	n=34(21)	n=29(18)	n=20(13)	n=4(3)	n=21(13)	n=160(100)
Breed selection criteria								
Body size								
	strongly agree	**33(63)**	**18(53)**	9(31)	**17(85)**	**4(100)**	**19(90)**	**100(63)**
	agree	8(15)	13(38)	**19(66)**	2(10)		2(10)	44(28)
	neutral	4(8)						4(3)
	disagree	7(13)	3(9)	1(3)	1(5)			12(8)
Disease resistance								
	strongly agree	**31(60)**	5(15)	4(14)			**18(86)**	58(36)
	agree	19(37)	**22(65)**	**20(69)**	**16(80)**	**4(100)**	2(10)	**83(52)**
	neutral	1(2)	6(18)	2(7)	3(15)		1(5)	13(8)
	disagree	1(2)	1(3)	3(10)	1(5)			6(4)
Easy handling								
	strongly agree	**41(79)**	**27(79)**	**20(69)**	**11(55)**	**2(50)**	7(33)	**108(68)**
	agree	8(15)	3(9)	6(21)	9(45)	**2(50)**	**12(57)**	40(25)
	neutral	2(4)	3(9)	3(10)			2(10)	10(6)
	disagree	1(2)	1(3)					2(1)
Milk production								

	strongly agree	**47(90)**	**30(88)**	**26(90)**	**19(95)**	**4(100)**	**20(95)**	**146(91)**
	agree	4(8)	3(9)	3(10)	1(5)		1(5)	12(8)
	neutral	1(2)	1(3)					2(1)
Easy to conceive								
	strongly agree	**44(85)**	10(29)	2(7)	3(15)	1(25)		60(38)
	agree	7(13)	**18(53)**	**24(83)**	**15(75)**	**3(75)**	**19(90)**	**86(54)**
	neutral	1(2)	6(18)	3(10)	2(10)		2(10)	14(9)

For each region, results in bold indicate the category with the highest frequency for that question

Table 8. Breeding methods and practice of artificial insemination by the smallholder dairy cattle farmers in Tanzania mainland. Data are shown as number of respondents and percentage of responses within each region n (%).

Character	**Category**	**Regions**						**Total**
		Njombe	**Mbeya**	**Tanga**	**Kilimanjaro**	**Arusha**	**Morogoro**	
Total respondents		n=54 (18)	n=55 (18)	n=53 (18)	n=66 (22)	n=16 (5)	n=57 (19)	n=301 (100)
Breeding method								
	artificial insemination	17(31)		**29(55)**	**34(52)**	**10(63)**	12(21)	102(34)
	both	**33(61)**	2(4)	24(45)	32(49)	5(31)	**42(74)**	**138(46)**
	natural service	4(7)	**53(96)**			1(6)	3(5)	61(20)
Total respondents		n=18(10)	n=55(31)	n=24(13)	n=32(18)	n=6(3)	n=45(25)	n=180(100)
Bull sources								
	Own Bull		2(4)	8(33)	4(13)	1(17)	6(13)	17(9)
	Community bulls only		4(7)					4(2)
	Own and neighbours' bulls	3(17)	3(5)			2(33)	**28(62)**	46(26)
	Neighbours' bulls	**15(83)**	**46(84)**	**16(67)**	**28(88)**	**3(50)**	11(24)	**113(63)**
Total respondents		n=31(14)	n=2(1)	n=53(24)	n=66(30)	n=15(7)	n=54(24)	n=221(100)
How is AI service obtained								
	*Immediately after calling the AI technician	3(10)		8(15)	20(30)	5(33)	3(6)	39(18)
	**Regularly	**16(52)**		**35(66)**	**31(47)**	**10(67)**	**39(72)**	**131(59)**
	Irregular with some interruptions on weekend	12(39)	**2(100)**	10(19)	15(23)		12(22)	51(23)
AI service Waiting time								
	1_to_3_hours	**12(39)**						12(5)
	4_to_6_hours	3(10)			1(2)	1(7)	1(2)	6(3)
	7_to_9_hours	9(29)		**52(98)**	**53(79)**	**14(93)**	**49(91)**	**177(80)**
	10_to_12_hours	7(23)	**2(100)**	1(2)	12(18)		4(7)	26(12)

NB: For each region, results in bold indicate the category with the highest frequency for that question.
*Farmer decides insemination time and call the technician at the time of insemination
**Farmer calls the technician, explains the signs and duration, the technician decides the insemination time

In response to questions about the constraints around successful breeding (Figure 15 and Table 9), almost half of the respondents, 142/301(47%), indicated that the high cost of breeding was a major constraint, with 96% (289/301) identifying high breeding costs as being at least a minor constraint. This is a higher proportion than the effects of poor oestrus detection (89%, 269/301), cows not displaying oestrus (79%, 234/301) and unavailability of AI services (51%, 154/301). Constraints around breeding varied markedly across regions. Except for high breeding cost, compared to farmers in Tanga, farmers in Njombe were more likely to report that all the constraints listed in Table 9 were major/moderate constraints on their farm. The relevant OR were 43.3 (95%CI: 11.7–160) for unavailability of AI service, 4.4 (95%CI: 1.9–10.4) for unavailability of breeding bull, 5.6 (95%CI: 2.4–13.1) for bull being located at a distance, 6.5 (95%CI: 2.7–15.4) for poor oestrus detection, and 12.9 (95%CI: 4.5–16.2) for cows not showing heat. For Mbeya, farmers had higher odds (compared to Tanga) of reporting the unavailability of an AI service (OR: 44.4, 95%CI: 12–82.6), poor oestrus detection (OR 3; 95%CI: 1.3–6.9) and cows not showing heat (OR 6.4; 95%CI: 2.2–18.6) as major/moderate constraints. Despite having similar percentages of farmers using mixed breeding (see Table 7), farmers in Kilimanjaro were less likely to report bull availability and bull distance as major/moderate constraints than farmers in Tanga (OR 0.12; 95%CI: 0.03–0.6, and 0.3; 95%CI: 0.1–1, respectively), while farmers in Morogoro were more likely than farmers in Tanga to report that heat detection was a problem (OR 3.2; 95%CI: 1.4–7.5).

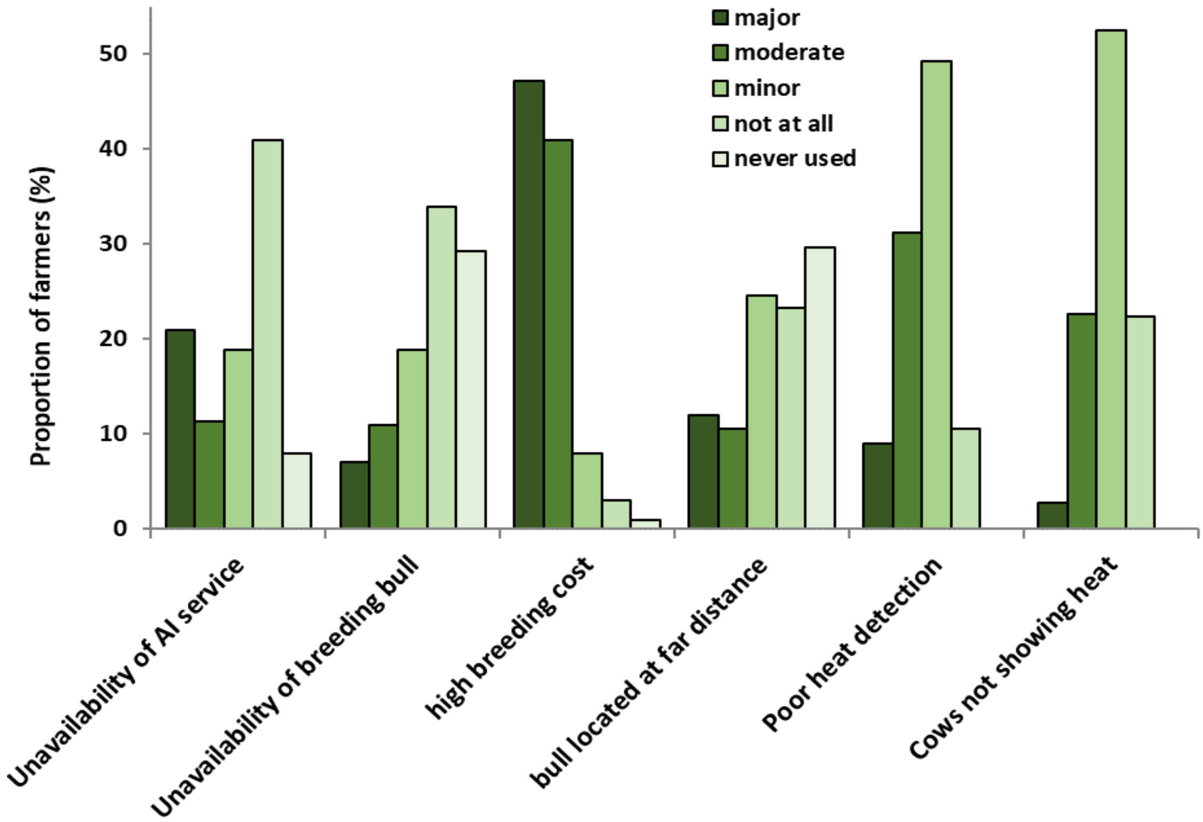

Figure 15. Constraints to successful breeding in smallholder dairy cattle farming in Tanzania

Table 9. Constraints for successful breeding in smallholder dairy cattle farming across the study regions in Tanzania mainland. Data are shown as number of respondents and percentage of responses within each region n (%).

Character	Category	Regions						Total
		Njombe	Mbeya	Tanga	Kilimanjaro	Arusha	Morogoro	
Total respondents		n=54 (18)	n=55 (18)	n=53 (18)	n=66 (22)	n=16 (5)	n=57 (19)	n=301 (100)
Unavailability of AI service								
	major	19(35)	**37(67)**	1(2)	4(6)		2(4)	63(21)
	moderate	**20(37)**	3(6)	2(4)	7(15)		2(4)	34(11)
	minor	10(19)		20(38)	11(12)	1(6)	15(26)	57(19)
	not at all	4(7)		**28(53)**	**44(67)**	**13(81)**	**34(60)**	**123(41)**
	never used	1(2)	15(27)	2(4)		2(13)	4(7)	24(8)
Unavailability of breeding bull								
	major	11(20)	1(2)	5(9)	2(3)		2(4)	21(7)
	moderate	**18(33)**	6(11)	6(11)			3(5)	33(11)
	minor	7(13)	**27(49)**	6(11)	10(15)		7(12)	57(19)
	not at all	12(22)	21(38)	6(11)	24(36)	6(38)	**33(58)**	**102(34)**
	never used	6(11)		**30(57)**	**30(46)**	**10(63)**	12(21)	88(29)
High breeding cost								
	major	**34(63)**	20(36)	**28(53)**	25(38)	6(38)	**29(51)**	**142(47)**
	moderate	15(28)	**25(46)**	22(42)	**35(53)**	**8(50)**	18(32)	123(41)
	minor	4(7)	7(13)	1(2)	5(8)	1(6)	6(11)	24(8)
	not at all	1(2)	3(6)	1(2)		1(6)	3(5)	9(3)
	never used			1(2)	1(2)		1(2)	3(1)
Bull located at far distance								
	major	**19(35)**	4(7)	7(13)	2(3)		4(7)	36(12)
	moderate	13(24)	6(11)	4(8)	3(5)	1(6)	5(9)	32(11)
	minor	7(13)	**28(51)**	6(11)	22(33)	1(6)	10(18)	74(25)
	not at all	9(17)	17(31)	6(11)	8(12)	4(25)	**26(46)**	70(23)

never used	6(11)		**30(57)**	**31(47)**	**10(63)**	12(21)	**89(30)**
Poor heat detection							
major	13(24)	3(6)		7(11)	1(6)	3(5)	27(9)
moderate	**21(39)**	**21(38)**	11(21)	16(24)	2(13)	23(40)	94(31)
minor	13(24)	**21(38)**	**37(70)**	**41(62)**	**11(69)**	**25(44)**	**148(49)**
not at all	7(13)	10(18)	5(9)	2(3)	2(13)	6(11)	32(11)
Cows not showing heat							
major	4(7)	1(2)	1(2)	1(2)		1(2)	8(3)
moderate	**27(50)**	**21(38)**	4(8)	8(12)		8(14)	68(23)
minor	7(13)	18(33)	**36(68)**	**47(71)**	**12(75)**	**38(67)**	**158(53)**
not at all	16(30)	15(27)	12(23)	10(15)	4(25)	10(18)	67(22)

For each region, results in bold indicate the category with the highest frequency for that question

4. Discussion

4.1. Smallholder dairy cattle household, family, and farm demographics

To achieve sustainable development of smallholder dairy cattle farming in Tanzania, a proper understanding of the key participants involved is essential. This includes a thorough knowledge of the features of the farmers and their farms, locality, and farming practices.

Smallholder dairy farming in Tanzania is generally collaborative, with household heads including other household members (spouse and/or children or relative) in decisions related to farming. In this survey, it was found that most farms/households (74%) were headed by men. This is consistent with other recent surveys, such as that of Kashoma and Ngou (2023) who reported, based on a survey of farms across 17 districts, that 68% of households were headed by men. However, both of these percentages are much lower than previous reports, e.g. the 90% reported by Kivaria et al. (2006b), in the Dar es Salaam region and the 93% reported by Swai et al. (2014) in Kilimanjaro and Arusha. These findings indicate that there has been an increase in the number of women involved in smallholder dairy farming. One positive reason for this increase is the focus of NGOs on the empowerment of women-led households. This was most apparent in Njombe, where almost equal numbers of men and women were household heads, consistent with the report by Msangya et al. (2015), 53% of the households in Njombe supported by the Heifer Project International Trust were led by women. The other, less positive, reason for the increased involvement of women in smallholder dairying is likely to be the rural-urban migration of men searching for better wages, therefore, by default, leaving women to manage the household and its livestock (Ojango et al., 2017).

In most regions, a herd size of 3 to 4 animals was the most common. However, in both Tanga and Morogoro, the most common herd size was >4 animals. The somewhat larger herd size reported in Tanga and Morogoro may reflect, at least in part, the proximity of these regions to Dar es Salaam, which is the biggest milk market in the country. However, the rapid increase in the population in the Dar es Salaam region in the recent past (Lupala, 2021) has not been reflected in recent increases in the size of farms in either Morogoro (Nkya et al., 1999) or Tanga (Zylstra et al., 1995), so market size is probably not the sole factor. The similarity of farm size across most regions is also reflected in the number of people/farms actively involved in farming, with 1-2 people actively involved in the majority

(67%) of farms. Tanga had both larger herds and more active people/farms, with 3-4 people per farm being the most common category, probably reflecting increased involvement of family members as previously reported (Swai et al., 2005a).

Across the six study regions, cash purchase was the principal (66%) source of a household's first dairy cattle beast, consistent with the 72% reported by Swai et al. (2014) in Kilimanjaro/Arusha. The only region where cash purchase was not the principal source was Mbeya, where a gift from a family member or friend was as common as cash purchase (49 vs 45% of respondents, respectively). This process, known as 'kufufya' by Nyakyusa speakers, involves an individual giving a heifer or cow (which could be pregnant or non-pregnant) to a relative or friend. When that animal calves, the original owner takes back the milking cow if the newborn calf is female, or if it is a bull calf, the new owner keeps the cow (until it produces a female calf) but shares the milk it produces with the original owner. This process has been popularised using the Kiswahili slogan "Kopa Ng'ombe lipa Ng'ombe" (meaning borrow a cow, pay a cow). Similar techniques have been used by NGOs (Kayunze et al., 2001; Msangya et al., 2015), with the recipient of a cow raising female offspring before passing on the younger animals to a new family/owner (De Vries (2012); "Passing on the Gift". Likewise, Kopa Ng'ombe lipa Ng'ombe, Passing on the Gift, has been a regionally specific process with only Tanga and Mbeya reporting that a significant proportion of respondents got their first cow from an NGO.

4.2. Farmers/respondents and attendants/workers' demographic characteristics

Most respondents (51%) in this survey were aged between 41 and 60 years, with 39% having <10 years of farming experience. According to Swai et al. (2014), only 11% of their respondents had <10 years of experience. The higher figures in this survey, even in the regions studied by Swai et al. (2014), strongly suggest that there have been a significant number of new entrants into dairy farming over the last 10 years. This appears to be particularly the case in Njombe and Morogoro as both regions had ≥50% of respondents with <10 years' experience.

As expected, farm assistants were younger (77% were <30 years of age) and less experienced (83% had <5 years of experience) than farm owners. For both groups, primary education was the highest education level (55% for farm owners, 66% for assistants) and dairy farming was a full-time occupation (77 vs 87%, respectively). Having a majority of smallholder farmers and assistants with at least primary education (which is a compulsory education) signifies that they are more likely to adopt and apply modern farming techniques to improve their productivity.

4.3. Smallholder dairy cattle households' sources of income

Across all respondents, very few (6%) relied solely on dairy cattle for their income. However, even for those who relied on other household income sources (i.e., employment, crop farming and business), the majority (84%) of them still depended on smallholder dairying as their major income source (except the Njombe region). According to Swai et al. (2014), dairying was the major source of income for only 32% of respondents in Kilimanjaro and Arusha regions, while Kashoma and Ngou (2023) reported 56.4%, from Arusha, Dar Es Salaam, Iringa, Kagera, Kilimanjaro, Mbeya, Morogoro, Mwanza, Njombe, Pwani and Tanga. This shows an increase in the number of households relying on smallholder dairying year by year. This trend can be expected to result in a stable household economy, providing sustainable income and improved nutrition. Furthermore, it indicates significant growth in the sector, leading to improved food security, economic development, and increased employment opportunities for many Tanzanians. Therefore, this study suggests that the government and other stakeholders support smallholder dairy cattle farmers in achieving increased and sustainable productivity.

4.4. Smallholder dairy cattle grazing systems and feed sources.

There were marked differences across regions in the source of non-dairy income. In Morogoro, 64% of respondents had moderate/major income from employment. This may be related to the proximity of institutions like Sokoine University and access to government-related jobs. Gillah et al. (2013) reported that 19% of farmers in Morogoro were government employees and 15% were retired officers. For the remaining regions, crop farming was the principal alternative source of income. In most regions, it was listed as a moderate/minor source of income by respondents (64% to 84% depending on region); however, in Njombe, it was a major source of income for 52% of respondents. This indicates that smallholder dairy cattle farming is expanding beyond urban and peri-urban areas, traditionally managed by government officers, to rural areas, where crop farmers are increasingly adopting these practices. The involvement of crop farmers in smallholder dairy cattle farming was also recorded in the previous studies (Kashoma & Ngou, 2023; Swai et al., 2014).

Zero grazing was the predominant system in all study regions (67 to 99% of respondents) except for Mbeya (only 16% of respondents). Zero grazing or 'cut-and-carry' uses natural pastures, with fresh forages being obtained from roadsides, highways, and non-cultivated areas such as communal lands, uncultivated fields, communal swamp areas and communal grazing areas (Swai & Karimuribo, 2011; Urio, 1986). Tethering was the predominant system in Mbeya (68% of farmers), which may reflect the longer periods in the Mbeya region (Busokelo district in particular) when grazing is available, since the area is a cooler highland area (770 to 2865 metres above sea level), which receives 1500 to 2700 mm rainfall per year (Makala, 2017; Nyunza & Mwakaje, 2012). The current survey evaluated the use of eight on-farm feed sources. The survey identified five types of feed sources: 1) commonly used feed sources with limited variability across regions (i.e. concentrates, and natural pastures); 2) commonly used feed sources with large differences in level of use by region (crop residuals); 3) rarely used feed sources with >75% farms reporting no use and >90% of farms no more than minor use (i.e. grazing, bought fodder and conserved feeds); 4) feed sources that are rarely used in most regions, but commonly used in one or more regions (e.g. cut fodder from outside); and 5) feed sources that vary markedly across and within regions (e.g. fodder plots in farm). These regional differences in feeding practices need to be considered when developing support programs. Furthermore, these results also show that it would be too simplistic to assume that all farms within a region use the same feed sources at the same time and in the same way, such that, even at the regional level, feed supply will require multifactorial solutions to achieve success.

The use of crop residuals as livestock feed could have many benefits: cost savings (crop residuals are more affordable), availability (most are locally available) and greater utilisation of agricultural by-products. Such practice can help to guarantee sustainable agricultural practices and more efficient resource management within the community of smallholder dairy cattle farming in countries like Tanzania.

4.5. Dairy breed selection criteria and breeding practice

Only 53% of farmers across the six regions had a breed preference. Surprisingly, the proportion of farmers from Njombe who had a preference was much higher than this average (at 96%). The reason for this difference is unclear. Despite the low proportion of respondents who had a specific breed preference, most respondents (91%) expressed their opinions on the cattle attributes they desired. Unsurprisingly, high milk production is the primary reason for their choices, as highlighted in the previous surveys done in Tanzania (Chawala et al., 2019; Gillah et al., 2014; Swai & Karimuribo, 2011). This preference (and the preference for large body size especially in Morogoro, Tanga and Mbeya) probably reflects the marketing of 'high yielding' cows to smallholders rather than the direct experience of the respondents of such cows playing an important role in improving farm incomes (Chung, 2024).

The breeding method was very dependent on the region, reflecting the generally poor AI infrastructure across much of Tanzania and the centralisation of the AI service at the National Artificial Insemination Centre (NAIC) in Arusha. Regions that predominantly used AI were generally close to the NAIC, with regions further away using a combination of natural insemination and AI. Nevertheless, across the six regions, 80% of farmers used at least some AI. For five of the six regions, >90% of farmers reported using some AI, with only Mbeya having the majority of farmers using bulls only (96%). Centralization of the AI centre in Tanzania could be the reason for the irregular availability of semen and other consumables like liquid nitrogen to farmers located away from NAIC. Similarly, as reported previously by Mwanga et al. (2019) in their study on factors influencing breeding decisions by smallholder dairy farmers in Sub-Saharan African countries. Also, irregularities in the supply of AI consumables by Kashoma and Ngou (2023). In another report (Kanuya et al., 2014), over 60% of farmers in Morogoro and Tanga reported experiencing challenges related to AI delivery systems. Though there are some imported doses of semen by private organizations (Katjiuongua, 2014; Ogutu et al., 2014), plans are underway to improve the available semen production by involving public-private partnerships and development partners (Ogutu et al., 2014). Further, Kusiluka et al. (2006) reported a lack of breeding services for smallholder dairy cattle farmers in the eastern zone of Tanzania.

The cost of AI varies with distance from the NAIC. The proximity to the AI centre means that AI services can be offered to farmers at a relatively low cost (i.e. between 15,000 and 25,000 TZs per insemination (~US$6-10) for first insemination). Nevertheless, irrespective of distance, AI was seen by many respondents as being expensive. The lack of a good AI infrastructure in Tanzania probably limits productivity on dairy farms, since AI confers significant advantages over natural mating in terms of genetic gain and disease control (Parkinson & Morrell, 2019). Increased use of AI could be greatly beneficial for smallholder productivity, reducing the risk of disease from the use of untested local bulls and improving production efficiency and longevity, especially if the focus is not just on increasing milk production. Furthermore, to sustain productivity, emphasis must be placed on improving the management and nutrition of the animals. This is because inadequate nutrition and management of animals may result in reduced milk yields, increased health disorders and most importantly, impaired reproductive ability (Van Saun, 1991). The high cost and unreliability of AI service were among the constraints highlighted in the previous studies from Tanzania (Kanuya et al., 2014) and in sub-Saharan African countries (Mwanga et al., 2019).

4.6. Smallholder dairy cattle farming constraints

Two areas of constraints were examined: general constraints and specific breeding-related constraints. High costs of inputs were identified as the leading constraint in the general constraints section of the survey, with 76% of all farmers reporting it as a highly significant constraint (range: 65% to 95% by region). In general, high input costs seemed to be perceived as a more important constraint than high breeding costs alone. In all regions, the proportion of farmers who reported high input costs as a highly significant constraint was higher than the proportion who reported high breeding costs as a major constraint. High cost of inputs was also reported previously: concentrates and veterinary drugs (Kivaria et al., 2006b) in Dar es Salaam and northern Tanzania (Swai et al., 2014). Furthermore, in all regions, the most common response about high input costs was that it was a highly significant constraint, whereas, for breeding costs, the most common response varied between major and moderate, depending on the region. Insufficient land and feed were also seen as highly significant/important constraints by most respondents, except in Tanga, where most respondents (51% and 59%, respectively) thought that they were of minor to moderate importance. This regional difference may reflect the high number of swamp areas and abandoned sisal plantations in the Tanga region areas from which farmers can reliably obtain forage.

The cost of breeding was seen as a major constraint by a high proportion of respondents in all regions (>80%), with no evidence that being near the NAIC made that cost less of a constraint. This was also highlighted previously that farmers are unable to pay for the AI service due to high costs and irregularities in the AI delivery system (Kashoma & Ngou, 2023). Irregularities in the AI delivery system were also reported to be a challenge for smallholder dairying improvement in Rwanda (Rugwiro et al., 2021). In contrast, distance from the NAIC did affect whether the lack of an AI service was an important constraint, with the regions close to Arusha reporting no or minor concerns and the regions far from Arusha reporting major/moderate concerns. Indeed, concerns about reproductive constraints were particularly prominent in Njombe, with all constraints (other than cost) being ranked as more important in Njombe than in Tanga. The pattern for Mbeya was similar but the differences were less marked. This probably reflects the different patterns of breeding in the two regions – natural service only predominates in Mbeya, while mixed and AI only predominate in Njombe. More reliance on AI leads to more concerns – again highlighting the importance of improving the AI infrastructure in dairying regions remote from Arusha.

The regional differences in the relative importance of constraints again highlight the importance of developing regional solutions to improve smallholder dairy farm productivity, while the variability in the relative importance of constraints across farms within a region highlights the importance of understanding what is driving those differences at the farm level. Previous studies on smallholder dairying constraints in Tanzania include inadequate, seasonal and irregular forage availability in Arusha, Kilimanjaro (Swai et al., 2014) and Dar es Salaam (Kivaria et al., 2006b). Also, the high cost and poor conception/pregnancy rates achieved by AI (Kanuya et al., 2014) was considered by farmers from Tanga and Morogoro to be a significant disincentive to breed by AI.

5. Conclusion

The primary objective of this study was to conduct a large-scale survey to understand the unique characteristics of smallholder dairy cattle farmers in Tanzania and to identify regional differences that might impact the development of the dairy farming industry. The findings of this study revealed significant regional differences in demographic factors such as gender, age and farming experience, reflecting the structure of the dairy industry and the availability of alternative income streams in different regions. These regional differences underscore the importance of tailoring interventions to farmers' specific needs and preferences in each locality rather than assuming a uniform approach will be effective.

This study also highlighted some areas that require attention within the specific agro-economic context of different regions in Tanzania. Addressing these issues will form the foundation for developing regionally tailored and sustainable solutions. A 'one size fits all' approach risks undermining the success of herd-improvement programs or other initiatives by failing to consider the needs of farmers in different regions. The sustainable development of Tanzania's smallholder dairy farming industry requires targeted and flexible strategies that consider these disparities. This includes a thorough understanding of the farmer's characteristics, preferences and constraints before implementing any programmes. Such considerations will enhance the likelihood of success for initiatives introduced by the government, NGOs or other stakeholders. Lastly, this study serves as the baseline for future research and action. Further qualitative research is recommended to explore the underlying reasons behind these regional differences, which were beyond the scope of this study, to refine strategies further and ensure the long-term success of the interventions aimed at improving the dairy industry in Tanzania.

6. References

Alonso, S., Toye, P. G., Msalya, G., Grace, D., & Unger, F. (2014). Smallholder dairy farming in Tanzania: Farming practices, animal health and public health challenges and opportunities. https://www.slideshare.net/ILRI/smallholder-dairy-tanzania

Brett, C. (2019). A new way to boost smallholder dairy productivity in Tanzania. *worldbank. org/voices*. https://blogs.worldbank.org/en/voices/new-way-boost-smallholder-dairy-productivity-tanzania

Chagunda, M. G., Bruns, E., King, J. M., & Wollny, C. (2004). Evaluation of the breeding strategy for milk yield of Holstein Friesian cows on large-scale dairy farms in Malawi. *The Journal of Agricultural Science*, *142*(5), 595-601. https://doi.org/https://doi.org/10.1017/S0021859604004666

Chawala, A. R., Banos, G., Peters, A., & Chagunda, M. G. G. (2019). Farmer-preferred traits in smallholder dairy farming systems in Tanzania. *Trop Anim Health Prod*, *51*(6), 1337-1344. https://doi.org/10.1007/s11250-018-01796-9

Chung, Y. B. (2024). Historicising sustainable livestock intensification and animal genetic improvement in Africa: towards a decolonial multispecies climate justice. *The Journal of Peasant Studies*, *51*(3), 674-694. https://doi.org/https://doi.org/10.1080/03066150.2023.2285430

De Vries, J. (2012). Passing on the gift as an approach to sustainable development programmes. *Development in Practice*, *22*(3), 373-384. https://doi.org/https://doi.org/10.1080/09614524.2012.664626

Gillah, K., Kifaro, G., & Madsen, J. (2012). Urban and peri urban dairy farming in East Africa: A review on production levels, constraints and opportunities. *Livestock Research for Rural Development*, *24*(11), 198. https://lrrd.cipav.org.co/lrrd24/11/gill24198.htm

Gillah, K., Kifaro, G., & Madsen, J. (2013). Management and production levels of cross-bred dairy cattle in Dar es Salaam and Morogoro urban and peri urban areas. *Livestock Research for Rural Development*, *25*(9), Article 165. https://www.lrrd.cipav.org.co/lrrd25/9/gill25165.html

Gillah, K. A., Kifaro, G. C., & Madsen, J. (2014). Effects of management practices on yield and quality of milk from smallholder dairy units in urban and peri-urban Morogoro, Tanzania. *Tropical Animal Health and Production*, *46*, 1177-1183. https://link.springer.com/content/pdf/10.1007/s11250-014-0624-3.pdf
https://link.springer.com/content/pdf/10.1007/s11250-014-0624-3.pdf

Kanuya, N., Mlangwa, J., & Shoo, J. (2014). Constraints associated with the use of Artificial Insemination (AI) and Natural Service (NS) in smallholder dairy herds in Tanga and Morogoro, Tanzania. *Tanzania Veterinary Journal*, *29*(1), 9-20. https://www.ajol.info/index.php/tvj/article/view/109771

Kashoma, I., & Ngou, A. (2023). Insight into the adoption and success of artificial insemination services in smallholder dairy farming systems: A cross-sectional study. *Tanzania Veterinary Journal*, *38*(1). https://doi.org/10.4314/tvj.v38i1.1

Katjiuongua, H. N., S. (2014). *Tanzania smallholder dairy value chain development: situation analysis and trends*. https://cgspace.cgiar.org/server/api/core/bitstreams/3b2a4eaf-8c8e-4030-8df5-a7c2364b68a9/content

Kayunze, K., Urassa, J., & Mwakalobo, A. (2001). Food status and income levels among dairy and non-dairy farmers in Chunya district, Tanzania. Proc. Of the 28th Scientific Conference of Tanzania Society of Animal Production (TSAP), 28, pp11-17,

Kivaria, F., Noordhuizen, J., & Kapaga, A. (2006b). Prospects and constraints of smallholder dairy husbandry in the Dar es Salaam region, Tanzania. *Outlook on Agriculture*, *35*(3), 209-215. https://doi.org/https://doi.org/10.5367/000000006778536819

Kurwijila, L., & Boki, K. (2003). A review of the small scale dairy sector-Tanzania. Milk and dairy products, post-harvest losses and food safety in Sub-Saharan Africa and the near East. *FAO prevention of Food Losses Programme*. Retrieved July 15, 2024, from https://www.fao.org/fileadmin/templates/ags/docs/dairy/P1assessmentsyria.pdf

Kurwijila, L., Henriksen, J., Aboud, A., & Kifaro, G. (1995). Strategies for market orientation of small scale milk producers and their organisations: proceedings of a workshop held in Morogoro, Tanzania, 20-24 March, 1995. https://agris.fao.org/search/en/providers/122621/records/647396c868b4c299a3fb736a

Kusiluka, L., Karimuribo, E., Mdegela, R., Kampaga, A., Bundala, A., Kivaria, F., Kabula, B., Manjurano, A., Turuka, F., & Loken, T. (2006). Constraints associated with production in smallholder dairy farms in the eastern coastal zone of Tanzania. *Bulletin of animal health and production in Africa*, *54*(4), 286-296.

Limbu, F. (1999). Agricultural technology economic viability and poverty alleviation in Tanzania. Presented at the structural Transformation Policy Workshop held at Serena Hotel, Nairobi Kenya. 27-30. Retrieved July 15, 2024, from https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=78dec6b0a7ef22682d883d54d9c20bc582e26020

Lupala, J. (2021). Exploring unbalanced urban spatial expansion in sprawling cities. Case study of Kimara Matangini, Kibululu and Dovya settlements in Dar es Salaam City, Tanzania. *Central European Journal of Geography and Sustainable Development*, *3*(2), 62-84. https://doi.org/https://doi.org/10.47246/CEJGSD.2021.3.2.5

Makala, A. (2017). *Mbeya region inverstment opportunities*. Mbeya Region: Regional Commissioner, Mbeya Retrieved from https://mbeya.go.tz/storage/app/media/uploaded-files/mbeya%20region.pdf

Mbwambo, N., Nigussie, K., & Stapleton, J. (2019). Dairy development in the Tanzanian livestock master plan. *Gates Open Res*, *3*(628), 628. https://doi.org/https://doi.org/10.21955/gatesopenres.1115533.1

McDermott, J. J., Staal, S. J., Freeman, H. A., Herrero, M., & Van de Steeg, J. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science*, *130*(1-3), 95-109. https://doi.org/https://doi.org/10.1016/j.livsci.2010.02.014

Mdoe, N., & Wiggins, S. (1997). Returns to smallholder dairying in the Kilimanjaro region, Tanzania. *Agricultural Economics*, *17*(1), 75-87. https://doi.org/https://doi.org/10.1111/j.1574-0862.1997.tb00465.x

MoLF. (2022). *Livestock Sector Transformation Plan (LSTP) 2022/23-2026/27*. Retrieved from https://www.mifugouvuvi.go.tz/uploads/publications/sw1675840376-LIVESTOCK%20SECTOR%20TRANSFORMATION%20PLAN%20(LSTP)%20202223%20-%20202627.pdf

Msangya, M., Urassa, J., & Mahonge, C. (2015). Contribution of Heifer In-Trust schemes to smallholder households' well-being in Highland area of Njombe Region, Tanzania. *Livestock and rural research and development*, *26*(12), Article 233. Retrieved July 15, 2024, from http://www.lrrd.org/lrrd25/9/gill25165.htm

Mwambene, P., Chawala, A., Illatsia, E., Das, S., Tungu, B., & Loina, R. (2014). Selecting indigenous cattle populations for improving dairy production in the Southern Highlands and Eastern Tanzania. *Livestock Research for Rural Development*, *26*(3), Article 46. Retrieved July 15, 2024, from http://www.lrrd.org/lrrd26/3/mwam26046.html

Mwanga, G., Mujibi, F., Yonah, Z., & Chagunda, M. (2019). Multi-country investigation of factors influencing breeding decisions by smallholder dairy farmers in sub-Saharan Africa. *Tropical Animal Health and Production*, *51*, 395-409. https://doi.org/https://doi.org/10.1007/s11250-018-1703-7

NBS&OCGS. (2021). *National Sample Census of Agriculture 2019/20*. Tanzania: National Bureau of Statistics (NBS) and Office of the Chief Government Statistician (OCGS) Retrieved from https://www.nbs.go.tz/nbs/takwimu/Agriculture/2019-20_Agri_Census_%20Main_Report.pdf

Nell, A. J., Schiere, H., & Bol, S. (2014). *Quick scan dairy sector Tanzania*. Dutch Ministry of Economic Affairs.

Njombe, A., Msanga, Y., Mbwambo, N., & Makembe, N. (2011, 25-27 May). The Tanzania dairy industry: Status, opportunities and prospects. 7th African Dairy Conference and Exhibition held at Moven Pick Palm Hotel, Nkya, R., Aboud, A., & Kessy, B. (1999). *Improving the productivity of smallholder dairy cattle in peri-urban Morogoro, United Republic of Tanzania*. Retrieved July 15, 2024, from https://inis.iaea.org/collection/NCLCollectionStore/_Public/30/042/30042864.pdf?r=1

Nyange, D., & Mdoe, N. (1995). Dairy industry in Tanzania and the prospect for small scale milk producers. Workshop on Strategies for Market Orientation of Small Scale Milk Producers and their Organisations, Morogoro (Tanzania), 20-24 Mar 1995,

Nyunza, G., & Mwakaje, A. G. (2012). Analysis of Round Potato Marketing in Tanzania. *International Journal of Business and Social Science*, *3*(23). https://repository.udsm.ac.tz/server/api/core/bitstreams/1847e26c-6414-41b3-9fe5-86529f25ca06/content

Ogutu, C., Kurwijila, L. R., & Omore, A. O. (2014). *Review of successes and failures of dairy value chain development interventions in Tanzania*. https://hdl.handle.net/10568/65154

Ojango, J. M., Mrode, R., Okeyo, A., Rege, J., Emerge-Africa, K., & Chagunda, M. (2017). Improving smallholder dairy farming in Africa. In *Achieving sustainable production of milk* (1st ed., Vol. 2, pp. 371-396). Burleigh Dodds Science Publishing.

Parkinson, T. J., & Morrell, J. M. (2019). Advantages and disadvantages of artificial insemination. In D. E. Noakes, Parkinson, T. J., & England, G. C. (Ed.), *Veterinary Reproduction and Obstetrics* (10th ed., pp. 746-777). WB Saunders.

Pasape, L. (2022). A Review of Success Factors Behind Community Action Research Program (CARP): A Case of Experiences From Smallholder Dairy Farmers of Lushoto in Tanzania. *Journal of Participatory Research Methods*, *3*(2). https://doi.org/https://doi.org/10.35844/001c.37544

Rugwiro, P., Pascal, N., Manirahaba, E., Aphrodis, T., Abijuru, J., Nizeyimana, B., Habumugisha, D., & Uwumukiza, D. (2021). Assessment of challenges associated with artificial insemination service delivery in dairy cattle in Rwanda. *International Journal of Veterinary Sciences and Animal Husbandry*, *6*, 45-57. https://doi.org/10.22271/veterinary.2021.v6.i3a.373

Suleiman, T., Mdegela, R., & Karimuribo, E. (2016). Characteristics of dairy farming and its effect on milk production: a case study of Unguja island of Zanzibar, Tanzania. *Livestock Research for Rural Development*, *28*(10), 174.

Sumberg, J. (1997). Policy, milk and the Dar es Salaam peri-urban zone: a new future for an old development theme? *Land Use Policy*, *14*(4), 277-293. https://doi.org/https://doi.org/10.1016/S0264-8377(97)00020-3

Swai, E., Karimuribo, E., Schoonman, L., French, N., Fitzpatrick, J., Kambarage, D., & Bryant, M. (2005a). Description, socio-economic characteristics, disease managements and mortality dynamics in smallholder's dairy production system in coastal humid region of Tanga, Tanzania. *Livestock Research for Rural Development*, *17*(4), Article 41. https://www.lrrd.cipav.org.co/lrrd17/4/swa17041.htm

Swai, E., Mollel, P., & Malima, A. (2014). Some factors associated with poor reproductive performance in smallholder dairy cows: the case of Hai and Meru districts, Northern Tanzania. *Livestock Research for Rural Development*, *26*(6), 1-2. Retrieved July 15, 2024, from https://lrrd.cipav.org.co/lrrd26/6/swai26105.htm

Swai, E. S., & Karimuribo, E. D. (2011). Smallholder Dairy Farming in Tanzania. *Outlook on Agriculture*, *40*(1), 21-27. https://doi.org/10.5367/oa.2011.0034

Urio, N. A. (1986). On-farm research on utilization of crop residues by smallholder dairy farmers in Hai district, Tanzania. *Towards Optimal Feeding of Agricultural Byproducts to Livestock in Africa*, 17.

Van Saun, R. J. (1991). Dry Cow Nutrition: The Key to Improving Fresh Cow Performance. *Veterinary Clinics of North America: Food Animal Practice*, *7*(2), 599-620. https://doi.org/https://doi.org/10.1016/S0749-0720(15)30785-4

Zylstra, L., Lyimo, C., & Rutamu, I. (1995). Milk production and Marketing in Tanga Region: Efficiency of farmer co-operatives versus private sector. Conference Proceedings presented at the Workshop on Strategies for Market Orientation of Small-Scale Milk Producers and their Organizations, Morogoro (Tanzania), p20-24, March 1995. Retrieved July 15, 2024, from https://www.fao.org/4/X5661E/x5661e0f.htm.

Declarations

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All authors contributed to the study design and conception. Athanas Ngou did the data collection under the guidance of Isaac Kashoma and Richard Laven. Data analysis and interpretation were done by Athanas Ngou, Richard Laven and Timoth Parkinson. The first draft of this manuscript was written by Athanas Ngou, and all authors commented on the versions of the manuscript. All authors read and approved the final document.

Competing interests

The authors declare that they have no competing interests.

Data availability

The generated and analysed datasets used in this study are available from the corresponding author upon request.

Ethics approval

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007) of the United Republic of Tanzania.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

The authors consent to the publication of this article, and participants' permission for publication was obtained where appropriate.

Competing interests

The authors declare that they have no competing interests.

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Chapter Four: Knowledge, Attitudes, and Practices of Smallholder Dairy Cattle Farmers in Tanzania: A Cross-sectional Survey on Cattle Infertility

Foreword: This chapter covers the knowledge, attitude and practices (KAP) of the 301 smallholder dairy farmers in Tanzania regarding issues related to infertility in their cattle. Also, the chapter covers the farmers' understanding of the causes and signs of infertility in dairy cattle, along with the perceived impact of infertility and how they manage it on their farms. As for chapter three, this study was also conducted among smallholder dairy cattle farmers across the thirteen districts from the six key dairy farming regions of Tanzania mainland. This study has been submitted for publication in the Veterinary Sciences Journal. In this thesis, the manuscript has been presented in the journal format and style.

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Knowledge, Attitudes, and Practices of Smallholder Dairy Cattle Farmers in Tanzania: A Cross-Sectional Survey on Cattle Infertility

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Simple Summary

Dairy cattle infertility is among the major challenges to smallholder dairy farming in Tanzania, yet it remains poorly understood by farmers. The current study investigated 301 farmers from the six key dairy-producing regions to explore their knowledge, attitudes and practices regarding dairy cattle infertility. Almost all farmers reported experiencing infertility in their herds and identified common infertility signs correctly, e.g., return to oestrus after breeding. Also, farmers reported poor feeding and housing, diseases and poor heat detection as important infertility causes, which were managed in various ways, including seeking assistance from veterinarians/livestock officers or culling. Our findings highlight that there is a wide recognition of dairy cattle infertility, but sometimes it is wrongly managed. Therefore, there is a need for the provision of better education to the farmers to reduce losses and improve herd productivity.

Abstract

Infertility is one of the major farming constraints facing smallholder dairy cattle farming in Tanzania. Despite its impact, there is limited information on how farmers understand and manage it. The present study aimed to assess farmers' knowledge, attitudes and practices related to dairy cattle infertility. A cross-sectional survey was conducted using a structured questionnaire involving 301 farmers across six major dairy-farming regions: Tanga, Arusha, Kilimanjaro, Mbeya, Morogoro and Njombe. Overall, 95% of respondents reported encountering infertility on their farms. Farmers were asked to identify signs of infertility from the list of 10 (8 correct and 2 distractors); the median score for correct identification was 7 (range 2–10). The most recognised sign was return to oestrus after insemination (94%). Most farmers correctly identified low milk yield and mastitis as not being signs of infertility. The main reported causes included poor nutrition/housing (93%), livestock diseases (89%), poor record keeping (85%), and poor oestrus detection (83%). Nearly all (98%) viewed infertility as a serious issue, predominantly naming repeat breeding (95%) and failure to produce a calf/year (90%). Management strategies included seeking veterinary services (94%), slaughter (69%), sell to other farmers (23%) and self-treatment (16%). Our findings highlight widespread awareness of infertility while pointing out gaps in management, which reinforces the need for improved farmer education and support services.

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Keywords: Tanzania; smallholder dairy farmers; dairy cattle infertility; knowledge; attitude; practices

1. Introduction

Smallholder dairy cattle farming is an important component of the agricultural sector in many developing countries, particularly for rural and peri-urban households [1]. It plays a vital role in the improvement of the livelihoods of many households, as it ensures food security and enhances access to animal protein [2,3]. In Tanzania, smallholder cattle dairying contributes about 99% of the total milk produced [4], with ~97% being consumed at the household level or sold locally through informal value chains with little or no processing [5]. Of the total milk production, local cattle breeds contribute ~2.6 billion L/year (67%), with improved dairy cattle breeds producing ~1.3 billion L/year (33%) [6]. The improved dairy cattle are the crosses of European dairy breeds (e.g., Friesian, Ayrshire, and Jersey) with local Zebu, especially the Tanzanian Shorthorn Zebu, Boran, and Sahiwal. However, the demand for milk and milk products in Tanzania is ~12 billion L/year [6,7]. Consequently, ~75% of dairy consumption in Tanzania is of imported products. The growing demand in Tanzania for dairy products [8] means this is likely to increase unless the efficiency and productivity of dairy farming are improved [9].

Tanzania's smallholder dairy farms produce most milk. However, Tanzanian smallholder dairy farmers face many constraints that limit their ability to improve the productivity of their farms. Most importantly, their farms are dominated by low-input-low-yield cattle breeds (~97% of cattle on their farms) [8], which limits their potential to increase yield. Other constraints include seasonal fluctuations in forage and feed availability, inability to access affordable veterinary and extension services, high levels of endemic disease and inadequate marketing of their products [8,10–12].

One key challenge facing smallholder dairy cattle farmers in Tanzania is the poor reproductive performance of their cattle [13–15]. This poor reproductive performance is characterised by low calving rates (65 births/100 cow years [13], prolonged intervals between calving and first observed oestrus (mean of 108 days [14]), and extended inter-calving intervals (mean 476–500 days [13,14]). This poor reproductive performance results in fewer calves being born, reduced lifetime milk production, and an increase in the proportion of cows in the herd that are not lactating. All these effects reduce household food security and limit the availability of milk for sale in the commercial market.

Improving reproductive performance on smallholder dairy farms will require significant input from farmers [16]. Obtaining such input will likely be dependent on farmer training and support programmes [14]. To optimise and target this training and support, data are needed on smallholder dairy cattle farmers' current knowledge, attitudes and practices (KAPs) concerning dairy cattle infertility. However, no studies have been undertaken in Tanzania specifically focused on understanding these KAPs. Therefore, the purpose of this research is to address that knowledge gap (via evaluation of farmers' KAPs on infertility) and provide insights to inform future efforts to improve fertility and increase the productivity of smallholder dairy farms in Tanzania. This research was conducted across six key dairying regions to capture regional variations in knowledge levels.

2. Methodology

This survey was undertaken alongside the survey described in a study by Ngou et al. [17]. A brief methodology is included here.

2.1. Ethical Considerations and Approval

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007). The first author conducted interviews with the assistance of local veterinarians or livestock officers who introduced the Author to the farmer/respondent (usually the family head). Informed written consent was given before the interview. To ensure confidentiality, all responses were anonymised, and no identifying information was linked to the data.

2.2. Study Area and Study Farm Selection

This cross-sectional survey was undertaken between May 2022 and February 2023 in six dairy-producing regions of Tanzania (Figure 1). Within each region, convenience sampling was used to identify study villages and the first study farm in each village. Snowball sampling was then employed to select other study farms in that village. If the owner or someone who could respond to the questionnaire was not available on a selected farm, the interviewer moved to the next one on the list.

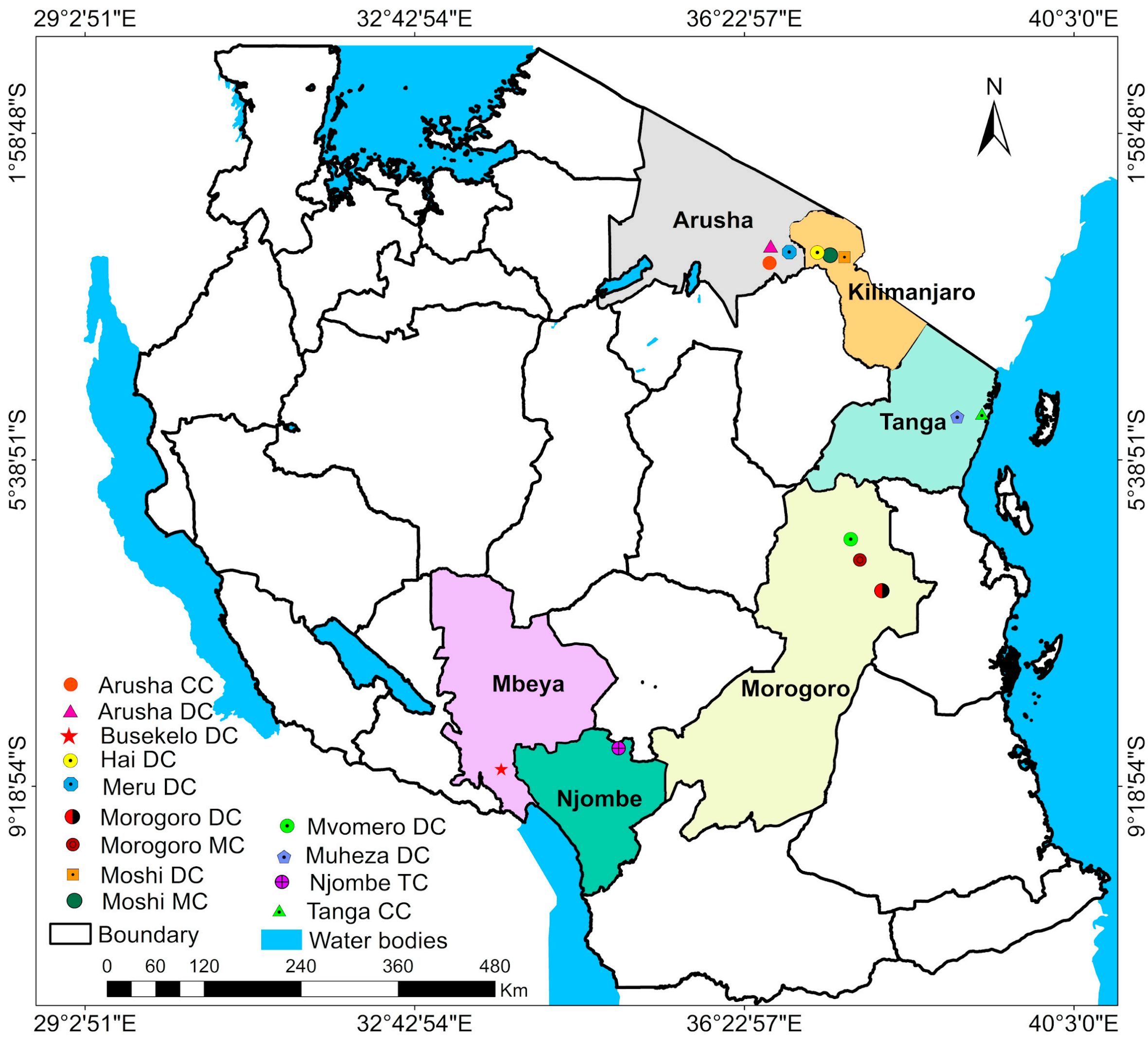

Figure 1. Map of Tanzania showing study regions and districts: Southern Highland regions, Northern Highland regions and Morogoro. NB: CC—City council, DC—District council and TC—Town council.

2.3. Field Data Collection

A questionnaire was developed to investigate a wide range of aspects of dairy-farming practice amongst smallholder dairy farmers. This paper mostly describes the responses to the questions related to the farmers' KAPs around dairy cattle infertility. Pretesting of the questionnaire was undertaken with 24 smallholder farmers (not included in the final dataset) and 11 experts (veterinarians/livestock officers and researchers). KoboToolbox version 2025.2 (Cambridge, MA, USA) was used for offline data collection. The first section of this part of the questionnaire comprised enquiries on the signs indicating infertility and its associated causes. This section was included to ascertain whether farmers correctly understood the signs of infertility. This was followed by a section on farmers' attitudes towards dairy cattle infertility on their farms. The last section asked the respondents about what they thought were their key practices on their farm concerning dairy cattle infertility, including its treatment, control, and prevention.

In the questionnaire, the term 'repeat breeding' was used to refer to cows that returned to oestrus after breeding, rather than the strict definition of the term that excludes cows with overt pathology of the reproductive system [18].

2.4. Data Management

Data from the questionnaire was downloaded from KoboToolbox to an Excel spreadsheet (Microsoft, Seattle, WA, USA). Data analysis was undertaken using SPSS version 25 (IBM, Seattle, WA, USA). Results for each question were tabulated and presented as overall results and by region. Where the effect of region on the answer to a question was thought to be of interest, logistic regression was used to analyse the impact of region upon the response, with the response to a question being the dependent variable and region the only predictor variable. Where responses in a category were <5% of respondents, categories were merged (based on proximity or compatibility) before analysis. Where this merging resulted in more than two ordered categories, ordinal logistic regression analysis was used, with the proportional odds assumption being tested using the test of parallel lines [19,20]. Multinomial logistic regression analysis was used, where the outcome was multinomial rather than ordinal (or the test of parallel lines had $p < 0.05$) [21].

For the section on the signs of infertility, each respondent was scored based on the number of correct answers. The effect of region on this score was analysed using an ordinal logistic regression with the respondent's score as the outcome variable and region as the only predictor variable.

For all analyses, Tanga was used as the reference region. Descriptive data from Arusha (i.e., proportions of respondents) are reported, but data from Arusha were not included in any statistical analysis of the effect of the region due to the low number of respondents in that region.

3. Results

3.1. Signs of Infertility

Across all 301 respondents, 285 (95%) reported having experienced infertility in their dairy herds, a relatively uniform result across the study regions (range across regions: 94–98% of respondents; Figure 2 and Table 1). The high proportion of respondents reporting that they had experienced infertility was consistent with the high proportion who correctly understood the signs of infertility. Overall, the median number of questions on the signs of infertility that were answered correctly was 7/10 (ranging, at the individual farmer level, from 2 to 10 correct). Across the 10 separate questions, the proportion of correct respondents ranged from 282/301 (94%) who identified repeat breeding as a sign of infertility, to 199/301 (66%) who identified failure to produce a calf in a year.

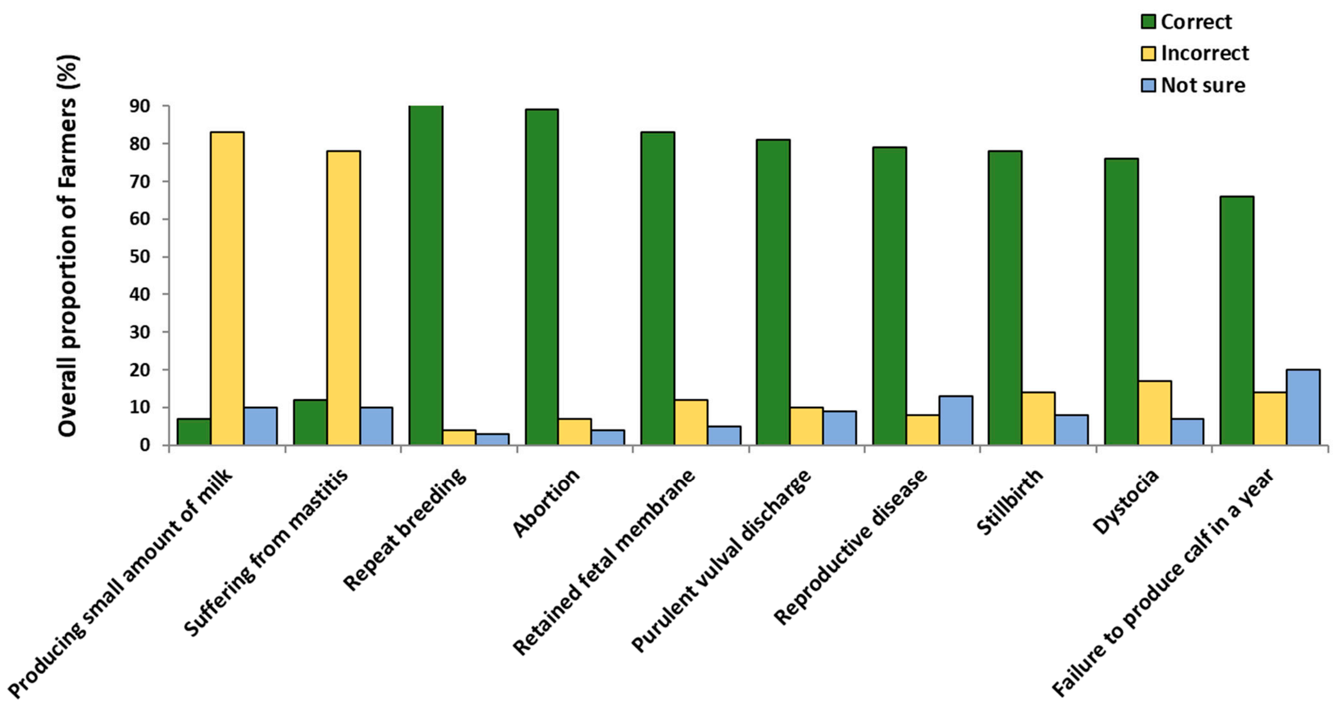

Figure 2. Smallholder dairy cattle farmers' knowledge of the signs of infertility in dairy cattle in Tanzania mainland.

Respondents from Morogoro had the highest average proportion of individual farmer correct answers (9/10), followed by those from Tanga and Kilimanjaro (8/10). In contrast, participants from Mbeya and Njombe had an average of 7 and 6 correct answers, respectively. Compared to Tanga, respondents in Morogoro had higher odds of having more questions correct (OR: 3.16, 95%CI: 1.59–6.30) while Njombe respondents had lower odds (OR: 0.21, 95%CI: 0.10–0.41).

To analyse the effect of region on the correct identification of individual signs of infertility the response 'incorrect' was combined with 'not sure' before analysis (i.e., both responses were defined as 'not correct'), except for the two distractor questions (mastitis and poor milk production) where the answer 'correct' was combined with 'not sure' as 'not correct'. Binary logistic regression analysis was then performed.

For the two distractor questions (i.e., producing less milk and suffering from mastitis), a high proportion of respondents correctly reported that *lower milk production* (83%) and *suffering from mastitis* (78%) were not signs of infertility. At the regional level, farmers from Morogoro were more likely to correctly identify less milk production or suffering from mastitis as not being signs of infertility than those from Tanga. The odds of a farmer from Morogoro identifying less milk production or suffering from mastitis as infertility signs were 0.06 (95%CI: 0.01–0.49) and 0.14 (95%CI: 0.03–0.66) times, respectively, those in Tanga.

Repeat breeding had the highest proportion of respondents identifying it as a sign of infertility (94%). Across the regions, this proportion varied from 100% (Arusha) to 82% (Njombe) (Table 1). The low proportion of incorrect respondents limited the power to identify the effect of region as, for example, compared to Tanga, respondents in Njombe had more than twice the odds of being 'not correct' for this question, but the wide 95% CI (OR: 2.18, 95%CI: 0.69–6.88) indicates that the data were compatible with both a moderate decrease and a large increase, hence no meaningful effect. Across all 301 respondents, 89% correctly identified abortion as a sign of infertility, ranging by region from 65% (Njombe) to 100% (Morogoro and Arusha). Farmers in Njombe had over 4 times greater odds of being 'not correct' for this question than farmers in Tanga (OR: 4.25, 95%CI: 1.54–11.8).

Table 1. Opinions of Tanzanian smallholder dairy farmers on signs of infertility. Data are shown as the number of respondents (%).

Character	Category	Regions										Total
		Tanga	Arusha	Kilimanjaro		Mbeya		Morogoro		Njombe		n = 301 (%)
Total Respondents		n = 53(%)	n = 16(%)	n = 66(%)	OR (95%CI)	n = 55(%)	OR (95%CI)	n = 57(%)	OR (95%CI)	n = 54(%)	OR (95%CI)	
Have you ever encountered infertility on your farm?												
	yes	**52 (98)**	**15 (94)**	**62 (94)**		**52 (95)**		**55 (96)**		**49 (96)**		**285 (95)**
	No	1 (2)	1 (6)	2 (3)	***	3 (5)	***	1 (2)	***	4 (2)	***	12 (4)
	I don't know			2 (3)				1 (2)		1 (2)		4 (1)
Sign of infertility												
Producing a small amount of milk												
	correct	5 (9)		4 (6)		1 (2)				11 (20)		21 (7)
	incorrect	**41 (77)**	**11 (69)**	**58 (88)**	0.47 (0.18–1.26)	**50 (91)**	0.34 (0.11–1.05)	**56 (98)**	**0.06 (0.01–0.49)**	**33 (61)**	2.17 (0.93–5.06)	**249 (83)**
	not sure	7 (13)	5 (31)	4 (6)		4 (7)		1 (2)		10 (19)		31 (10)
Suffering from mastitis												
	correct	6 (11)		12 (18)		7 (13)		1 (2)		10 (19)		36 (12)
	incorrect	**42 (79)**	**14 (88)**	**45 (68)**	1.78 (0.77–4.14)	**44 (80)**	0.96 (0.37–2.44)	**55 (97)**	**0.14 (0.03–0.66)**	**35 (65)**	2.07 (0.87–4.84)	**235 (78)**
	not sure	5 (9)	2 (13)	9 (14)		4 (7)		1 (2)		9 (17)		30 (10)
Repeat breeding												
	correct	**48 (91)**	**16 (100)**	**65 (99)**		**53 (96)**		**56 (98)**		**44 (82)**		**282 (94)**
	incorrect	3 (6)			0.15 (0.02–1.31)	1 (2)	0.36 (0.07–1.96)		0.17 (0.02–1.52)	7 (13)	2.18 (0.69–6.88)	11 (4)
	not sure	2 (4)		1 (2)		1 (2)		1 (2)		3 (6)		8 (3)
Abortion												
	correct	**47 (89)**	**16 (100)**	**65 (99)**		**48 (87)**		**57 (100)**		**35 (65)**		**268 (89)**
	incorrect	5 (9)		1 (1)	0.12 (0.01–1.04)	5 (9)	1.14 (0.36–3.65)		***	10 (19)	**4.25 (1.54–11.8)**	21 (7)
	not sure	1 (2)				2 (4)				9 (17)		12 (4)
Retained foetal membrane (RFM)												
	correct	**44 (83)**	**15 (94)**	**64 (97)**		**42 (76)**		**54 (95)**		**31 (57)**		**250 (83)**
	incorrect	7 (13)	1 (6)	1 (2)	**0.15 (0.03–0.74)**	9 (16)	1.51 (0.59–3.91)	3 (5)	0.27 (0.07–1.07)	15 (28)	**3.63 (1.48–8.90)**	36 (12)
	not sure	2 (4)		1 (2)		4 (7)				8 (15)		15 (5)
Purulent vulval discharge												
	correct	**45 (85)**	**15 (94)**	**58 (88)**		**37 (67)**		**57 (100)**		**32 (59)**		**244 (81)**
	incorrect	2 (4)	1 (6)	3 (5)	0.78 (0.27–2.23)	13 (24)	**2.74 (1.07–7.00)**		***	10 (19)	**3.87 (1.53–9.78)**	29 (10)
	not sure	6 (11)		5 (8)		5 (9)				12 (22)		28 (9)
Suffering from reproductive disease												
	correct	**43 (81)**	**16 (100)**	**60 (91)**		**31 (56)**		**55 (97)**		**34 (63)**		**239 (79)**
	incorrect	1 (2)		1 (2)	0.43 (0.15–1.27)	14 (26)	**3.33 (1.39–7.95)**	1 (2)	**0.16 (0.03–0.75)**	7 (13)	**2.53 (1.05–6.11)**	24 (8)
	not sure	9 (17)		5 (8)		10 (18)		1 (2)		13 (24)		38 (13)
Stillbirth												
	correct	**42 (79)**	**15 (94)**	**55 (83)**		**35 (64)**		**56 (98)**		**32 (59)**		**235 (78)**
	incorrect	7 (13)	1 (6)	4 (6)	0.76 (0.30–1.93)	13 (24)	2.18 (0.92–5.17)	1 (2)	**0.07 (0.01–0.55)**	16 (30)	**2.63 (1.11–6.19)**	42 (14)
	not sure	4 (8)		7 (11)		7 (13)				6 (11)		24 (8)
Dystocia												

Table 1. *Cont.*

Character	Category	Regions										Total
		Tanga	Arusha	Kilimanjaro		Mbeya		Morogoro		Njombe		n = 301 (%)
Total Respondents		n = 53(%)	n = 16(%)	n = 66(%)	OR (95%CI)	n = 55(%)	OR (95%CI)	n = 57(%)	OR (95%CI)	n = 54(%)	OR (95%CI)	
	correct	**36 (68)**	**12 (75)**	**59 (89)**	**0.25 (0.10–0.67)**	**36 (66)**	1.12 (0.50–2.49)	**54 (95)**	**0.12 (0.03–0.43)**	**32 (59)**	1.46 (0.66–3.21)	**229 (76)**
	incorrect	11 (21)	3 (19)	2 (3)		15 (27)		3 (5)		16 (30)		50 (17)
	not sure	6 (11)	1 (6)	5 (8)		4 (7)				6 (11)		22 (7)
Failure to produce a calf in a year												
	correct	**44 (83)**	7 (44)	**44 (67)**	**2.44 (1.01–5.90)**	**38 (69)**	2.19 (0.87–5.47)	**31 (54)**	**4.1 (1.69–9.95)**	**35 (65)**	**2.65 (1.07–6.59)**	**199 (66)**
	incorrect	5 (9)	1 (6)	3 (5)		12 (22)		6 (11)		16 (30)		43 (14)
	not sure	4 (8)	**8 (50)**	19 (29)		5 (9)		20 (35)		3 (6)		59 (20)

For each region, the answer with the highest frequency (with its percentage in brackets) is in bold. OR: odds ratio; CI: confidence interval. ***: Indicates absence of figure for OR, 95%CI because of extremely low variabilities in farmers' responses. Data from Arusha were not included in the analysis. Calculation and interpretation of the OR: For this analysis 'incorrect' and 'not sure' were merged as 'not correct' and compared to 'correct' using binomial logistic regression (except for mastitis/milk production where 'correct' and 'not sure' were merged as 'not correct' and compared to 'incorrect). OR are odds, compared to Tanga, of a respondent from the region answering 'not correct'; i.e., for RFM, the odds of a respondent from Njombe answering 'not correct' were 3.63 times higher than those for a respondent from Tanga. OR values in bold are those where 95% CI excludes 1.

For *retained foetal membranes* (RFM), 83% of all 301 respondents correctly identified it as a sign of infertility; the range across regions was 57% (Njombe) to 97% (Kilimanjaro). As for abortion, respondents in Njombe had higher odds of being 'not correct' for this question (OR: 3.63, 95%CI: 1.48–8.90) than those in Tanga; and, in addition, farmers in Kilimanjaro had lower odds of being 'not correct' (OR: 0.15, 95%CI: 0.03–0.74) than those in Tanga. For *purulent vaginal discharge*, 81% of all respondents correctly identified it as a sign of infertility, ranging from 59% (Njombe) to 100% (Morogoro). Again, Njombe respondents had higher odds of being recorded as 'not correct' than those from Tanga (OR: 3.87, 95%CI: 1.53–9.78). Respondents from Mbeya (OR: 2.74, 95%CI 1.07–7.00) were also more likely to be 'not correct' than those from Tanga.

Regarding *reproductive diseases*, 79% of respondents correctly identified this as indicating infertility, with the highest proportion recorded in Arusha (100%) and the lowest in Mbeya (56%). As for purulent vaginal discharge, respondents from both Mbeya and Njombe had higher odds of being 'not correct' than respondents in Tanga (OR: 3.33, 95%CI: 1.39–7.95, and 2.53: 95%CI: 1.39–7.95, respectively). In contrast, respondents in the Morogoro region had lower odds of being 'not correct' (OR: 0.16, 95%CI: 0.03–0.75). For *stillbirths*, 78% of all respondents reported this correctly as an infertility sign, ranging from 98% (Morogoro) to 59% (Njombe). Once again, compared to those in Tanga, respondents from Njombe had higher odds (OR: 2.63, 95%CI: 1.11–6.19) of being 'not correct' and those in Morogoro had lower odds (OR: 0.07, 95%CI: 0.01–0.55).

For dystocia, 76% of all respondents were categorised as correct, with the highest proportion being recorded in Morogoro (95%) and the lowest in Njombe (59%). Compared to those from Tanga, respondents from Kilimanjaro had lower odds of being 'not correct' (OR: 0.25, 95%CI: 0.10–0.67), as did those from Morogoro (OR: 0.12, 95%CI: 0.03–0.43). As identified earlier, *failure to produce a calf per year* had the lowest proportion of correct respondents of all questions (66%). Across the regions, the largest proportion of 'correct' responses was in Tanga (83%) and the lowest in Morogoro (54%). Respondents from three regions had higher odds of being 'not correct' than those in Tanga: Morogoro (OR: 4.1, 95%CI: 1.69–9.95), Njombe (OR: 2.65, 95%CI: 1.07–6.59) and Kilimanjaro (OR: 2.44, 95%CI: 1.01–5.90).

For all 10 questions, the proportion of Njombe farmers who were correct was lower than in Tanga (Table 1), with the 95% CI for the OR excluding 1 for 6/10 questions. The equivalent figures for Mbeya, the region with the second highest proportion of 'not correct' answers, were that proportions correct were lower for 7/10 questions, and the 95%CI for the OR excluded 1 for 2/10 questions. In contrast, respondents in Kilimanjaro and Morogoro, the regions with the lowest proportion of 'not correct' answers across all 10 questions, had higher proportions of correct answers than those in Tanga for 8/10 and 9/10 questions, respectively, with the 95%CI for the OR excluding 1 for 2/10 and 5/10 questions.

3.2. Farmers' Perceptions of the Causes of Cattle Infertility

The respondents' understanding of the causes of infertility on their farms is summarised in Figure 3 and Table 2. To evaluate regional differences in farmers' perceptions of the causes of infertility, three categories were created: (i) 'agree' (combining strongly agree and agree), (ii) 'neutral', and (iii) 'disagree' (combining disagree and strongly disagree). The effect of the region was analysed using ordinal logistic regression analysis, with 'agree' being higher than 'neutral', which was higher than 'disagree'.

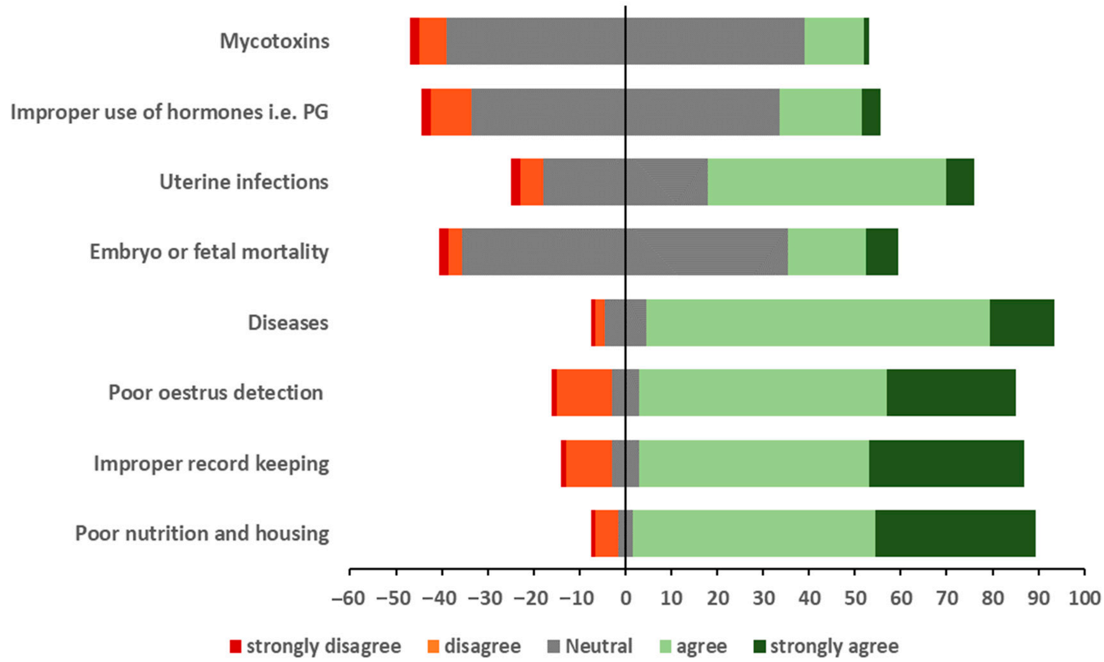

Figure 3. The opinions of Tanzanian smallholder dairy farmers on the causes of infertility on their farms. The x-axis is the overall percentage of respondents (n = 285) in each category, with '0' being the midpoint of the 'neutral' response.

Most (93%) respondents agreed or strongly agreed that poor *nutrition and housing* caused infertility on their farm (feeding and housing were put together as adopted from a previous study [16] on smallholder dairy cow management and fertility). This was the highest proportion of 'agree' responses for any of the eight causes in this survey. At the regional level, the proportion of respondents agreeing ranged from 98% in Kilimanjaro and Morogoro to 84% in Njombe. As the proportion of neutral results overall (3%) was <5%, respondents in this category were merged with those in the category 'disagree' (to form a 'neutral/disagree' category) and a binomial logistic regression was used to compare the odds of a respondent in a region being 'neutral/disagree' rather than 'agree'. However, although the fit of the model increased when the region was included (Akaike's Information Criterion (AIC) was 24.7 compared to 32.5 for the intercept-only model), none of the individual region comparisons with Tanga had an OR whose 95%CI excluded 1 (Table 2). Most (89%) respondents agreed/strongly agreed that disease was a cause of infertility on their farm, ranging at the regional level from 96% (Morogoro) to 88% (Njombe). As only 2% of respondents disagreed that disease was a cause of infertility on their farm, this category was merged with neutral, and a binomial logistic regression was used to compare the odds of a respondent in a region being 'disagree/neutral' rather than 'agree'. However, as for 'poor nutrition and housing', although the fit of the model slightly decreased when the region was included (AIC was 26.3 compared to 27.1 for the intercept-only model), none of the individual region comparisons with Tanga had an OR whose 95%CI excluded 1 (Table 2).

Table 2. Opinions of Tanzanian smallholder dairy farmers on the causes of infertility on their farms. Data are shown as the number of respondents (%).

Character	**Category**	**Regions**									**Total**
		Tanga	**Arusha**	**Kilimanjaro**		**Mbeya**		**Morogoro**		**Njombe**	
Total Respondents		**n = 52 (18)**	**n = 15 (5)**	**n = 62 (22)**	**OR (95% CI)**	**n = 52 (18)**	**OR (95% CI)**	**n = 55 (19)**	**OR (95% CI)**	**n = 49 (17)**	**OR (95% CI)**	**n = 285(%)**
Poor nutrition and housing											
	Strongly agree	13 (25)	6 (40)	15 (24)		**32 (62)**		12 (22)		**26 (53)**		104 (37)
	Agree	**35 (67)**	**9 (60)**	**46 (74)**	0.19 (0.02–1.82)	12 (23)	2.18 (0.61–7.75)	**42 (76)**	0.22 (0.02–2.06)	15 (31)	2.34 (0.66–8.34)	**159 (56)**
	Neutral	2 (4)				3 (6)		1 (2)		1 (2)		7 (3)
	Disagree	1 (2)		1 (2)		5 (10)				7 (14)		14 (5)
	Strongly disagree	1 (2)										1 (0.4)
Diseases											
	Strongly agree	2 (4)		1 (2)		10 (19)				**25 (51)**		38 (13)
	Agree	**46 (88)**	**14 (93)**	**52 (84)**	2.04 (0.59–7.05)	**33 (63)**	2.51 (0.72–8.75)	**53 (96)**	0.45 (0.08–2.58)	18 (37)	1.67 (0.44–6.33)	**216 (76)**
	Neutral	4 (8)	1 (7)	9 (15)		5 (10)		2 (4)		4 (18)		25 (9)
	Disagree					4 (8)				2 (4)		6 (2)
	Strongly disagree											
Improper farm record-keeping											
	Strongly agree	14 (27)	7 (47)	13 (21)		5 (10)		**34 (62)**		**23 (49)**		96 (34)
	Agree	**33 (64)**	**8 (53)**	**47 (76)**	0.30 (0.06–1.61)	**26 (50)**	**6.16 (2.11–18.0)**	19 (35)	0.34 (0.06–1.83)	11 (22)	**3.76 (1.12–11.3)**	**144 (51)**
	Neutral			1 (2)		6 (12)		1 (2)		7 (14)		15 (5)
	Disagree	4 (8)		1 (2)		15 (29)		1 (2)		8 (16)		29 (10)
	Strongly disagree	1 (2)										1 (0.4)
Poor oestrus detection											
	Strongly agree	14 (27)	4 (27)	20 (32)		15 (29)		9 (16)		**19 (39)**		81 (28)
	Agree	**32 (62)**	**10 (67)**	**41 (66)**	0.13 (0.02–1.13)	**19 (37)**	**4.63 (1.67–12.9)**	**41 (75)**	0.78 (0.22–2.72)	13 (27)	**4.22 (1.51–11.8)**	**156 (55)**
	Neutral	4 (8)	1 (7)			2 (4)		3 (6)		5 (10)		15 (5)
	Disagree	2 (4)		1 (2)		16 (31)		2 (4)		12 (25)		33 (12)
	Strongly disagree											
Uterine infections											
	Strongly agree			1 (2)		1 (2)				15 (31)		17 (6)
	Agree	23 (44)	**12 (80)**	**37 (60)**	0.54 (0.26–1.11)	11 (21)	**3.63 (1.65–7.96)**	**49 (89)**	**0.11 (0.04–0.30)**	**16 (33)**	0.59 (0.27–1.29)	**148 (52)**
	Neutral	**29 (56)**	3 (20)	24 (39)		**29 (56)**		6 (11)		13 (27)		104 (37)
	Disagree					11 (21)				2 (4)		13 (5)
	Strongly disagree									3 (6)		3 (1)
Embryo or foetal mortality											
	Strongly agree	2 (4)				5 (10)				13 (27)		20 (7)
	Agree	3 (6)	2 (13)	9 (15)	0.80 (0.35–1.82)	8 (15)	0.66 (0.28–1.57)	10 (18)	0.67 (0.29–1.56)	**16 (33)**	**0.20 (0.08–0.48)**	48 (17)
	Neutral	**47 (90)**	**13 (87)**	**53 (85)**		**35 (67)**		**45 (82)**		10 (20)		**203 (71)**
	Disagree					4 (8)				7 (14)		11 (4)
	Strongly disagree									3 (6)		3 (1)
Improper use of hormones, i.e., PGF2α											

Table 2. *Cont.*

Character	Category	Regions										Total
		Tanga	Arusha	Kilimanjaro		Mbeya		Morogoro		Njombe		
Total Respondents		**n = 52 (18)**	**n = 15 (5)**	**n = 62 (22)**	**OR (95% CI)**	**n = 52 (18)**	**OR (95% CI)**	**n = 55 (19)**	**OR (95% CI)**	**n = 49 (17)**	**OR (95% CI)**	**n = 285(%)**
	Strongly agree	1 (2)	1 (7)					1 (2)		5 (10)		8 (3)
	Agree	12 (23)	2 (13)	4 (7)		4 (8)		9 (16)		**17 (35)**		48 (17)
	Neutral	**35 (67)**	**12 (80)**	**57 (92)**	1.59 (0.76–3.34)	**29 (56)**	**5.36 (2.36–12.1)**	**43 (78)**	1.13 (0.53–2.43)	10 (20)	1.11 (0.46–2.67)	**186 (65)**
	Disagree	3 (6)		1 (2)		18 (35)		2 (4)		2 (4)		26 (9)
	Strongly disagree	1 (2)				1 (2)				15 (31)		17 (6)
Mycotoxins												
	Strongly agree									3 (6)		3 (1)
	Agree	5 (10)	2 (13)	6 (10)				8 (15)		16 (33)		37 (13)
	Neutral	**44 (85)**	**13 (87)**	**56 (90)**	0.66 (0.23–1.88)	**37 (71)**	**8.24 (2.27–25.0)**	**47 (86)**	0.48 (0.17–1.38)	**26 (53)**	**0.19 (0.07–0.53)**	**223 (78)**
	Disagree					14 (27)				3 (6)		17 (6)
	Strongly disagree	3 (6)				1 (2)				1 (2)		5 (2)

NB: The answer with the highest frequency (with its percentage in brackets) for each region is bolded. OR: odds ratio; CI: confidence interval. Data from Arusha were not included in the analysis. Calculation and interpretation of the OR: For this analysis, the effect of region on the proportion of respondents in the categories 'agree' (combining strongly agree and agree), 'neutral' and 'disagree' (combining disagree and strongly disagree) were assessed using ordinal logistic regression, except for 'poor nutrition and housing' and 'livestock diseases' where binomial logistic regression was used (i.e., agree against neutral/disagree) because their overall responses for neutral or disagree category was <5%). OR are odds, compared to Tanga, of a respondent being in a lower category, e.g., regarding whether mycotoxins were important, Njombe respondents had lower odds (OR: 0.19. 95%CI: 0.07–0.53) of being in a lower category (e.g., disagree rather than neutral/agree) than farmers in Tanga, i.e., Njombe farmers were more likely to think mycotoxins were important than farmers in Tanga. OR values in bold are those where the 95%CI excludes 1.

For *improper farm record keeping*, 85% of all the respondents agreed/strongly agreed that it was associated with infertility on their farm, ranging at the regional level from 97% (Kilimanjaro and Morogoro) to 60% (Mbeya). Respondents in both Mbeya and Njombe had higher odds of being in a lower category (i.e., were more likely to disagree than neutral or agree that improper record keeping is associated with infertility) than respondents in Tanga (OR: 6.16, 95%CI: 2.11–18.0 and OR: 3.36, 95%CI: 11.12–11.3, respectively). For *poor oestrus detection*, 83% of all the respondents agreed/strongly agreed that it caused infertility on their farm, ranging at the regional level from 98% (Kilimanjaro) to 66% (Mbeya and Njombe). Again, respondents from Mbeya and Njombe had higher odds (OR: 4.63, 95%CI: 1.67–12.9 and OR: 4.22, 95%CI: 1.51–11.8, respectively) of being in a lower category (e.g., were more likely to disagree than being neutral or agree) than those in Tanga. A small majority (58%) of all the respondents agreed/strongly agreed that *uterine infections* caused infertility on their farm, ranging from 89% (Morogoro) to 23% (Mbeya). Respondents' odds of being in a lower category were higher in Mbeya (OR: 3.63, 95%CI: 1.65–7.96) and lower in Morogoro (OR: 0.11, 95%CI: 0.04–0.30) than respondents in Tanga.

The most common overall response (71%) of respondents concerning *embryo or foetal mortality* as a cause of infertility on their farm was 'neutral', ranging from 90% (Tanga) to 20% (Njombe). Only respondents in Njombe had lower odds (OR: 0.20, 95%CI: 0.08–0.48) of being in a lower category than respondents in Tanga. Similarly, 65% of all the respondents were neutral regarding the *improper use of hormones* as a cause of infertility, ranging from 92% (Kilimanjaro) to 20% (Njombe). Respondents in Mbeya had higher odds (OR: 5.36, 95%CI: 2.36–12.1) of being in a lower category than those in Tanga. Lastly, 78% of all the respondents' responses regarding mycotoxins as an infertility cause were neutral, ranging from 90% (Kilimanjaro) to 53% (Njombe). Respondents in Mbeya had higher odds (OR: 8.24, 95%CI: 2.27–25.0), while those in Njombe had lower odds (OR: 0.19, 95%CI: 0.07–0.53) of being in a lower category than those in Tanga.

3.3. Farmers' Attitudes Towards Infertility

A total of 285 respondents reported having encountered infertility challenges in their herds. Among those respondents, 98% (280/285) recognised that it was a problem for them, ranging from 100% (Tanga, Arusha, Kilimanjaro and Morogoro) to 92% (Njombe). For respondents who thought infertility was a problem in their herd, 48% (133/280) considered that it had major consequences, ranging from 58% (Morogoro) to 31% (Njombe) (Figure 4 and Table 3). The effect of region on the extent to which respondents thought infertility was a problem on their farm was analysed using multinomial logistic regression as the parallel lines assumption was not met ($p < 0.05$). Compared to the respondents in the Tanga region, only respondents in Njombe had higher odds of regarding infertility as a moderate (OR: 2.48, 95%CI: 1.05–5.86) or a minor (OR: 4.67, 95%CI: 1.04–20.8) problem on their farm rather than a major problem.

Three categories were created to evaluate regional differences in farmers' attitudes regarding infertility: (i) 'major', (ii) 'moderate' and (iii) 'negligible' (merging of 'minor' and 'not at all'). All analyses used ordinal logistic regression to assess the regional effect on farmers' attitudes towards infertility issues on their farms, except for *repeat breeding*, *reproductive diseases*, and *stillbirth*, where binomial logistic regression was used and the categories used were 'negligible' against 'other' (merging of 'major' and 'moderate'). Across the 285 respondents, 82% considered *repeat breeding* as a major infertility problem, ranging from 93% (Arusha) to 67% (Njombe). Compared to Tanga, only respondents in Njombe had lower odds (OR: 0.17, 95%CI: 0.05–0.56) of considering it a major issue rather than 'moderate' or 'negligible' using binomial logistic regression, i.e., major against other categories (merging of 'moderate' and 'negligible'). For *failure to produce a calf in a year*, the most common response was moderate, with 44% of farmers considering it to have a moderate impact, ranging from 93% (Arusha) to 13% (Tanga). Compared to Tanga, respondents from Morogoro, Njombe, Kilimanjaro and Mbeya had higher odds of being in a lower category with OR (95%CI) of 38.0 (15.12–95.8), 23.0 (9.03–58.7), 7.64 (3.2–17.9), and 5.48 (2.2–13.7), respectively (Table 3).

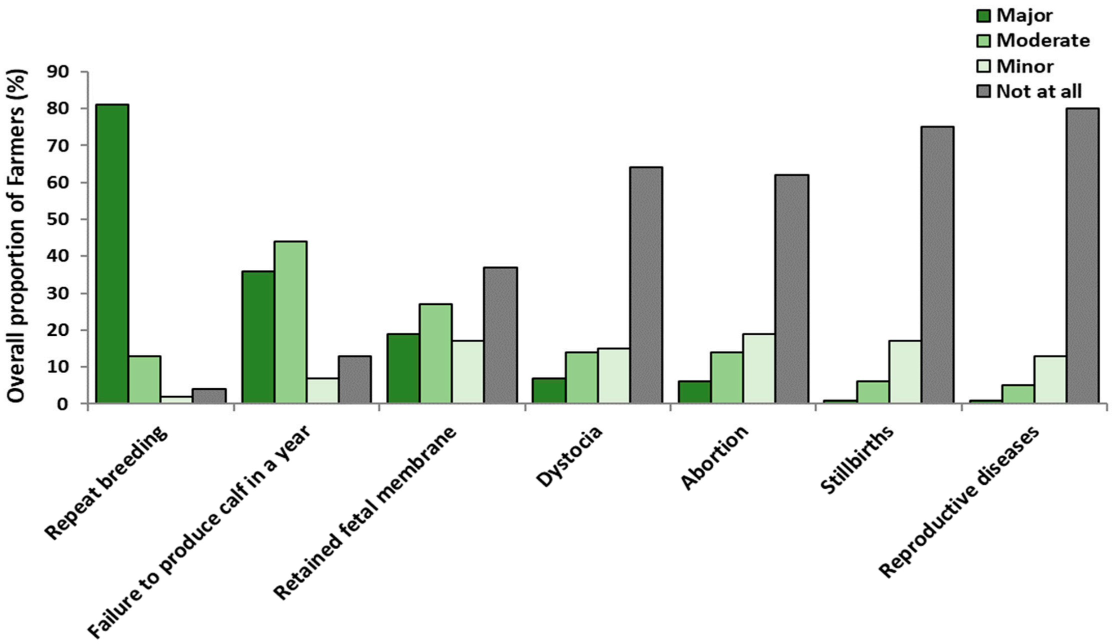

Figure 4. Perception of the Tanzanian smallholder dairy farmers (n = 285/301) on the impact of experienced infertility problems on their farm.

The attitude of the majority of all the respondents (54%) was that the impact of *retained foetal membranes* (RFM) on infertility on their farm was negligible, ranging from 73% (Arusha) to 35% (Njombe). Respondents in Mbeya and Njombe had lower odds of being in the lower category (meaning that farmers in these regions were more likely to perceive RFM as a moderate or major issue on their farms) with OR (95%CI) of 0.44 (0.21–0.93) and 0.44 (0.21–0.91), respectively, compared to those in Tanga. *Dystocia* was considered to have a negligible impact as an infertility problem by 79% of all respondents, ranging from 93% (Arusha) to 63% (Njombe). There was no clear statistical difference between responses from Tanga compared to other regions, however, many of the 95%CI were wide (e.g., 0.98 to 5.62 for Njombe respondents) which means that, although our data were compatible with the absence of a regional effect, they were also compatible with a large effect of region (e.g., for Njombe respondents a large increase in their odds of being in a lower category) so we cannot exclude important differences between regions. The impact of *abortions* was considered to be similar to *dystocia*, with 80% of all respondents, ranging from 87% (Tanga and Arusha) to 75% (Mbeya), considering them to have a negligible impact. As for *dystocia*, no clear regional difference was identified in farmers' attitudes regarding the impact of abortion, but again the 95%CI was wide (e.g., 0.16–1.20 for Mbeya vs. Tanga). An even higher proportion of respondents (93%) considered *stillbirths* to have a negligible impact on their farms. This ranged by region from 100% (Arusha) to 89% (Morogoro). Again, there were no clear statistical regional differences in farmers' attitudes regarding the impact of *stillbirths*, but the 95% CI were wide (e.g., 0.21 to 5.55 for the Njombe region). Lastly, 93% of all respondents, ranging from 98% (Kilimanjaro and Tanga) to 60% (Njombe), considered reproductive disease to be a negligible problem on their farms. Respondents in Njombe had higher odds (OR: 9.95, 95%CI: 1.20–82.8) of considering reproductive diseases as having a negligible impact on their farms than respondents in Tanga.

Table 3. Perceived importance of animal infertility cases experienced by smallholder dairy cattle farmers in Tanzania. Data are shown as the number of respondents (%).

Character	Category	Regions										Total
		Tanga	Arusha	Kilimanjaro		Mbeya		Morogoro		Njombe		
Total Respondents		**n = 52 (18)**	**n = 15 (5)**	**n = 62 (22)**	**OR (95% CI)**	**n = 52 (18)**	**OR (95% CI)**	**n = 55 (19)**	**OR (95% CI)**	**n = 49 (17)**	**OR (95% CI)**	**n = 285(%)**
Do you consider infertility a problem on your farm?												
Total respondents		**n = 52 (19)**	**n = 15 (5)**	**n = 62 (22)**	**OR (95% CI)**	**n = 51 (18)**	**OR (95% CI)**	**n = 55 (20)**	**OR (95% CI)**	**n = 45 (16)**	**OR (95% CI)**	**n = 285(%)**
	Yes	**52 (100)**	**15 (100)**	**62 (100)**	***	**51 (98)**	***	**55 (100)**	***	**45 (92)**	***	**280 (98)**
	No					1 (2)				4 (8)		5 (2)
(If yes), To what extent is infertility a problem on your farm?												
Total respondents		**n = 52 (19)**	**n = 15 (5)**	**n = 62 (22)**	**OR (95% CI)**	**n = 51 (18)**	**OR (95% CI)**	**n = 55 (20)**	**OR (95% CI)**	**n = 45 (16)**	**OR (95% CI)**	**n = 280(%)**
	Major	**28 (54)**	**8 (53)**	25 (40)		**26 (51)**		**32 (58)**		14 (31)		**133 (48)**
	Moderate	21 (40)	6 (40)	**33 (53)**	1.76 (0.82–3.79)	22 (43)	1.13 (0.51–2.52)	17 (31)	0.71 (0.31–1.60)	**24 (53)**	**2.48 (1.05–5.86)**	123 (44)
	Minor	3 (6)	1 (7)	4 (6)	1.49 (0.30–7.33)	3 (6)	1.08 (0.20–5.82)	6 (11)	1.75 (0.40–7.66)	7 (16)	**4.67 (1.04–20.8)**	24 (9)
What is the importance of these infertility problems on your farm?												
Repeat breeding [b]												
	Major	**48 (92)**	**14 (93)**	**50 (81)**	0.35 (0.11–1.15)	**42 (81)**	0.35 (0.10–1.20)	**47 (85)**	0.49 (1.14–1.74)	**33 (67)**	**0.17 (0.05–0.56)**	**234 (82)**
	Moderate	3 (6)	1 (6)	9 (15)		7 (13)		5 (9)		11 (22)		36 (13)
	Minor			1 (2)		1 (2)		2 (4)		1 (2)		5 (2)
	Not at all	1 (2)		2 (3)		2 (4)		1 (2)		4 (8)		10 (4)
Failure to produce a calf in a year [a]												
	Major	**43 (83)**	1 (7)	19 (31)	**7.64 (3.2–17.92)**	**28 (54)**	**5.48 (2.20–13.7)**	3 (5)	**38.0 (15.1–95.8)**	10 (20)	**23.0 (9.03–58.7)**	103 (36)
	Moderate	7 (13)	**14 (93)**	**41 (66)**		12 (23)		**30 (55)**		**22 (45)**		**126 (44)**
	Minor	1 (2)		2 (3)		3 (6)		12 (22)		2 (4)		20 (7)
	Not at all	1 (2)				9 (17)		10 (18)		12 (31)		36 (12)
Retained foetal membrane [a]												
	Major	7 (13)	3 (22)	7 (11)	1.39 (0.66–2.92)	**17 (33)**	**0.44 (0.21–0.93)**	7 (13)	1.09 (0.52–2.30)	12 (24)	**0.44 (0.21–0.91)**	53 (19)
	Moderate	15 (29)	1 (7)	14 (23)		13 (25)		15 (27)		**20 (41)**		78 (27)
	Minor	10 (19)	4 (27)	13 (21)		8 (15)		9 (16)		4 (8)		48 (17)
	Not at all	**20 (38)**	**7 (47)**	**28 (45)**		14 (27)		**24 (44)**		13 (27)		**106 (37)**
Dystocia [a]												
	Major	2 (4)	1 (7)	1 (2)	0.41 (0.14–1.19)	6 (12)	1.35 (0.54–3.34)	2 (4)	0.84 (0.33–2.16)	8 (16)	2.35 (0.98–5.62)	20 (7)
	Moderate	9 (17)		5 (8)		7 (13)		8 (15)		10 (20)		39 (14)
	Minor	12 (23)	3 (20)	5 (8)		12 (23)		8 (15)		3 (6)		43 (15)
	Not at all	**29 (56)**	**11 (73)**	**51 (82)**		**27 (52)**		**37 (67)**		**28 (57)**		**183 (64)**
Abortion [a]												
	Major	1 (2)	1 (7)	3 (5)	0.54 (0.20–1.44)	6 (12)	0.43 (0.16–1.20)	5 (9)	0.65 (0.23–1.87)	1 (2)	0.62 (0.22–1.78)	17 (6)
	Moderate	6 (12)	1 (7)	11 (18)		7 (13)		5 (9)		9 (18)		39 (14)
	Minor	13 (25)	2 (13)	12 (19)		6 (12)		18 (33)		2 (4)		53 (19)
	Not at all	**32 (62)**	**11 (73)**	**36 (58)**		**33 (63)**		**27 (49)**		**37 (76)**		**176 (62)**
Stillbirths [b]												

Table 3. *Cont.*

Character	Category	Regions										Total
		Tanga	Arusha	Kilimanjaro		Mbeya		Morogoro		Njombe		
Total Respondents		**n = 52 (18)**	**n = 15 (5)**	**n = 62 (22)**	**OR (95% CI)**	**n = 52 (18)**	**OR (95% CI)**	**n = 55 (19)**	**OR (95% CI)**	**n = 49 (17)**	**OR (95% CI)**	**n = 285(%)**
Reproductive diseases [(b)]	Major	1 (2)				1 (2)		1 (2)				3 (1)
	Moderate	2 (4)		4 (6)	1.13	4 (8)	1.74	5 (9)	2.00	3 (6)	1.07	18 (6)
	Minor	13 (25)	4 (27)	9 (15)	(0.24–5.28)	7 (13)	(0.39–7.68)	12 (22)	(0.47–8.45)	4 (8)	(0.21–5.55)	49 (17)
	Not at all	**36 (69)**	**11 (73)**	**49 (79)**		**40 (77)**		**37 (67)**		**42 (86)**		**215 (75)**
	Major	1 (2)						1 (2)		2 (4)		4 (1)
	Moderate		2 (13)	1 (2)	0.84	2 (4)	2.04	4 (7)	5.10	6 (12)	**9.95**	15 (5)
	Minor	6 (12)	1 (7)	7 (11)	(0.05–13.7)	4 (8)	(0.18–23.2)	17 (31)	(0.58–45.2)	3 (6)	**(1.20–82.8)**	38 (13)
	Not at all	**45 (87)**	**12 (80)**	**54 (87)**		**46 (88)**		**33 (60)**		**38 (78)**		**228 (80)**

NB: The answer with the highest frequency (with its percentage in brackets) for each region is bolded. OR: odds ratio; CI: confidence interval. ***: Indicates absence of figure for OR, 95%CI because of lack of or extremely low variabilities in farmers' responses. Data from Arusha were not included in the analysis. Calculation and interpretation of the OR: For this analysis, i.e., the effect of region on the extent of experienced infertility cases on farms by smallholder dairy cattle farmers, three categories were created: 'major', 'moderate and 'negligible' (merging of 'minor' and 'not at all'). All analyses used ordinal logistic regression [(a)], except for repeat breeding, reproductive diseases and stillbirth where binomial logistic regression [(b)] was used and the categories used were 'negligible' against 'other' (merging of 'major' and 'moderate'), because one of the categories had less than 5% proportion of the total, i.e., only 1% of the respondents considered reproductive diseases to have major impact on their farm. OR are odds, compared to Tanga, i.e., Njombe respondents had higher odds (OR: 9.95, 95%CI: 1.20–82.8) of regarding stillbirths as having a negligible impact on their farms compared to those in Tanga and relative to 'other' (major or moderate). OR values in bold are those where 95%CI excludes 1.

3.4. Farmers' Practices Regarding Dairy Cattle Infertility

Farmers' practices were evaluated by allowing them to select from predefined options regarding the actions they take once they have an infertile animal on their farms (Table 4). To evaluate regional differences in farmers' practices, three categories were made: (i) 'agree' (combining strongly agree and agree), (ii) 'neutral' and (iii) 'disagree' (merging disagree and strongly disagree), with that order being used for an ordinal regression.

Table 4. Practices of the smallholder dairy cattle farmers in Tanzania when they encounter infertile cattle on their farm. Data are shown as the number of respondents (%).

Character Category	Regions										Total
	Tanga	**Arusha**	**Kilimanjaro**		**Mbeya**		**Morogoro**		**Njombe**		
Total Respondents	**n = 52 (18)**	**n = 15 (5)**	**n = 62 (22)**	**OR (95% CI)**	**n = 52 (18)**	**OR (95% CI)**	**n = 55 (19)**	**OR (95% CI)**	**n = 49 (17)**	**OR (95% CI)**	**n = 285(%)**
What do you do when you have an infertile cow on your farm?											
Report to the veterinary service provider											
Strongly agree	20 (38)	4 (27)	12 (19)		**28 (54)**		20 (36)		**37 (71)**		121 (42)
Agree	**32 (62)**	**10 (67)**	**48 (77)**		19 (37)		**31 (56)**		9 (17)		**149 (52)**
Neutral		1 (7)	1 (2)	***	1 (2)	***	4 (7)	***	2 (4)	***	9 (3)
Disagree			1 (2)		4 (8)				3 (6)		8 (3)
Strongly disagree									1 (2)		1 (0.3)
Slaughter the animal											
Strongly agree	4 (8)	4 (27)	13 (21)		4 (8)		15 (27)		**16 (31)**		56 (19)
Agree	**21 (40)**	**10 (67)**	**40 (65)**	0.16	**23 (44)**	0.98	**38 (69)**	**0.04**	13 (25)	0.87	**145 (50)**
Neutral	10 (19)	1 (7)	6 (10)	(0.07–	6 (12)	(0.47–		**(0.01–**	5 (10)	(0.41–	28 (10)
Disagree	16 (31)		3 (5)	0.39)	19 (37)	2.03)	2 (4)	**0.17)**	17 (33)	1.84)	57 (20)
Strongly disagree	1 (2)								1 (2)		2 (1)
Sell to other farmers											
Strongly agree					1 (2)				3 (6)		4 (1)
Agree	10 (19)	3 (20)	13 (21)	0.72	16 (31)	0.56	9 (16)	0.80	11 (21)	0.60	62 (22)
Neutral	9 (17)		16 (26)	(0.35–	8 (15)	(0.26–	16 (29)	(0.38–	5 (10)	(0.24–	54 (19)
Disagree	**30 (58)**	**12 (80)**	**33 (53)**	1.48)	**27 (52)**	1.21)	**29 (53)**	1.67)	**23 (44)**	1.50)	**154 (53)**
Strongly disagree	3 (6)						1 (2)		10 (19)		14 (5)
Treat the animal by myself											
Strongly agree		1 (7)	1 (2)		2 (4)		1 (2)		2 (4)		7 (2)
Agree	6 (12)	3 (20)	5 (8)	1.22	6 (12)	0.85	8 (15)	0.80	11 (21)	0.45	39 (14)
Neutral	2 (4)		2 (3)	(0.43–	1 (2)	(0.30–	1 (2)	(0.29–	1 (2)	(0.17–	7 (2)
Disagree	**37 (71)**	**11 (73)**	**52 (84)**	3.51)	**41 (79)**	2.40)	**38 (69)**	2.20)	**29 (56)**	1.15)	**208 (72)**
Strongly disagree	7 (13)		2 (3)		2 (4)		7 (13)		9 (17)		27 (9)

NB: The answer with the highest frequency (with its percentage in brackets) for each region is bolded. OR: odds ratio; CI: confidence interval. Data from Arusha were not included in the analysis. ***: Indicates absence of figure for OR, 95%CI because of lack of or extremely low variabilities in farmers' responses. Calculation and interpretation of the OR: For this analysis, three categories were made: 'agree' (combining strongly agree and agree), 'neutral' and 'disagree' (combining disagree and strongly disagree). Analyses were performed using ordinal logistic regression with agree being the highest category and disagree the lowest. OR are odds ratios compared to Tanga, e.g., Morogoro respondents had lower odds (OR: 0.04, 95%CI: 0.01–0.17) of being in a lower category than respondents in Tanga, regarding the use of animal slaughter to manage infertility. OR values in bold are those where 95%CI excludes 1.

Almost all farmers (94%), ranging from 100% (Tanga) to 88% (Njombe), reported *consulting a veterinary service provider* whenever they encountered an infertility case on their farms. Sixty-nine % of all respondents, ranging from 96% (Morogoro) to 48% (Tanga) agreed that *animal slaughter* was the best way to manage infertility. Compared to farmers in Tanga, farmers in Morogoro had higher odds of using slaughter to manage fertility (odds of being in a lower category (i.e., disagree (rather than agree/neutral) or disagree/neutral vs. agree) OR: 0.04, 95%CI: 0.01–0.17). Most farmers (58%), ranging from 80% (Arusha) to 52% (Mbeya), disagreed with the practice of *selling an infertile animal to another farmer*. No clear regional differences were identified concerning this practice. An even higher proportion of farmers (81%), ranging across the regions from 87% (Kilimanjaro) to 73% (Arusha and Njombe), disagreed with the practice of *self-treating an infertile animal* on their farm. However, no clear differences were noted across the region, but there was a wide 95% CI (Table 4).

In response to the question, "*Have you ever managed infertility using traditional methods?*" only eighteen farmers across the regions reported using traditional methods to address infertility. However, of those 18, 13 were in Njombe. Repeat breeding, RFM, and dystocia were among the conditions reported to be traditionally managed by smallholder dairy cattle farmers. One example of such is the extraction of the corner incisor teeth (Figure 5) as a "treatment" of a repeat breeder cow/heifer, which was practised by 13 farmers from the Njombe region. Other reported treatments included using natural herbs and receiving assistance from traditional healers.

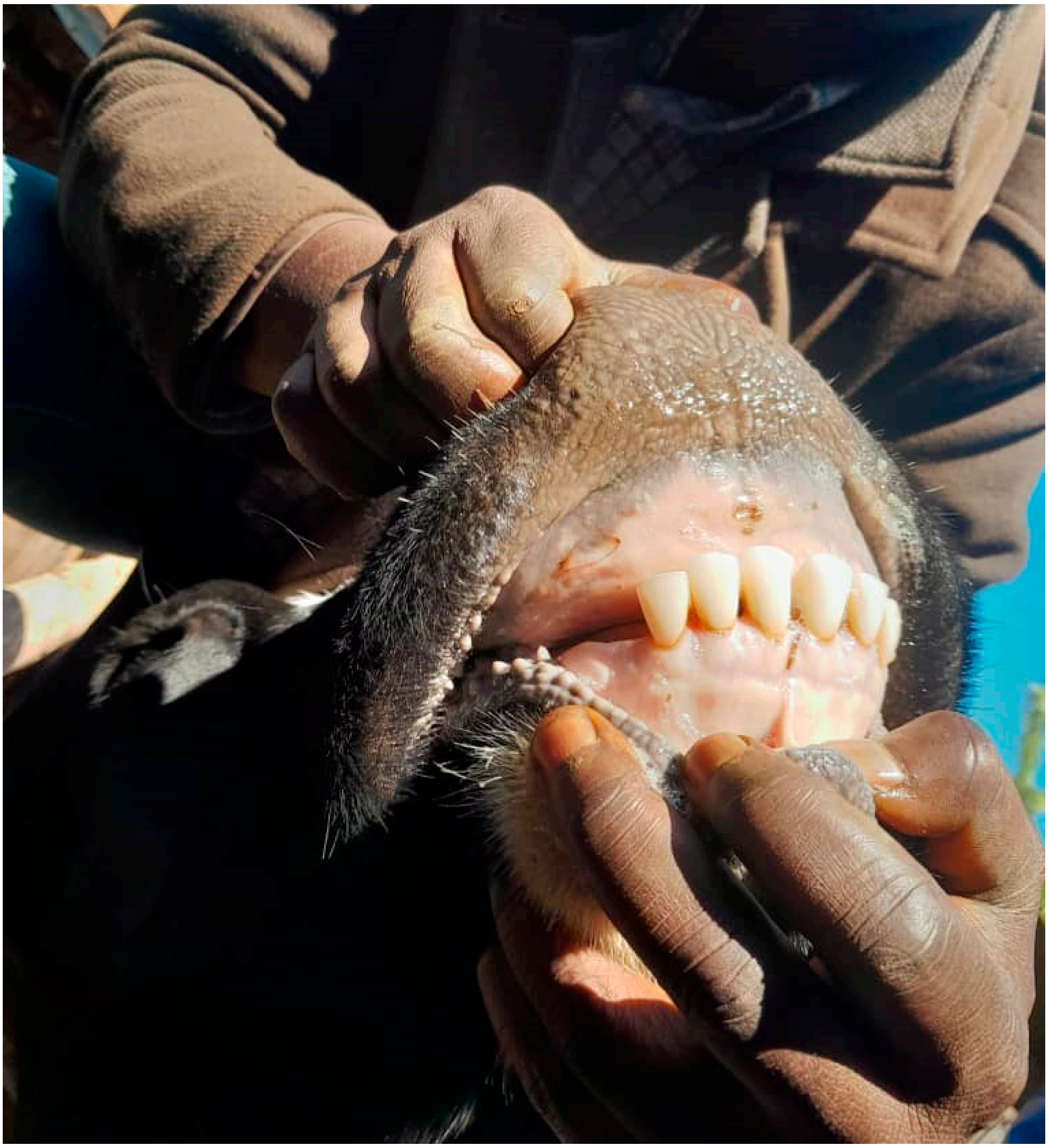

Figure 5. An animal without corner incisor teeth (removed as a management practice for repeat breeding) was observed in the Njombe region, Tanzania.

4. Discussion

Infertility creates a substantial obstacle to improving the productivity and sustainability of smallholder dairy cattle farming in many developing countries, including Tanzania. The occurrence of infertility and other constraints to smallholder dairy farming arises from the combination of numerous factors, of which the KAPs of farmers are key [22,23]. Comprehensive knowledge of the KAPs of smallholder dairy cattle farmers concerning infertility is therefore a valuable start towards developing specific interventions to improve herd management, fertility and productivity (especially milk yield). Gathering these data requires acknowledging that smallholder dairy farming in Tanzania mostly operates under traditional practices, with limited access to modern veterinary services and education on fertility management.

Most of the farmers correctly understood what the signs of infertility were, with the majority correctly answering at least 7 of the questions (Table 1); however, there was significant farmer-to-farmer variation, with the lowest farmer only having 2/10 questions correct. Over 80% of the smallholder dairy cattle farmers across the regions were able to identify conditions like repeat breeding, abortion, retained foetal membranes (RFM) and purulent vulval discharge as indicators of infertility. However, a significant minority (34%) of farmers did not agree (or were uncertain) that an inability to produce a calf per year constituted infertility. This belief was highest among respondents from the Morogoro and Kilimanjaro regions, where farmers appear to prioritise milk yield and strategically manage calving intervals to meet specific farming or market objectives. Farmers can extend the lactation period by delaying insemination beyond 60–90 days postpartum, maximising milk production and potentially taking advantage of the higher milk prices during particular seasons. This intentional practice of producing calves less frequently than once yearly reflects a trade-off between reproductive efficiency and economic gains from milk production.

There was a clear effect of region on farmer recognition of the signs of infertility, with farmers from the Morogoro and Kilimanjaro regions appearing to be better informed than those from other regions, whilst Njombe farmers had the poorest levels of knowledge (Table 2). It is interesting to consider the extent to which this pattern reflects the education levels of the participants across regions; the majority of respondents from the Mbeya (66%) and Njombe (63%) regions had only primary education, while 68% and 46%, respectively, of farmers from Morogoro and Kilimanjaro had formal education beyond primary school [17]. This difference in education may be related to the Kilimanjaro region having the highest number of secondary schools of any of the regions in this study [24] and the location in Morogoro of Sokoine University of Agriculture (the only agricultural university in Tanzania). However, this study did not evaluate the association between the education level of the farmer and the availability of schools or universities. A previous study on the effect of education on production efficiency found a strong positive association in Asia and less in Latin America [25].

The causes of infertility that were highlighted by the majority of farmers as important on their farms were poor nutrition and housing, livestock disease, improper farm record keeping, poor oestrus detection and uterine infections, all of which have been highlighted as important by previous studies in both Tanzania [26] and in other similar systems outside of Tanzania, e.g., in Malawi: Banda, Kamwanja, Chagunda, Ashworth and Roberts [16]. The other infertility causes listed in Table 3 were seen as less important by our respondents. However, as the focus of this question was to ask the farmers their opinion on what was causing infertility on their farm, for most causes identified as less important, we do not know whether they were unimportant or whether they were important but were missed by our respondents. For example, embryo/foetal mortality can be difficult to recognise, especially when pregnancy diagnosis is uncommon, and can be a difficult concept for uneducated farmers to understand, so it may play a larger role in Tanzanian dairy infertility than suggested by this survey.

Most farmers across the regions regarded infertility as a significant (moderate to major) constraint on their farming; indeed, in most regions except for Njombe and Kilimanjaro, infertility was a major concern to the majority of farmers. Across all regions, repeat breeding was seen as an extremely important form of infertility. The perceived importance of repeat breeding is likely related to the ease of diagnosis (and its non-complex nature), with farmers directly observing cows repeatedly coming into oestrus without conceiving and recognising the instant economic losses from repeated breeding expenses.

There were significant differences across regions in opinions on the impact of failing to produce a calf annually. Across all respondents, 63% thought that failure to produce a calf annually had a moderate or smaller impact on farming. However, in the Tanga and Mbeya regions, failure to produce a calf annually was considered to have a major impact by 83% and 54% of respondents, respectively. This large difference across regions does not align with the underlying scientific consensus that the ideal calving interval for most cows is approximately 12 to 13 months [27], but rather likely reflects varying market conditions. In the Tanga and Mbeya regions, farmers' cooperatives like CHAWAMU (Tanga) and UTAMBUZI (Mbeya) provide a year-round milk market, where there is limited seasonal variation in milk price. In this situation, it is clear that calving cows as frequently as feasible optimises milk production and milk income. Conversely, farmers in other regions (e.g., Morogoro) have highly seasonal pricing [28], with high prices and willing buyers in the dry season, compared to lower prices and production above demand during the rainy season [29] and thus smallholders can be tempted to alter breeding to target those prices. However, maximising milk production during the dry season poses greater challenges for farmers due to feed and water scarcity [28,30,31], which results in poorer fertility and a further increase in calving interval. Another study on beef reported that a calving date should consider not only the quantity but also the quality of the available feed [32].

Farmers' perception of the importance of different infertility conditions is likely to depend on how often they observe these conditions. For example, most farmers would encounter cows that need multiple inseminations to become pregnant (i.e., returns to oestrus), so it is not surprising that they ascribe to it a high level of significance, although other forms of infertility (i.e., abortion, stillbirth, RFM) have a much greater impact on the productivity of the individual animal [33–35]. In other words, because of the lower frequency (compared to repeat breeding) of these latter forms of infertility, farmers tend to underestimate their impact. However, their occurrence not only impacts farmers in terms of costs associated with veterinary services but also affects the animals by reducing production [36,37] and shortening overall lifetime productivity [38,39]. For example, in Tanzania, a study by Kashoma and Ngou [40] showed that RFM causes a significant economic loss (i.e., 364,133.00 Tanzanian shillings (157.00 USD) per cow, reduced milk production (95.4%) and treatment costs (4.6%)). On top of these losses to the farmer, RFM leaves the animal sub-fertile even after successful treatment and recovery. Similarly, in developed countries, RFM has been reported to reduce milk sales and an overall reduction in animal fertility [41,42].

Farmers in this survey generally seemed to recognise the value of veterinary services, with 94% reporting that they would consult a veterinary service provider when facing any form of infertility on their farm, and 81% disagreeing with the practice of self-treating their infertile animals. Nonetheless, a minority of farmers continue to practice traditional methods of managing infertility, with 25% (13/49) of farmers from Njombe still extracting incisor teeth as a means of managing repeat breeding (Figure 5). This continued use of traditional methods suggests that there may be issues around the adequate provision of effective veterinary services, especially as the respondents knew that the first author (who was conducting the questionnaire) was a veterinarian and may have been reluctant to be negative about the role of veterinarians in managing infertility.

There was variation across respondents in how to manage persistently infertile animals. The majority (69%) supported the idea of culling infertile animals, consistent with infertility being an important cause of involuntary culling in East Africa [43]. However, 23% of all respondents supported selling infertile animals to other farmers. Respondents stated that they sold such animals to other regions or urban areas, particularly Dar es Salaam.

Furthermore, the main limitation of this study is its reliance on self-reported data; however, in the present study, we employed a guided interview as a strategy to overcome this limitation. We acknowledge that the use of selected regions in this study can limit the generalisation of our findings; nonetheless, these findings lay a good foundation for future research on infertility in smallholder dairy cattle farming in Tanzania.

5. Conclusions

The main objective of this study was to identify the knowledge gaps of smallholder dairy cattle farmers in Tanzania (i.e., via evaluation of farmers' KAPs on infertility) and thus provide insights to improve fertility and productivity on such farms. There was marked variation in knowledge of the signs of infertility across regions, which may reflect the level of farmer education, but across regions, there was general agreement that repeat breeding was the most important infertility problem, and that nutrition/housing and disease were the main underlying causes of infertility. These results underscore the need for targeted, region-specific strategies to improve reproductive outcomes and highlight the importance of further qualitative studies to better understand regional differences. Furthermore, they also show that there is a need for improved education and outreach programmes to address farmers' knowledge gaps and thereby enhance their capacity to manage and prevent infertility on their dairy farms.

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Data Availability Statement: The generated and analysed datasets used in this study are available from the corresponding author upon request.

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References

1. McDermott, J.J.; Staal, S.J.; Freeman, H.A.; Herrero, M.; Van de Steeg, J. Sustaining Intensification of Smallholder Livestock Systems in the Tropics. *Livest. Sci.* **2010**, *130*, 95–109. [CrossRef]
2. Paris, T.R. Crop–Animal Systems in Asia: Socio-Economic Benefits and Impacts on Rural Livelihoods. *Agric. Syst.* **2002**, *71*, 147–168. [CrossRef]
3. Leslie, J.; Swai, E.S.; Karimuribo, E.; Bell, C. *Tanga and Southern Highland Dairy Development Programmes: Socio-Economic Aspects and Farmer Perception of Dairy Cattle Keeping and Animal Diseases*; DFID/NRRD Animal Health Research Programme Report; University of Reading: Reading, UK, 1999.
4. NBS; OCGS. *National Sample Census of Agriculture 2019/20*; National Bureau of Statistics (NBS) and Office of the Chief Government Statistician (OCGS): Dodoma, Tanzania, 2021.
5. CSIRO. Dairy Production in Tanzania. In 90% of Milk in Tanzania Is Produced by Cattle. The Majority of This Is Produced in Low Input, Low Yielding Systems and Consumed by the Producer's Household—CSIRO Research; Edited by Tanzania-Dairy-Factsheet-Jan-2020. 2020. Available online: www.csiro.au (accessed on 30 July 2021).
6. MLF (Ministry of Livestock and Fisheries). Hotuba Ya Bajeti Ya Wizara Ya Mifugo Na Uvuvi Kwa Mwaka Wa Fedha 2024/2025. Government of Tanzania: Ministry of Livestock and Fisheries, United Republic of Tanzania. 2024. Available online: https://www.mifugouvuvi.go.tz/uploads/documents/sw-1745301165-sw1715596084-COMBINED%20HOTUBA%20YA%20WIZARA%20YA%20MIFUGO%20NA%20UVUVI%2013%20MAY%202024%20(1)-compressed.pdf (accessed on 15 July 2024).
7. Kolumbia, L. Milk Self-Sufficiency: Tanzania Requires Nine Billion Litres. *The Citizen*, 6 May 2024.
8. Brett, C.I. A New Way to Boost Smallholder Dairy Productivity in Tanzania. In Worldbank. org/voices. 2019. Available online: http://www.worldbank.org/?_gl=1*1r96r2s*_gcl_au*OTg3MDc3NTcuMTcxNjk3ODM1MQ (accessed on 15 March 2021).
9. Mdoe, N. Smallholder Dairy Production and Marketing of Milk in Hai District, Tanzania. Ph.D. Thesis, University of Reading, Reading, UK, 1993.
10. Kusiluka, L.J.; Karimuribo, E.D.; Mdegela, R.H.; Kampaga, A.M.; Bundala, A.; Kivaria, F.; Kabula, B.; Manjurano, A.; Turuka, F.M.; Loken, T. Constraints Associated with Production in Smallholder Dairy Farms in the Eastern Coastal Zone of Tanzania. *Bull. Anim. Health Prod. Afr.* **2006**, *54*, 286–296. [CrossRef]
11. Kivaria, F.M.; Noordhuizen, J.P.M.; Kapaga, A.M. Prospects and Constraints of Smallholder Dairy Husbandry in the Dar Es Salaam Region, Tanzania. *Outlook Agric.* **2006**, *35*, 209–215. [CrossRef]
12. Lyimo, Z.C.; Nkya, R.; Schoonman, L.; Van Eerdenburg, F.J.M. Post-Partum Reproductive Performance of Crossbred Dairy Cattle on Smallholder Farms in Sub-Humid Coastal Tanzania. *Trop. Anim. Health Prod.* **2004**, *36*, 269–279. [CrossRef]
13. Swai, E.S.; Bryant, M.J.; Karimuribo, E.D.; French, N.P.; Ogden, N.H.; Fitzpatrick, J.L.; Kambarage, D.M. A Cross-Sectional Study of Reproductive Performance of Smallholder Dairy Cows in Coastal Tanzania. *Trop. Anim. Health Prod.* **2005**, *37*, 513–525.
14. Swai, E.S.; Kyakaisho, P.; Ole-Kawanara, M.S. Studies on the Reproductive Performance of Crossbred Dairy Cows Raised on Smallholder Farms in Eastern Usambara Mountains, Tanzania. *Livest. Res. Rural Dev.* **2007**, *19*, 2007.
15. Kanuya, N.L.; Kessy, B.M.; Bittegeko, S.B.; Mdoe, N.S.; Aboud, A.A. Suboptimal Reproductive Performance of Dairy Cattle Kept in Smallholder Herds in a Rural Highland Area of Northern Tanzania. *Prev. Vet. Med.* **2000**, *45*, 183–192.
16. Banda, L.J.; Kamwanja, L.A.; Chagunda, M.G.; Ashworth, C.J.; Roberts, D.J. Status of Dairy Cow Management and Fertility in Smallholder Farms in Malawi. *Trop. Anim. Health Prod.* **2012**, *44*, 715–727. [CrossRef]
17. Ngou, A.; Laven, R.; Parkinson, T.; Kashoma, I.; Donaghy, D. A Survey of Smallholder Dairy Cattle Farmers in Tanzania: Farmer Demographic Characteristics and Basic Management Constraints. 2024; *Preprint*.
18. Pérez-Marín, C.C.; Quintela, L.A. Current Insights in the Repeat Breeder Cow Syndrome. *Animals* **2023**, *13*, 2187. [CrossRef]
19. Liu, X. Statistical Software Applications & Review Ordinal Regression Analysis: Fitting the Proportional Odds Model Using Stata, Sas and Spss. *J. Mod. Appl. Stat. Methods* **2009**, *8*, 632–645.
20. Begg, M.D. *An Introduction to Categorical Data Analysis*, 2nd ed.; Alan Agresti, John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2007; ISBN 978-0-471-22618-5.
21. Chan, Y.H. Biostatistics 305. Multinomial Logistic Regression. *Singap. Med. J.* **2005**, *46*, 259.
22. Mulugeta, T.; Ilomo, M.; Mueke, A.; Onyango, C.; Matsaunyane, L.; Kritzinger, Q.; Alexandersson, E. Smallholder Farmers' Knowledge, Attitudes, and Practices (Kap) Regarding Agricultural Inputs with a Focus on Agricultural Biologicals. *Heliyon* **2024**, *10*, e26719. [CrossRef] [PubMed]
23. WHO. *Advocacy, Communication and Social Mobilization for Tb Control: A Guide to Developing Knowledge, Attitude and Practice Surveys*; World Health Organization: Geneva, Switzerland, 2008.
24. TAMISEMI. *Number of Secondary Schools by Ownership, 2018*; TAMISEMI, Ed.; President's Office—Regional Administration and Local Government (PO-RALG): Dodoma, Tanzania, 2018.
25. Phillips, J.M. Farmer Education and Farmer Efficiency: A Meta-Analysis. *Econ. Dev. Cult. Change* **1994**, *43*, 149–165. [CrossRef]

26. Swai, E.S.; Karimuribo, E.D.; Schoonman, L.; French, N.P.; Fitzpatrick, J.; Kambarage, D.; Bryant, M.J. Description, Socio-Economic Characteristics, Disease Managements and Mortality Dynamics in Smallholder's Dairy Production System in Coastal Humid Region of Tanga, Tanzania. *Livest. Res. Rural Dev.* **2005**, *17*, 2005.
27. Temesgen, M.Y.; Assen, A.A.; Gizaw, T.T.; Minalu, B.A.; Mersha, A.Y. Factors Affecting Calving to Conception Interval (Days Open) in Dairy Cows Located at Dessie and Kombolcha Towns, Ethiopia. *PLoS ONE* **2022**, *17*, e0264029. [CrossRef]
28. Wassena, F.J.; Mangesho, W.E.; Chawala, A.; Laswai, G.H.; Bwire, J.M.; Kimambo, A.E.; Lukuyu, B.; Sikumba, G.; Maass, B.L. Effects of Season and Location on Cattle Milk Produced and Producer Milk Prices in Selected Villages of Tanga and Morogoro Regions, Tanzania. *Livest. Res. Rural Dev.* **2015**, *27*.
29. Schooman, L.; Swai, E.S. Marketing, Handling and Physical Quality of Raw Marketed Milk in Tanga Region of Tanzania. *Livest. Res. Rural Dev.* **2011**, *23*, 13–19.
30. Njombe, A.P.; Msanga, Y.; Mbwambo, N.; Makembe, N. The Tanzania Dairy Industry: Status, Opportunities and Prospects. In Proceedings of the 7th African Dairy Conference and Exhibition, Dar es Salaam, Tanzania, 25–27 May 2011.
31. Mtengeti, E.J.; Phiri, E.C.H.; Urio, N.A.; Mhando, D.G.; Mvena, Z.; Ryoba, R.; Mdegela, R.; Singh, B.R.; Mo, M.; Wetlesen, A. Forage Availability and Its Quality in the Dry Season on Smallholder Dairy Farms in Tanzania. *Acta Agric. Scand Sect. A* **2008**, *58*, 196–204. [CrossRef]
32. Funston, R.N.; Grings, E.E.; Roberts, A.J.; Tibbitts, B.T. Invited Review: Choosing a Calving Date. *Prof. Anim. Sci.* **2016**, *32*, 145–153. [CrossRef]
33. Koreyba, L.V. Major Diseases of Pregnancy and Abortion in Cows. *Sci. Messenger Lviv Natl. Univ. Verterinary Med. Biotechnol. Ser. Vet. Sci.* **2023**, *25*, 62–66. [CrossRef]
34. Deka, R.P.; Magnusson, U.; Grace, D.; Randolph, T.F.; Shome, R.; Lindahl, J.F. Estimates of the Economic Cost Caused by Five Major Reproductive Problems in Dairy Animals in Assam and Bihar, India. *Animals* **2021**, *11*, 3116. [CrossRef] [PubMed]
35. Relić, R.; Vuković, D. Reproductive Problems and Welfare of Dairy Cows. *Bull. Univ. Agric. Sci. Vet. Med. Cluj-Napoca. Vet. Med.* **2013**, *70*, 301–309.
36. Kumari, S.; Prasad, S.; Kumaresan, A.; Manimaran, A.; Patbandha, T.K.; Pathak, R.; Boro, P.; Mohanty, T.K.; Ravi, S.K. Risk Factors and Impact of Retained Fetal Membranes on Performance of Dairy Bovines Reared under Subtropical Conditions. *Trop. Anim. Health Prod.* **2015**, *47*, 285–290. [CrossRef]
37. Dubuc, J.; Duffield, T.F.; Leslie, K.E.; Walton, J.S.; LeBlanc, S.J. Effects of Postpartum Uterine Diseases on Milk Production and Culling in Dairy Cows. *J. Dairy Sci.* **2011**, *94*, 1339–1346. [CrossRef]
38. Beagley, J.C.; Whitman, K.J.; Baptiste, K.E.; Scherzer, J. Physiology and Treatment of Retained Fetal Membranes in Cattle. *J. Vet. Intern. Med.* **2010**, *24*, 261–268. [CrossRef] [PubMed]
39. Ansari-Lari, M.; Mohebbi-Fani, M.; Rowshan-Ghasrodashti, A. Causes of Culling in Dairy Cows and Its Relation to Age at Culling and Interval from Calving in Shiraz, Southern Iran. *Vet. Res. Forum* **2012**, *3*, 233–237.
40. Kashoma, I.P.; Ngou, A.A. Retained Fetal Membrane in Tanzanian Dairy Cows: Economic Impacts and Subsequent Reproductive Performances. *J. Vet. Med. Sci.* **2021**, *4*, 1059.
41. Laven, R.A.; Peters, A.R. Bovine Retained Placenta: Aetiology, Pathogenesis and Economic Loss. *Vet. Rec.* **1996**, *139*, 465–471. [CrossRef]
42. Tucho, T.T.; Ahmed, W.M. Economic and Reproductive Impacts of Retained Placenta in Dairy Cows. *J. Reprod. Infertil.* **2017**, *8*, 18–27.
43. Allan, F.K.; MacVicar, I.S.; Peters, A.R.; Schnier, C. Systematic Map of Recent Evidence on Reproductive Performance of Cattle in Africa. *Trop. Anim. Health Prod.* **2024**, *56*, 218. [CrossRef] [PubMed]

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Chapter Five: A cross-sectional study of reproductive performance of improved dairy cattle under smallholder dairy farming in Tanzania

Foreword: This chapter covers the evaluation of farm records from the 322 smallholder dairy cattle farms to establish the measure of reproductive performance, alongside the determination of the records and reproductive status (pregnancy diagnosis) of 1279 cattle by employing rectal scanning using ultrasound. Also, the chapter proposes the best way to determine reproductive performance under smallholder dairying in Tanzania. As for chapters three and four, this study was also conducted among smallholder dairy cattle farmers across the thirteen districts from the six key dairy farming regions of the Tanzanian mainland. Furthermore, this study has been submitted for publication in the Tropical Animal Health and Production Journal. In this thesis, the manuscript has been presented in the journal format and style.

Title: A cross-sectional study of reproductive performance of improved dairy cattle under smallholder dairy farming in Tanzania

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Abstract

A large-scale study of dairy herds was conducted to understand the variation in reproductive performance of smallholder dairy cattle across Tanzania's regions and to identify the most effective method for evaluating reproductive performance on such farms. Data were collected from 322 farms across six regions of Tanzania, with a total of 1279 cattle being examined for pregnancy status using transrectal ultrasound. Additional data were gathered on key reproductive performance indicators, including calving to first service interval (data available for 595 of the 1279 pregnancy tested cows; 47%), first service to conception interval (492/1279; 38%), calving to conception interval (313/1279; 24%), and inter-calving interval (424/1279; 33%). Over the entire study population, pregnancy was detected in 586/1279 (46%) cattle, with the highest and lowest proportions recorded in the Mbeya (55%) and Tanga (37%) regions, respectively. Of the pregnant cattle, 76% were cows and 24% were heifers. Morogoro had the highest proportion of pregnant cows (53% of cows in the region), while Mbeya led in the proportion of pregnant heifers (83% of heifers in the region). Considering the difficulties in maintaining proper records, especially those related to calving and breeding, the most accurate way to determine reproductive performance in smallholder dairy farming is by employing a direct pregnancy diagnosis, which provides a more precise and current assessment of the herd's reproductive performance. To improve reproductive outcomes, strengthening record-keeping systems is essential, and more personnel should be trained in the use of ultrasound for pregnancy diagnosis.

Keywords: Smallholder dairy cattle farmers, reproductive performance, farm records keeping, pregnancy diagnosis

1. Introduction

Nearly all milk produced in Tanzania originates from smallholder dairy farms, which typically operate under low-technology, low-input and low-output systems (Brett, 2019). As a result, despite Tanzania possessing the second-largest cattle herd in Africa (World_Bank, 2024), the country still faces a substantial milk deficit of nearly 9 billion litres (Kolumbia, 2024; MLF, 2024). This shortfall highlights the pressing need to boost the productivity of Tanzanian cattle, particularly those managed by smallholder farmers. One key constraint on smallholder dairy farms is their poor reproductive performance, which markedly reduces milk production, longevity, and lifetime productivity, while increasing involuntary culling and production costs (Shalloo et al., 2014). Furthermore, it results in significant non-monetary costs such as reduced food security within the community, increased poverty, and reduced social status (Banda & Tanganyika, 2021). The loss of these non-monetary benefits is particularly crucial in regions such as sub-Saharan Africa, where the economic value of livestock is often exceeded by its social value (Chisoni et al., 2025). Improving reproductive performance on Tanzanian dairy farms is thus likely to have significant benefits for smallholder dairy farmers and their communities.

To develop a programme for improving reproductive performance, we need to have a baseline against which we can judge the impact of any changes. Recent information on the reproductive performance of smallholder dairy cattle in Tanzania is scarce (Allan et al., 2024). Furthermore, even the older published data that we have is limited in extent, focusing on reproductive performance in only 1 to 3 districts across Tanzania (Mdoe, 1993; Kanuya et al., 2000; Msanga et al., 2000; Lyimo et al., 2004; Swai et al., 2005b; Allan et al., 2024). Thus, we need up-to-date information on reproductive performance on smallholder dairy farms from the key dairying regions across Tanzania to provide a usable baseline for future programmes. Such information will also help to identify any differences in reproductive performance across regions, thereby supporting the assessment of whether region-specific targets and programs are necessary. Additionally, we need to identify the most effective method for measuring reproductive performance on Tanzanian smallholder dairy farms.

The present study was therefore designed to measure the reproductive performance of dairy cattle in smallholder dairy farming systems across Tanzania. It focused on (i) the evaluation of available farm records, and (ii) the reproductive examination of individual animals to establish their pregnancy status. Based on these data, the study proposed ways to enhance dairy cattle reproductive performance on smallholder properties.

2. Methodology

This survey was conducted simultaneously with the study described by Ngou et al. (2025). A brief outline of the methodology is included here.

2.1. Ethical considerations and approval

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007). Informed written consent was obtained before data collection, and the results were anonymised.

2.2. Study area, study farms and study animals' selection

This cross-sectional study was conducted between May 2022 and February 2023 in six regions of Tanzania (See Figure 1). Within each region, convenience sampling was utilised to identify study villages and the first study farm in each village. Snowball sampling was subsequently employed to select additional study farms in that village. All farmers who participated in the survey of reproductive knowledge were also included in this study of reproductive performance. However, during the farm selection process for the survey, some farms identified through snowball sampling did not have someone available who was capable of responding to the questionnaire and were thus excluded from the survey of reproductive knowledge. On such farms, if the farm records were of sufficiently high quality, all cows eligible for pregnancy diagnosis were examined, and the data were included in this study of reproductive performance.

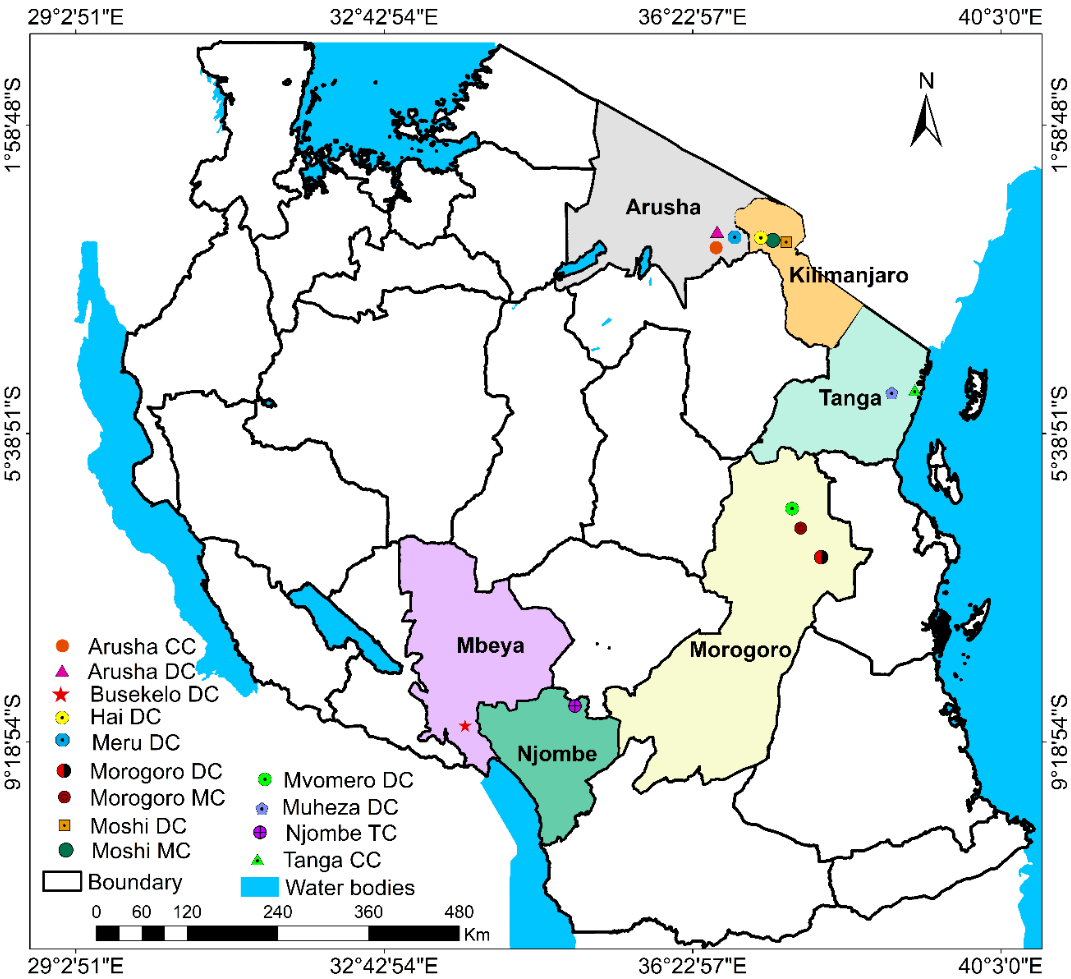

Figure 1. Map of Tanzania showing study regions and districts: Southern Highland regions, Northern Highland regions and Morogoro. NB: CC - City council, DC - District

2.3. Field data collection

Upon arrival at the farm, a local veterinarian or livestock officer introduced the author to the farmer/respondent (usually the family head). Then, the farmer was asked to prepare and provide all reproduction-related farm and individual animal records so that the author could review them. Data collection was conducted by the author, with the assistance of the local veterinarian and livestock officer.

On each farm, individual data were collected from all mature female cattle (i.e. all cows that had calved at least once and all heifers considered by the farmer or owner to be mature enough for breeding). Records collected included animal identity, breeding and calving date(s), and parity. Where date information was absent, the author directly asked the farmer about the missing information, using associated events such as religious observances (e.g. Eid and Christmas), other school and public holidays, and the presence of any visitors at the time of mating/calving, to help remind the farmer when an event had occurred. Alongside these records, measurements were made of body condition score (BCS; 1 to 5 scale; Wildman et al. (1982), body weight (heart girth measurements using a Rondo measuring tape) and pregnancy status. Pregnancy status was determined using transrectal ultrasonography (Veterinary Ultrasound scanner - CD66V, Wuhan Darppon Medical Technology, China). All records, whether recorded or provided by the farmer, were further cross-checked during the pregnancy examination of the individual cows. For example, if the service date did not match the estimated gestational age, the farmer was questioned to obtain more accurate information. To some farms, the estimated gestational age was used to remind farmers of the service date or when a farmer wanted to know the expected calving month.

2.4. Definition of reproductive parameters

The following measures of reproductive performance were calculated from the farm and individual animal records/farmer recollections. The definitions were adopted from Noakes (1997) and Hudson et al. (2018) with slight modifications to suit the focus of the present study.

i. Inter-calving interval (ICI): interval between successive calvings;

ii. Calving to first service interval (CFSI): number of days from the most recent calving to the date of the farmer's first recorded (or remembered) insemination of the cow after that calving;

iii. The calving-to-conception interval (CCI): number of days from the most recent calving to the service that had resulted in the pregnancy detected by transrectal ultrasonography. This was usually the last recorded (remembered) service (Artificial insemination (AI) or natural), but this could be altered if the dates did not match the gestational age;

iv. First service to conception interval (FSCI): number of days between the first recorded (or remembered) service and the service that was identified as resulting in pregnancy;

v. Pregnancy status (pregnant or non-pregnant) at the time of farm assessment. Cows that were not detected as pregnant at the visit, but which had been inseminated within the past 28 days, were re-examined, if possible, when 28 days had passed. If re-examination was not possible, the cow was recorded as not pregnant; and

vi. The voluntary waiting period (VWP): number of days allowed by the farmer between a cow calving and attempting to breed her again.

2.5. Data management

Data were entered into an Excel spreadsheet (Microsoft, Seattle, USA). Results were tabulated and presented as overall results and by region. Descriptive statistics (mean (95% confidence interval (CI)) and median with range) were calculated overall and for each region. The effect of region on VWP, ICI, pregnancy status and CCI was then analysed. For the VWP, a generalised linear model with VWP as an ordinal outcome and region as the predictor variable was used. For ICI, a generalised estimating equation model was used with $\log_{10}$ ICI as the linear outcome variable, farm as the subject variable, cowID as the within-subject variable and region as the predictor variable. For pregnancy status, a generalised estimating equation model was used with pregnancy status (yes/no) as the binomial outcome variable, farm as the subject variable, cow identification (ID) as the within-subject variable and region as the predictor variable. For CCI, the data were analysed using a mixed-effects Cox regression, with farm as the random effect and region as a fixed effect. The association between VWP and CCI was analysed using a linear model with the natural log average CCI for a farm and a farm's reported CCI as predictor variables. All analyses were undertaken using SPSS version 29, except for the mixed-effect Cox regression, which was analysed using R-Studio.

3. Results

Most of the surveyed farmers maintained their farm and animal records using basic and easily accessible methods, for example, noting them down on paper or, in some cases, writing directly on walls. While these practices were common, inconsistencies and missing records were frequently encountered; for instance, over 50% of animals had only one recorded service date, typically the last one that resulted in pregnancy, suggesting that earlier services were often not documented by the farmers. This has limited the ease and completeness of data retrieval during the data collection.

3.1. Number of farms and animals involved in the study

Reproductive performance data were collected from 322 farms across the six regions, with 1279 female cattle examined across all farms (see Table 1).

Table 1. The number of regions, districts, farms and animals visited during a cross-sectional study on smallholder dairy cattle reproductive performance in Tanzania.

Regions visited	Farms visited per region (%*)	Animals examined per region (%*)
Arusha	16 (5)	43 (3)
Kilimanjaro	65 (20)	219 (17)
Mbeya	69 (21)	217 (17)
Morogoro	60 (19)	279 (22)
Njombe	56 (17)	139 (11)
Tanga	56 (17)	382 (30)
Total	**322 (100)**	**1279 (100)**

Key: *percentage of total farms or cattle

Table 2 summarises, by region, the measures collected from farms and the number of cows for which data were available. The Table also illustrates the proportion of eligible cows assessed for each production and reproductive parameter in smallholder dairy farms. For the reproductive performance parameters, the proportion of cows with data available to calculate that parameter ranged from 100% for pregnancy status (as all eligible cows were pregnancy-tested) to 24% for CCI.

Table 2. Number of cattle pregnancies tested per region, and number of cattle for which age, milk production and reproductive performance parameters were available.

Region	Parameter							
	Pregnancy test	**Parity**	**Milk production**	**CFSI**	**FSCI**	**ICI**	**CCI**	**Total**
Arusha	43	29/43	26/43	22/43	14/43	17/43	10/43	**43**
Kilimanjaro	219	169/219	160/219	107/219	93/219	72/219	58/219	**219**
Mbeya	217	106/217	119/217	76/217	110/217	67/217	44/217	**217**
Morogoro	279	202/279	200/279	114/279	119/279	78/279	75/279	**279**
Njombe	139	106/139	92/139	73/139	59/139	39/139	39/139	**139**
Tanga	382	316/382	245/382	203/382	97/382	151/382	87/382	**382**
Total	1279	928	841	595	492	424	313	**1279**
% Total	**100**	**73**	**66**	**47**	**38**	**33**	**24**	

Key: CFSI: Calving to first service interval, FSCI: First service to conception interval, ICI: Inter-calving interval, CCI: Calving to conception interval

3.2. Physical and productive traits of smallholder dairy cattle

The physical traits of the pregnancy-tested smallholder dairy cattle are shown in Table 3 and Figure 2. The overall median body weight was 344 kg (ranging from 150 to 650 kg), while their overall median BCS was 3 (range 1.5 to 4.5).

Table 3. Regional distribution of body weight and body condition score in smallholder dairy cattle in six regions of Tanzania.

Region	n (% of total cattle)	Mean	Median (minimum - maximum)
Body weight (kg)			
Arusha	43 (3)	340	350 (180-500)
Kilimanjaro	219 (17)	356	350 (150-510)
Mbeya	217 (17)	344	337 (192-562)
Morogoro	279 (22)	335	350 (175-475)
Njombe	139 (11)	335	333 (192-506)
Tanga	382 (30)	354	344 (192-650)
Overall	1279 (100)	346	344 (150-650)
Body condition score (1-5)			
Arusha	43 (3)	3	3 (2.5-4)
Kilimanjaro	219 (17)	3	3 (2-4)
Mbeya	217 (17)	3	3 (1.5-4)
Morogoro	279 (22)	3	3 (1.5-4)
Njombe	139 (11)	2.9	3 (1.5-4.5)
Tanga	382 (30)	3.1	3 (1.5-4)
Overall	1279 (100)	3	3 (1.5-4.5)

Note: Body condition scoring as per Wildman et al. (1982).

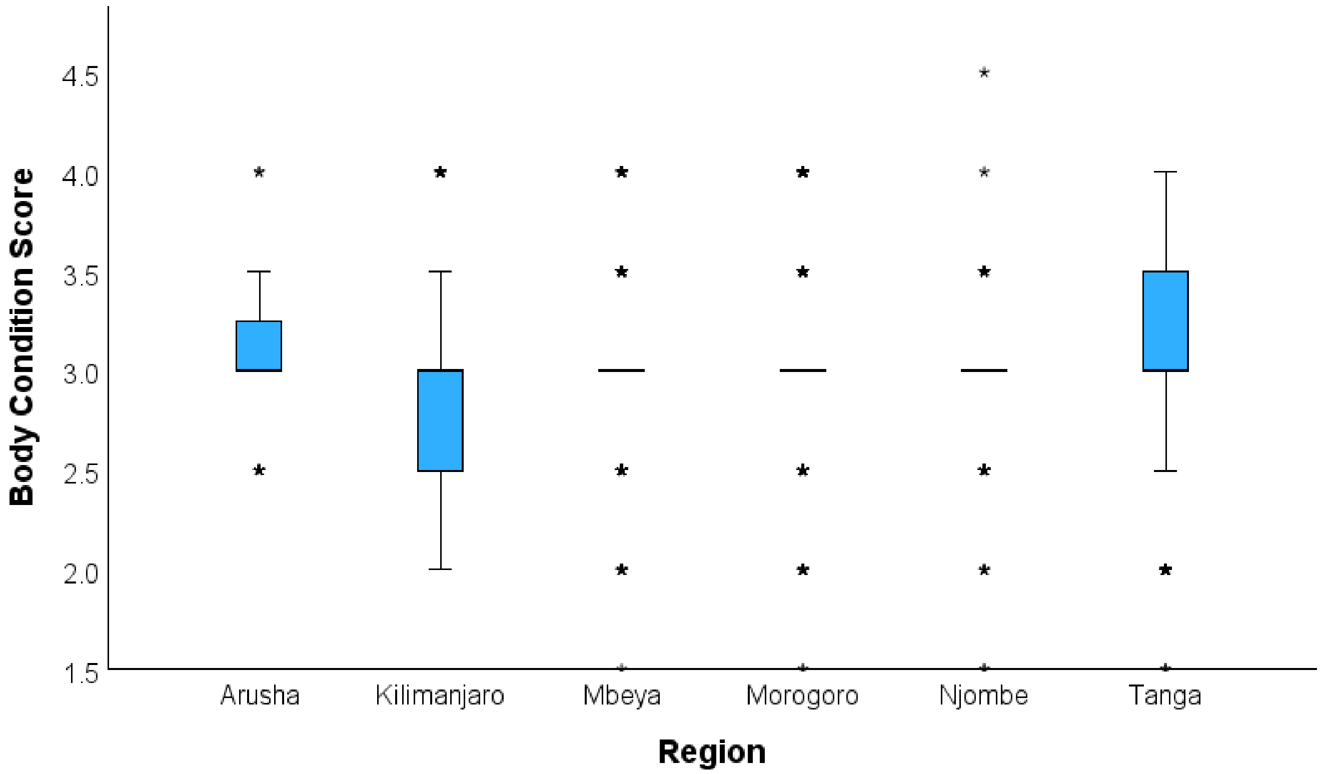

Figure 2. Distribution of body condition score (BCS) (scale 1 to 5) (Wildman et al., 1982) for cows in smallholder dairy farms in 6 regions of Tanzania. The boxplots display the distribution of BCS across regions, where the central box represents the middle 50% of the data, and the line (black) inside shows the median; whiskers extend to the minimum and maximum values, and asterisks represent outliers.

Table 4 includes information on parity and milk yield. Across the study regions, overall median parity (for lactating cows or cows that were known to have been lactating) was 2 (ranging from 1 to 12). Seven per cent of the cows in the current study had no records of parity. This was primarily due to cows being purchased without prior reproductive history; other reasons included poor record keeping practices and cows being purchased from informal sources. The percentage of adult cows with no parity records varied across regions, ranging from 0% (Tanga and Arusha) to 22% (Mbeya). Across all regions, 20% of the pregnancy-tested cattle were heifers (zero parity), ranging from 15% (Morogoro) to 33% (Arusha). Milk yield records were available for 841 cows, with 14% of eligible cows (excluding heifers) having no information on milk yield. Overall, the median reported milk yield was 12 L/day (ranging from

2 to 35 L/day). Regionally, median reported milk yield ranged from 11 L/cow/day (Tanga) to 15 L/cow/day (Arusha and Njombe).

Table 4. Regional distribution of parity and milk yield among smallholder dairy cattle in Tanzania.

Region	Cows with available records (% of all cows examined)	Mean	Median (minimum-maximum)	Heifers (% of all cattle in region)
Parity				
Arusha	29 (100)	3	2 (1-7)	14 (33)
Kilimanjaro	169 (99)	2.6	2 (1-10)	48 (22)
Mbeya	106 (78)	2.8	2 (1-12)	63 (29)
Morogoro	202 (87)	2.3	2 (1-7)	41 (15)
Njombe	106 (96)	2.6	2 (1-11)	28 (20)
Tanga	316 (100)	2.8	2 (1-10)	64 (17)
Overall	928 (93)	2.6	2 (1-12)	258 (20)
Milk yield (L/day)				
Arusha	26 (93)	14.6	12 (8-30)	
Kilimanjaro	160 (95)	13.1	12 (2-30)	
Mbeya	119 (84)	13.5	14 (2-28)	
Morogoro	200 (86)	12.1	12 (4-35)	
Njombe	92 (86)	14.7	15 (6-24)	
Tanga	244 (81)	11.3	10 (3-34)	
Overall	841 (86)	12.6	12 (2-35)	

3.3. Measurement of reproductive performance

Reproductive parameters are reported in Tables 5 and 6. Median herd VWP was 90 days (range 35 to 360). Compared to the Tanga region, only farms in the Mbeya region had lower odds (Odds ratio (OR): 0.22, 95% CI: 0.11-0.43) of having a longer herd VWP, with the rest of the regions having higher odds of having a longer VWP.

Calving to conception interval data were available for 313 cattle (i.e. of the examined cattle, 313 were pregnant and had a known previous calving date). The overall median value was 189 days (ranging from 38 to 1548 days) (see Figure 3). For the analysis of the effect of region on CCI, data were added for an additional 516 cows, which were non-pregnant but had a known previous calving date. For these cows, their data were censored at the interval between calving and the date of the pregnancy examination (i.e. these cows had not yet conceived by the time of pregnancy examination; therefore, their true time to conception was unknown and only known to be at least as long as the interval observed – that is date of pregnancy examination). Across the regions, only animals from the Njombe region had a clearly higher hazard of pregnancy (i.e. 95% CI of the hazard ratio (HR) did not include 1) than cows from the Tanga region (HR: 2.86, 95% CI: 1.4-5.85). Meaning that cows from the Njombe region were more likely to become pregnant sooner (or faster) than those in the Tanga region. For the other four regions our data were compatible with both a higher and a lower hazard of pregnancy than cows in the Tanga region (see Table 5), although for cows in Kilimanjaro our data did exclude a biologically important increase in the hazard of pregnancy compared to cows in Tanga (upper limit of 95% CI for HR was 1.07).

A total of 178 farms reported a VWP and had at least one cow with a CCI (known last calving date and pregnant). The comparison of a farm's VWP and its average CCI identified that a longer VWP increased average CCI, with a 10-day increase in VWP increasing average CCI by 1.02 (95% CI 1.01 to 1.04) times, with the model predicting that, for a farm with a VWP of 50 days, expected average CCI would be 187 days and for a farm with a VWP of 125 days, expected average CCI would be 217 days (390 days longer). The model also identified that a farm's VWP accounted for only 4% of the variance in farm average CCI.

The ICI data were available for 424 cows. Across all regions, the median ICI was 468 days (range 283-1531 days). Table 5 presents the difference in the estimated marginal means (95% CI) between a region and Tanga in ICI (differences and ICI are back transformed from the $\log_{10}$ estimated marginal means). Across the regions, cows in both had longer back-transformed mean ICI than cows in Tanga; the mean difference was 141.2 days (95% CI: 72.6-234.7) for Kilimanjaro and 99.1 days (95% CI: 47.3-141.2) for Morogoro. For the remaining regions, our data were compatible with both a longer and a shorter ICI than in Tanga. However, for Njombe, our data suggest that the mean ICI is unlikely to be much higher than in Tanga (upper 95% CI 11.4 days longer).

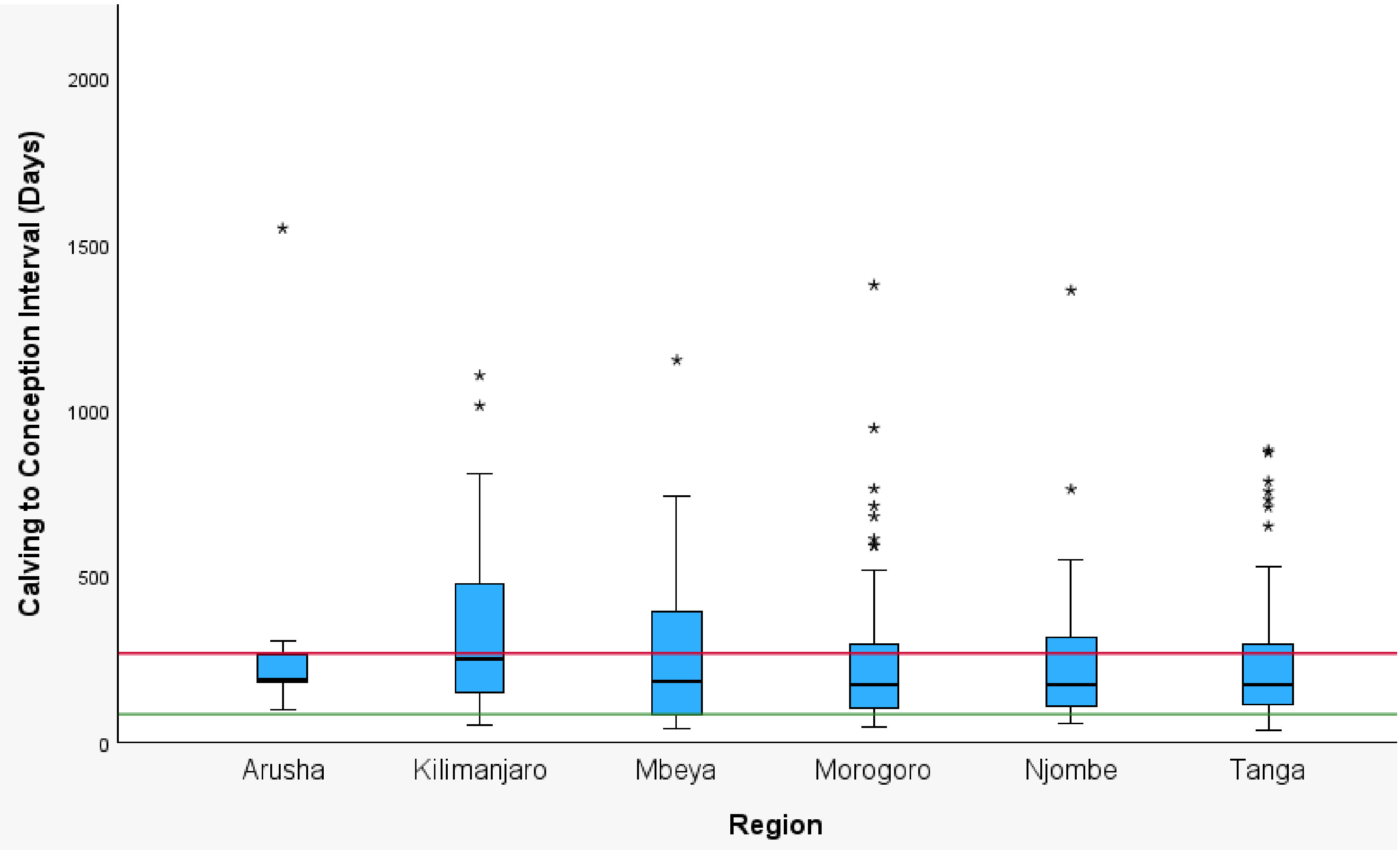

Figure 3. The boxplots display the distribution of CCI (in days) across regions, where the central box represents the middle 50% of the data, and the line (black) inside shows the median; whiskers extend to the minimum and maximum values, and asterisks represent outliers. Note: CCI stands for calving to conception interval; the green line represents the standard CCI, i.e., 85 days post-calving, while the red line represents the mean CCI, i.e., 268 days.

First service to conception interval (FSCI)was evaluated in 492 animals. Across all cows, FSCI ranged from 0 to 477 days, with 359/492 (73%) of cows having a FSCI of 0. This means that, among the cows with FSCI, 73% became pregnant within that first service. This is extremely unlikely, especially in tropical conditions, as monitored first service conception rates generally vary between 25 and 50% (Kanuya et al., 2014; Tadesse et al., 2022). These data thus suggest that farmers were remembering their most recent service rather than the first service. No further analysis was undertaken.

Overall median CFSI was 166 days (range 28 to 1822 days) (see Figure 4), with 25% of cows having CFSI of 303 days or more. The median and the upper quartile are much longer than the median VWP, again suggesting that farmers are reporting their most recent insemination rather than the first one. No further analysis was thus undertaken.

Pregnancy status was established for 1279 cattle. Of these, 588 (46%) were found to be pregnant, of which 443 (76%) were cows and 143 (24%) were heifers (see Table 6). The pregnancy rate in the heifers alone was 143/258 (55%), whereas the pregnancy rate in the cows that had calved at least once was 443/1021 (43%). Thus, across all regions, the relative risk of a heifer being pregnant was 1.3 (95% CI: 1.1 to 1.5) times higher than that of a cow that had calved at least once. Across the regions, the odds of any eligible female cattle being pregnant were clearly higher in Mbeya (OR: 2.07, 95% CI: 1.47-2.9), Morogoro (OR: 1.81, 95% CI: 1.32-2.47) and Njombe (OR: 1.56, 95% CI: 1.05-2.3) than in Tanga. For the other regions, there were too few cows examined in Arusha to accurately determine the likely difference in odds of being pregnant compared to Tanga. In contrast, for Kilimanjaro, our data were consistent, with results ranging from a marked increase in odds of pregnancy to effectively no biologically important difference in odds. Much of the difference between regions in pregnancy status seemed to be driven by the reproductive performance of heifers. In adult cows alone, only Morogoro had a clear difference in odds of pregnancy compared to Tanga (OR 1.71; 95% CI 1.22-2.4), whereas for heifers, all regions (except for Arusha) had OR whose 95% CI did not include 1 (Table 6). For all regions except Morogoro and Tanga, the raw proportion of pregnant animals was higher in heifers than in cows, and for all regions except Morogoro, the difference in proportion of cows and heifers that were pregnant was ≥9%. The largest difference was seen in Mbeya, where the proportion of pregnant heifers was 34% (95% CI 25.4 -49.5%) higher than the proportion of pregnant cows.

For adult cows only, the odds of a cow being pregnant were higher (OR: 1.71, 1.22-2.4) in Morogoro than in the Tanga region. For heifers only, the odds of being pregnant were higher in Mbeya, Kilimanjaro, Njombe and Morogoro with OR (95% CI) of 12.1 (5.17-28.2), 4.26 (1.92-9.47), 3.95 (1.55-10) and 2.43 (1.07-5.52), respectively, compared to the Tanga region.

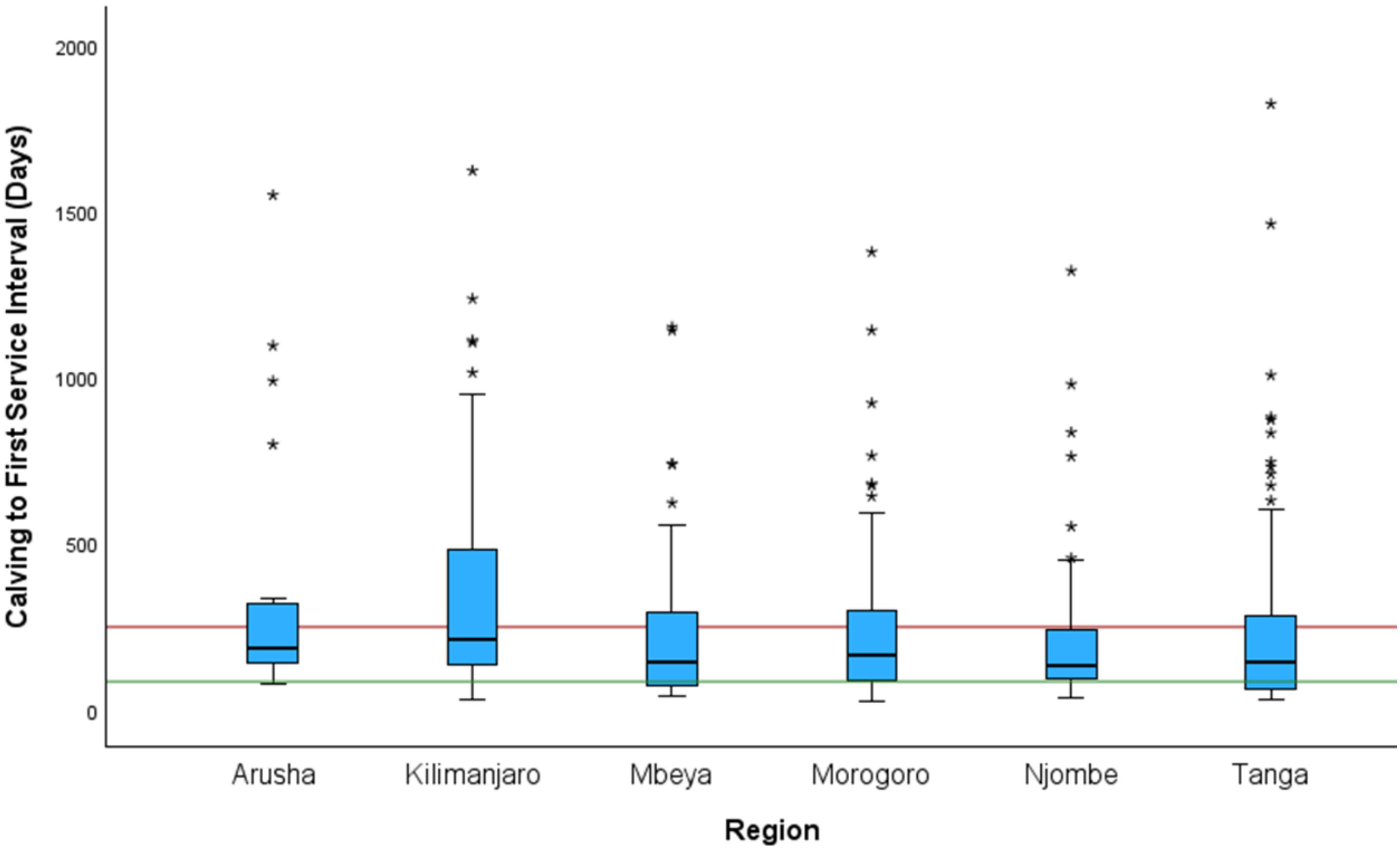

Figure 4. The boxplots display the distribution of CFSI (in days) across regions, where the central box represents the middle 50% of the data, and the line (black) inside shows the median; whiskers extend to the minimum and maximum values. Asterisks represent outliers.
Note: CFSI stands for calving to first service interval; the green line represents the CFSI required to get a 365-day interval between calvings, i.e. 85 days post-calving, and the red line represents the mean CFSI across all regions, i.e. 249 days.

Table 5. Regional distribution of reproductive performance parameters in smallholder dairy cattle in Tanzania.

Farm voluntary waiting period (VWP) (days)

Region	n (% of all farms)	Mean	Median (IQR)	Minimum	Maximum	OR (95% CI)†
Arusha	16 (5)	127.5	105 (79-161)	75	255	4.18 (1.77-13.1)
Kilimanjaro	65 (20)	113	90 (75-120)	60	360	1.99 (1.05-3.76)
Mbeya	69 (21)	72.5	60 (45-90)	35	180	0.22 (0.11-0.43)
Morogoro	60 (19)	119.7	105 (75-135)	45	303	3.88 (1.97-7.63)
Njombe	56 (17)	96.2	90 (90-90)	90	150	2.03 (1.11-3.73)
Tanga	56 (17)	92.5	90 (75-90)	45	195	Reference
Overall	322 (100)	99.6	90 (75-105)	35	360	

Calving to conception interval (CCI) (days)

Region	n (% of all eligible cattle)	Mean	Median (IQR)	Minimum	Maximum	HR (95% CI)†
Arusha	10 (23)	233.4	188.5 (174-276)	97	1548	1.24 (0.43-3.54)
Kilimanjaro	58 (26)	264.5	253.5 (148-479)	54	1105	0.55 (0.28-1.07)
Mbeya	44 (20)	177.1	183.5 (80-408)	41	1151	1.61 (0.85-3.05)
Morogoro	75 (27)	187.6	176 (104-301)	46	1377	1.32 (0.72-2.42)
Njombe	39 (28)	190.2	173 (104-318)	59	1361	2.86 (1.4-5.85)
Tanga	87 (23)	179.7	175 (111-297)	38	880	Reference
Overall	313 (24)	268.3	189 (111-334)	38	1548	

Inter-calving interval (ICI) (days)

Region	n (% of all eligible cattle)	Mean	Median (IQR)	Minimum	Maximum	Mean Difference (95% CI)†
Arusha	17 (40)	509.6	445 (405-614)	350	1253	20.7 (-54 to 108)
Kilimanjaro	72 (33)	633.2	638 (456-801)	283	1531	143 (58.4 to 244)
Mbeya	67 (31)	482.7	430 (369-568)	286	1425	-6.7 (-43.1 to 35)
Morogoro	78 (28)	582.2	559 (425-776)	301	1389	93.5 (28.9 to 165)
Njombe	39 (28)	457.7	406 (382-512)	350	949	-32 (-81 to 24.2)
Tanga	151 (40)	489	447 (385-567)	288	1265	Reference
Overall	424 (33)	563.4	468 (398-686)	283	1531	

First Service to Conception Interval (FSCI) (days)

Region	n (% of all eligible cattle)	Mean	Median (IQR)	Minimum	Maximum	Number with zero FSCI (% of cows in region)
Arusha	14 (33)	20.4	0 (0-2)	0	209	11 (79)
Kilimanjaro	93 (42)	24.6	0 (0-15)	0	477	69 (74)
Mbeya	110 (51)	15	0	0	333	93 (85)
Morogoro	119 (21)	20.6	0 (0-22)	0	229	86 (72)
Njombe	59 (42)	18.3	0	0	181	45 (76)
Tanga	97 (25)	20.4	0 (0-35)	0	148	55 (57)
Overall	492 (38)	20	0 (0-21)	0	477	359 (73)

Calving to first service interval (CFSI) (days)

Region	n (% of all eligible cattle)	Mean	Median (IQR)	Minimum	Maximum
Arusha	22 (51)	348.9	136 (136-186)	80	1548
Kilimanjaro	107 (49)	336.4	210 (132-484)	33	1621
Mbeya	76 (35)	232.3	142 (72-297)	41	1151
Morogoro	114 (41)	240.7	167 (87-298)	28	1377
Njombe	73 (53)	215.8	131 (93-243)	35	1320
Tanga	203 (53)	215	144 (62-281)	29	1822
Overall	595 (47)	249	166 (87-303)	28	1822

Key: IQR, interquartile range; CI, confidence interval. All results from raw data, except where indicated (†). Odds ratio (OR) for VWP are derived from ordinal logistic regression, HR for CCI were derived from a mixed model Cox regression analysis, and the mean differences for ICI are back-transformed from the output of generalised estimating equations (GEE) fitted to $\log_{10}$ transformed ICI data. No regional analysis was undertaken for either FSCI or CFSI.

Table 6. Comparison between regions in the proportion of pregnant all cattle, cows, and nulliparous heifers on 322 smallholder dairy cattle across Tanzania.

Region	Total (% of all cattle in study)	Pregnant (% of all cattle in the region)	OR (95% CI)	Cows (% of all cattle in region)	Pregnant cows (% of all cows in region)	OR (95% CI)	Heifers (% of all cattle in region)	Pregnant heifers (% of all heifers in region)	OR (95% CI)
Arusha	43 (3)	16 (37)	0.99 (0.52-1.9)	29 (67)	10 (34)	0.81 (0.37-1.81)	14 (33)	6 (43)	1.92 (0.58-6.3)
Kilimanjaro	219 (17)	95 (43)	1.28 (0.91-1.8)	171 (78)	65 (38)	0.95 (0.65-1.39)	48 (22)	30 (63)	4.26 (1.92-9.47)
Mbeya	217 (17)	120 (55)	2.07 (1.47-2.9)	154 (71)	68 (44)	1.22 (0.83-1.8)	63 (29)	52 (83)	12.1 (5.17-28.2)
Morogoro	279 (22)	145 (52)	1.81 (1.32-2.47)	238 (85)	125 (53)	1.71 (1.22-2.4)	41 (15)	20 (49)	2.43 (1.07-5.52)
Njombe	139 (11)	67 (48)	1.56 (1.05-2.3)	111 (80)	50 (45)	1.27 (0.82-1.96)	28 (20)	17 (68)	3.95 (1.55-10)
Tanga	382 (30)	143 (37)	Reference	318 (83)	125 (39)	Reference	64 (17)	18 (28)	Reference
Overall	1279 (100)	586 (46)		1021 (80)	443 (43)		258 (20)	143 (55)	

Key: OR: odds ratios derived from binary logistic regression. CI stands for confidence interval

4. Discussion

The present study was part of an overall evaluation of smallholder dairy cattle farming in Tanzania. Specifically, the study aimed to evaluate the reproductive performance of dairy cattle on smallholder dairy farms across six regions of Tanzania and to identify the most effective way of evaluating reproductive performance on such farms, given the limited resources available. The present study also aimed to establish whether there were regional differences and/or regional best practices for keeping smallholder dairy cattle. Because herd size is typically small (i.e. 2-4 dairy animals), this had to be achieved by agglomerating data from many farms across each region. Unfortunately, the Arusha region had too few farmers participating (following the unavailability of local veterinarians and livestock officers, who were participating in the national livestock identification program, resulting in reluctance among farmers to participate), making it difficult to extract useful trends from that region.

These results, except for pregnancy status, are based on farmer records/recollections. There was a wide variability in the level of record keeping across the study farms, with most documentation being informal, often on paper or displayed on walls. This clearly affected the availability of reproductive data, but is also likely to have influenced the accuracy, consistency and reliability of all data collected. Although most farmers surveyed attempted to track herd information, key events such as breeding and calving were often overlooked, particularly when male calves were born, calves died early, or breeding occurred multiple times. In such cases, farmers relied more on memory or verbal accounts rather than records, increasing the risk of inaccuracies. Similar issues were reported by Kanuya et al. (1997), so it seems that the situation has not substantially improved in the last 25 years. The accuracy of the data was a particular issue for data that included first service; simply accepting these data as correct resulted in a 73% conception rate to first service, a rate which is likely to be unachievable within a single region, let alone across all regions. The most likely reason for this high apparent conception rate is that farmers only remembered the last service date, thus rendering both CFSI and FSCI as reproductive parameters that are not useful on Tanzanian smallholder dairy farms.

However, the issue is not just one of accuracy; fewer than 50% of cows presented for pregnancy testing had sufficient records available for evaluating any of the four key reproductive parameters measured in the present study (i.e. CFSI, FSCI, CCI, and ICI) (see Table 2). The CCI is often recommended as a key method for determining a farm's reproductive efficiency because of its simplicity and speed relative to ICI (Hudson et al., 2018), which was the parameter for which the lowest proportion (24%) of animals had sufficient data. This is because calculating a CCI requires a cow to be pregnant and have a previous calving date. In the dataset of the present study, only 65% of the pregnancy-tested cattle had a recorded previous calving date, and of these, only 38% were pregnant. Using the alternative measure "days open" would not solve this issue, as although days open includes data from non-pregnant cows, to calculate days open, we need to know the time from calving to culling or death, or the maximum interval between calving and insemination. Measuring time from calving to culling requires collecting data from cows that are no longer on the farm. In contrast, the maximum interval between calving and insemination does not appear to be a concept supported in this system, with our maximum reported calving-to-service interval being > 1800 days (see Table 5). Fetrow et al. (1990) suggested that non-pregnant cows past their voluntary waiting period could be included in the calculation of days open, but their assumption was that such cows would be seen in oestrus, bred, and conceive 10 days after the pregnancy examination. This assumption is overly optimistic for Tanzanian smallholder dairy farms, and the variability in CCI across farms means that there is no value in attempting to calculate a single Tanzanian equivalent to their 10-day recommendation.

Nevertheless, in aged pregnancy-tested cows, CCI is likely to be relatively accurate as it only requires a calving date, which farmers are likely to remember relatively accurately even when it is not recorded. Thus, the median CCI and interquartile range (IQR) (189 days; 111-334) reported in the present study probably reflects the true distribution of CCI in smallholder dairy cattle in Tanzania, especially as our data are consistent with earlier studies in Tanzania, which also reported prolonged CCI, e.g. 122 days (Kanuya et al., 1997), 221 days (Kanuya et al., 2000) and 123 ± 11 days (Lyimo et al., 2004). However, it is likely that our maximum reported (1237 days) is an underestimate, especially as the maximum reported 'CFSI' was 1822 days. Similarly, the regional median CCI probably reflects the true distribution of CCI in smallholder dairy cattle in those regions. Modelling of CCI using survival analysis did not identify clear differences in CCI between most regions. After accounting for the clustering of CCI by farm, only Njombe had a hazard of pregnancy which was clearly different (i.e. appreciably higher) from that of Tanga; for all the other regions, our data were compatible with CCI being similar to that of Tanga. This analysis highlights the importance of the farm, even within the region, as a factor determining reproductive outcomes and the need for more data to properly evaluate the impact of the region on CCI.

One of the major factors determining CCI is VWP. In order to achieve a 365-day inter-calving interval, CCI should be 85 days (Esslemont, 1992; Plaizier et al., 1997; Plaizier et al., 1998). To obtain this, a VWP of 45 to 60 days is generally recommended, with the optimal VWP of 90% of cows being <10 weeks (Inchaisri et al., 2011). However, in all regions, except Mbeya, median farmer-reported VWP was 90 days or more (see Table 5), with only 62/320 farmers who reported their VWP having a VWP of ≤70 days. However, in contrast to intensively managed dairy cows, where VWP has a marked influence on CCI (Inchaisri et al., 2011), such that an increase in VWP from 50 to 125 days has been shown to extend days open by approximately 76 days (Ma et al., 2022). In the present dataset, an increase in VWP over the same range resulted in a 30 days increase in CCI. It is unclear how much attention farmers involved in the present study paid to their reported VWP, with 52/313 cows with a CCI having a CCI that was shorter than the reported VWP. Further research is required to understand what Tanzanian smallholder dairy farmers understand about the concept of VWP and how they apply it on their farms.

The final reproductive parameter – ICI is a classic parameter for demonstrating a herd's reproductive performance (Fetrow et al., 2007), and as such, provides a simple comparison across studies, regions and countries. The present study reported an ICI with a median of 468 days (range: 398 to 686 days). Notably, cows in the Kilimanjaro and Morogoro regions had a median ICI exceeding 550 days, ~ 1.5 times the target 365 days (to produce one calf per year). These findings are consistent with previous studies of smallholder dairy farms in Tanzania, which have shown similarly prolonged ICI: 477 days (Kanuya et al., 2000); 500 days (Swai et al., 2005b); 480 ± 2 days (Asimwe & Kifaro, 2007); 476 ± 14 days (Swai et al., 2007) and in African countries, an ICI of up to 32.5 months (Allan et al., 2024). However, our study was not designed just to report outcomes, but to identify the best method of ongoing monitoring reproductive performance on smallholder dairy farms, and as Fetrow et al. (2007) state, the large timespan needed to get two calving dates means that it is of very limited value as a monitoring tool. This is particularly a problem in systems such as Tanzanian smallholder dairy farms, which have very elongated ICI. However, an additional problem is that the calculation of the ICI relies on two sets of farmer-recorded data: the last calving date and the prior calving date. In this survey, only 33% of cows had two calving dates reported by the farmer, the lowest percentage among all parameters, except CCI, which was limited by the requirement that a cow be pregnant. This issue with CCI can be solved, at least partly by repeating the pregnancy examination at a later date or (as was done in the present study) using survival analysis to include every cow with a known last calving date. However, ICI relies completely on farmer records, so if two calving dates have not been recorded for a multiparous cow, data on the ICI will be forever absent. Furthermore, relying on farmers' recollections for dates over 350 days ago (and in many cases, over 500 days ago) is likely to be inaccurate.

In contrast, measuring pregnancy status using transrectal ultrasound does not need farm records. It simply requires a skilled technician to go on farm and for the farmer to present all eligible cows for examination. It is particularly useful for cows that are brought in with an unknown history, which is not an uncommon situation among smallholder dairy farmers in Tanzania. The proportion of pregnant cattle on farm reflects reproductive success; if cattle become pregnant more quickly and fewer fail to become pregnant, then the proportion of pregnant cattle will increase. As such, repeated strategic measurements of the proportion pregnant can provide an ongoing monitoring of reproductive performance, with targets set based on a baseline such as those reported in the present study. An additional advantage of monitoring reproduction using pregnancy diagnosis is that it is very popular with farmers. Multiple farmers were very pleased to learn the pregnancy status of their animals, especially in cows, as they often had no records. The absence of records was not only due to frequent purchases from undocumented sources but also originated from limited awareness of the importance of proper farm record keeping, reliance on memory and the lack of standardised systems for tracking reproductive events. Pregnancy testing thus provided farmers with information that they could directly use in the future. Some farmers even accompanied the first author to nearby farms to help others access the pregnancy testing service and to learn from successful peers, providing support to those facing challenges. The other advantage of pregnancy diagnosis is that its value is increased if farms have records (even if they are limited in nature). Pregnancy diagnosis also increases farmers’ contact with experts, i.e. technicians, veterinarians, and experienced farmers, which may help encourage better record-keeping practices.

The main issue with recording the proportion of pregnant animals is that there are very few studies that report this parameter. Most East African studies that have reported proportions of pregnant cattle have actively measured pregnancy rates in a specified cohort (e.g., inseminated cows (Nishimwe et al., 2015), percentage pregnant after first service (Kanuya et al., 2000), lactating cows (Kanuya et al., 2006) and synchronised cattle (Kabuni et al., 2025). Studies that have measured the proportion of cows pregnant in an unselected group of cows include: Muraya et al. (2018) and Mungube et al. (2019) in Kenya (28.7 and 45.5% of cows pregnant, respectively) and Lobago et al. (2006) in Ethiopia (40.8%). Thus, our finding that 46% of the cattle presented for examination were pregnant is at the upper end of previously reported proportions. Overall pregnancy rates varied by region (see Table 5). This regional effect was particularly marked for heifers, which were also more likely to be pregnant than cows. We need more data on what is driving the difference between heifers and cows and between regions, but it is likely that a high proportion of pregnant heifers, especially in Mbeya, reflects the use of natural service

5. Conclusion

Overall reproductive performance was poor by international standards in the study farms, with high median CCI and ICI reported across all regions. Record-keeping practices were generally unsatisfactory across all study regions, with only a minority of cattle having sufficient data to calculate our targeted reproductive measures. In addition, data from farmer recollection, rather than farmer records (e.g., first service date) was shown to be inaccurate. Our data thus strongly support the use of proportion pregnant as the standard reproductive measure until record keeping improves substantially.

6. References

Allan, F. K., MacVicar, I. S., Peters, A. R., & Schnier, C. (2024). Systematic map of recent evidence on reproductive performance of cattle in Africa. *Tropical Animal Health and Production*, *56*(7), 218. https://doi.org/10.1007/s11250-024-04074-z

Asimwe, L., & Kifaro, G. (2007). Effect of breed, season, year and parity on reproductive performance of dairy cattle under smallholder production system in Bukoba district, Tanzania. *Livestock Research for Rural Development*, *19*(10), 1-9.

Banda, L. J., & Tanganyika, J. (2021). Livestock provide more than food in smallholder production systems of developing countries. *Animal Frontiers*, *11*(2), 7-14. https://doi.org/10.1093/af/vfab001

Brett, C. (2019). A new way to boost smallholder dairy productivity in Tanzania. *worldbank. org/voices*. https://blogs.worldbank.org/en/voices/new-way-boost-smallholder-dairy-productivity-tanzania

Chisoni, M., Guillaume, L., & Karl, M. R. (2025). Editorial: Estimating non-monetary societal burden of livestock disease management. In *Frontiers in Veterinary Science* (Vol. 12): Frontiers Media S.A.

Esslemont, R. J. (1992). Measuring dairy herd fertility. *Veterinary Record: Journal of the British Veterinary Association*, *131*(10), 209-212. https://doi.org/https://doi.org/10.1136/vr.131.10.209

Fetrow, J., McClary, D., Harman, R., Butcher, K., Weaver, L., Studer, E., Ehrlich, J., Etherington, W., Guterbock, W., Klingborg, D., Reneau, J., & Williamson, N. (1990). Calculating selected reproductive indices: recommendations of the American Association of Bovine Practitioners. *Journal of Dairy Science*, *73*(1), 78-90.

Fetrow, J., Stewart, S., Eicker, S., & Rapnicki, P. (2007). Reproductive health programs for dairy herds: analysis of records for assessment of reproductive performance. In *Current therapy in large animal theriogenology* (pp. 473-489). Elsevier Inc.

Hudson, C., Cook, J. G., & Laven, R. (2018). Veterinary control of herd fertility in intensively managed dairy herds. In D. Noakes, T. Parkinson, & G. England (Eds.), *Veterinary Reproduction and Obstetrics* (10th ed., pp. 467-484). Elsevier.

Inchaisri, C., Jorritsma, R., Vos, P. L. A. M., van der Weijden, G. C., & Hogeveen, H. (2011). Analysis of the economically optimal voluntary waiting period for first insemination. *Journal of Dairy Science*, *94*(8), 3811-3823. https://doi.org/10.3168/jds.2010-3790

Kabuni, K., Komba, E. V., Laven, R., Parkinson, T., & Peters, A. (2025). Assessing the Feasibility of Using Ambient Temperature Semen and Prostaglandin-Based Synchronisation in Beef Cattle under Tropical Conditions of Tanzania. *Asian Journal of Research in Animal and Veterinary Sciences*, *8*(2), 203-211.

Kanuya, N., Agger, J., & Pedersen, K. (1997). Assessing the reproductive performance of a Tanzanian dairy herd: the importance of proper record keeping. *Tanzania Veterinary Journal*, *17*(3), 63-71.

Kanuya, N., Kessy, B., Bittegeko, S., Mdoe, N., & Aboud, A. (2000). Suboptimal reproductive performance of dairy cattle kept in smallholder herds in a rural highland area of northern Tanzania. *Preventive Veterinary Medicine*, *45*(3-4), 183-192. https://doi.org/https://doi.org/10.1016/S0167-5877(00)00134-3

Kanuya, N., Mlangwa, J., & Shoo, J. (2014). Constraints associated with the use of Artificial Insemination (AI) and Natural Service (NS) in smallholder dairy herds in Tanga and Morogoro, Tanzania. *Tanzania Veterinary Journal*, *29*(1), 9-20.

Kanuya, N. L., Matiko, M. K., Kessy, B. M., Mgongo, F. O., Ropstad, E., & Reksen, O. (2006). A study on reproductive performance and related factors of zebu cows in pastoral herds in a semi-arid area of Tanzania. *Theriogenology*, *65*(9), 1859-1874. https://doi.org/10.1016/j.theriogenology.2005.10.016

Kolumbia, L. (2024, May 6). Milk self-sufficiency: Tanzania requires nine billion litres. *The Citizen*. https://www.thecitizen.co.tz/tanzania/news/national/milk-self-sufficiency-tanzania-requires-nine-billion-litres--4225090

Lobago, F., Bekana, M., Gustafsson, H., & Kindahl, H. (2006). Reproductive performances of dairy cows in smallholder production system in Selalle, Central Ethiopia. *Tropical Animal Health and Production*, *38*(4), 333-342. https://doi.org/10.1007/s11250-006-4328-1

Lyimo, Z., Nkya, R., Schoonman, L., & Van Eerdenburg, F. (2004). Post-partum reproductive performance of crossbred dairy cattle on smallholder farms in sub-humid coastal Tanzania. *Tropical Animal Health and Production*, *36*(3), 269-279.

Ma, J., Burgers, E. E. A., Kok, A., Goselink, R. M. A., Lam, T. J. G. M., Kemp, B., & van Knegsel, A. T. M. (2022). Consequences of extending the voluntary waiting period for insemination on reproductive performance in dairy cows. *Animal Reproduction Science*, *244*, N.PAG-N.PAG. https://doi.org/10.1016/j.anireprosci.2022.107046

Mdoe, N. (1993). *Smallholder dairy production and marketing of milk in Hai District, Tanzania* University of Reading, Reading, GB]. Reading, GB. http://hdl.handle.net/10625/12343

MLF. (2024). *Hotuba ya bajeti ya Wizara ya Mifugo na Uvuvi kwa mwaka wa fedha 2024/2025*. (1715697161). Government of Tanzania: Ministry of Livestock and Fisheries, United Republic of Tanzania Retrieved from https://www.bunge.go.tz/uploads/budgetspeeches/1715697161-Hotuba_ya_Bajeti_ya_Wizara_ya_Mifugo_na_Uvuvi_kwa_Mwaka_wa_Fedha_2024_2025.pdf

Msanga, Y., Bryant, M., Rutam, I., Minja, F., & Zylstra, L. (2000). Effect of environmental factors and of the proportion of Holstein blood on the milk yield and lactation length of crossbred dairy cattle on smallholder farms in north-east Tanzania. *Tropical Animal Health and Production*, *32*, 23-31.

Mungube, E., Njarui, D., Maichomo, M., Olum, M., Ndirangu, P., Kabirizi, J., Ndikumana, J., & Mwangi, G. (2019). Reproductive performance indicators of dairy cattle in selected small-scale dairy farms in semi-arid Eastern Kenya. *Livestock Research for Rural Development*, *31*(6).

Muraya, J., Vanleeuwen, J. A., Makau, D. N., Crane, M. B., McKenna, S. L. B., Gitau, G. K., Tsuma, V. T., & Wichtel, J. J. (2018). Cross-sectional study of productive and reproductive traits of dairy cattle in smallholder farms in Meru, Kenya. *Livestock Research for Rural Development*, *30*(10).

Ngou, A., Laven, R., Parkinson, T., Kashoma, I., & Donaghy, D. (2025). Understanding Smallholder Dairy Farming in Tanzania: A Cross-Sectional Survey of Farmer Demographics and Management Constraints. Preprint. https://doi.org/https://doi.org/https://doi.org/10.21203/rs.3.rs-4993873/v1

Nishimwe, K., Bizimana, J., Manishimwe, R., Ayabagabo, J., Byukusenge, M., Habimana, R., & Bareeba, F. (2015). Factors affecting the pregnancy rate in small scale dairy farms after the artificial insemination in rural area, Rwanda. *International Journal of Livestock Research*, *5*(3), 19. https://doi.org/http://dx.doi.org/10.5455/ijlr.20150316053842

Noakes, D. E. (1997). *Fertility and obstetrics in cattle* (2nd ed ed.). Blackwell Science.

Plaizier, J., King, G., Dekkers, J., & Lissemore, K. (1997). Estimation of economic values of indices for reproductive performance in dairy herds using computer simulation. *Journal of Dairy Science*, *80*(11), 2775-2783.

Plaizier, J., Lissemore, K., Kelton, D., & King, G. (1998). Evaluation of overall reproductive performance of dairy herds. *Journal of Dairy Science*, *81*(7), 1848-1854. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(98)75755-8

Shalloo, L., Cromie, A., & McHugh, N. (2014). Effect of fertility on the economics of pasture-based dairy systems. *Animal*, *8*(222-231), 222-231. https://doi.org/10.1017/S1751731114000615

Swai, E., Bryant, M., Karimuribo, E., French, N., Ogden, N., Fitzpatrick, J., & Kambarage, D. (2005b). A cross-sectional study of reproductive performance of smallholder dairy cows in coastal Tanzania. *Tropical Animal Health and Production*, *37*(6), 513-525.

Swai, E., Kyakaisho, P., & Ole-Kawanara, M. (2007). Studies on the reproductive performance of crossbred dairy cows raised on smallholder farms in eastern Usambara mountains, Tanzania. *Livestock Research for Rural Development*, *19*(5), Article 61. https://doi.org/http://www.lrrd.org/lrrd19/5/swai19061.htm

Tadesse, B., Reda, A. A., Kassaw, N. T., & Tadeg, W. (2022). Success rate of artificial insemination, reproductive performance and economic impact of failure of first service insemination: a retrospective study. *BMC Veterinary Research*, *18*(1), 226. https://doi.org/10.1186/s12917-022-03325-1

Wildman, E. E., Jones, G. M., Wagner, P. E., Boman, R. L., Troutt, H. F., Jr., & Lesch, T. N. (1982). A Dairy Cow Body Condition Scoring System and Its Relationship to Selected Production Characteristics. *Journal of Dairy Science*, *65*(3), 495-501. https://doi.org/10.3168/jds.S0022-0302(82)82223-6

World_Bank. (2024, June 26, 2026). *Tanzania economic update: Harnessing the opportunity for a climate-smart and competitive livestock sector in Tanzania*. The World Bank. Retrieved April 04 from https://www.worldbank.org/en/news/feature/2024/06/26/tanzania-economic-update-harnessing-the-opportunity-for-a-climate-smart-and-competitive-livestock-sector-in-afe-tanzania

Declarations

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Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors contributed to the study design and conception. AN did the data collection under the guidance of IK and RL. Data analysis and interpretation were done by AN, RL and TP. The first draft of this manuscript was written by AN, and all authors commented on the versions of the manuscript. All authors read and approved the final document.

Data availability

The generated and analysed datasets used in this study are available from the corresponding author upon acceptable request.

Ethics approval

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007) of the United Republic of Tanzania.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

Authors' consent to the publication of this article and participants' permission for publication were achieved where appropriate.

Competing interests

The authors declare that they have no competing interests.

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Footnotes

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List of abbreviations

- TALIRI - Tanzania Livestock Research Institute
- DC - District Council
- TC - Town Council
- MC - Municipal Council
- CC - City Council
- IMB - International Business Machines
- CI - Confidence Interval
- OR - Odds Ratio
- HR -Hazard Ratio

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Chapter Six: The Impact of Socioeconomic and Management Predictors on the Recognition of Infertility Signs and Reproductive Performance in Smallholder Dairy Cattle Farming in Tanzania

Foreword: This chapter covers the evaluation of the relationship between the 13 predictor variables and the four outcome variables, using multivariable analysis. The multivariable analysis was conducted using data from the past three chapters, i.e. farmer demographics and farming constraints; farmers' knowledge, attitude, practice (KAP) on infertility in dairy cattle and the reproductive performance determination (chapters three, four and five). This study has been submitted for publication in the Journal of the South African Veterinary Association. In this thesis, the manuscript has been presented in the journal format and style.

Title: The Impact of Socioeconomic and Management Predictors on the Recognition of Infertility Signs and Reproductive Performance in Smallholder Dairy Cattle Farming in Tanzania

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Abstract

Understanding the factors influencing dairy farmers' awareness of infertility and reproductive performance is vital for improving productivity. The current study employed multivariable analyses to assess the association between 13 predictor variables (covering farmer demographics, understanding of cattle infertility issues and perceived farming constraints) and four key outcome measures: recognition of infertility signs, recognition of failure to produce a calf per year as an indicator of infertility, pregnancy status and inter-calving interval (ICI). Smaller herd sizes were associated with poorer recognition of infertility signs and lower pregnancy rates (PR), while less experienced farmers had better recognition of infertility signs and higher PR. Cows whose owners considered repeat breeding as a major or moderate constraint on their farms had shorter ICI than those who considered that it had a negligible impact, while farmers who used only AI were more likely to consider failure to produce a calf per year than those who used AI and a bull. For the other predictors, except for region, our data did not identify clear effects on outcome variables, either in the univariable models or the multivariable models. This does not mean that such predictors have no effect on our outcomes, just that our data do not allow us to distinguish between a negative outcome, a positive outcome and no meaningful effect. More data is required to better establish which of these is correct. Of all the predictors, region appeared the most consistent and impactful variable, being selected and having at least one category with a clear effect across all the outcome variables. This indicates the presence of strong regional disparities in reproductive outcomes, likely reflecting broader structural, environmental or institutional differences across regions. Our findings underline the importance of context-specific approaches, particularly regionally tailored interventions, in enhancing reproductive performance among smallholder dairy systems in Tanzania.

Keywords: Predictor and outcome variables, multivariable analysis, reproductive performance

1. Introduction

Effective reproductive performance is crucial for optimising the lifetime productivity of a dairy cow (Lucy 2001, Hudson et al. 2018). Poor reproductive performance results in lower milk production, reduced sales of calves and less choice of herd replacements, and increased costs associated with breeding, feeding and labour (Diro et al. 2021). Subfertility in dairy cattle remains a persistent constraint that affects the productivity and profitability of dairy farming worldwide (Roman et al. 2024, Workie et al. 2021). This is particularly important in countries where smallholder dairy cattle farming predominates, such as Tanzania, as fertility-related constraints are particularly strong (Kivaria et al. 2006b, Shalloo et al. 2014) and significantly limit the ability of smallholder dairy farming to support individual farm profitability and thus local development (Njombe et al. 2011, Kanuya et al. 2000, Kanuya et al. 2006). In a previous chapter, we measured the reproductive performance of over 320 dairy farms across Tanzania. We concluded that there was a marked variation in reproductive performance between farms and regions. In this study, we aim to investigate further some of the factors that may be behind these farm and region-level differences, using data from our survey of smallholder dairy cattle farmers. Our focus was to examine how farm and farmer demographics, reproductive management practices, perceived infertility problems and key farming constraints influenced farmers' knowledge of infertility and their overall reproductive performance.

Therefore, the current study aimed to examine the association between the selected predictor variables and the chosen output variables to provide insights into how they influence perceptions and experiences of infertility and reproductive performance among smallholder dairy cattle farms in Tanzania.

2. Methodology

The methodology of this study is well documented by prior research conducted as part of the main study (Ngou et al. 2025). A concise summary of the selected predictors and outcome variables is presented in Table 1. The following sections outline the data sources, variable selection process and analytical methods used in this study.

2.1. Ethical considerations and approval

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007). Informed written consent was obtained prior to data collection, and the results were anonymised.

2.2. Study design and site selection

This on-farm cross-sectional study on the reproductive performance of smallholder dairy cattle under the smallholder dairy cattle farming system was conducted in six regions (Arusha, Kilimanjaro, Mbeya, Morogoro, Njombe and Tanga) of the Tanzania mainland from May 2022 to February 2023. Convenience sampling was used to identify the study regions, districts, villages, and the first study farm in each village. Snowball sampling was subsequently employed to select additional study farms in that village.

2.3. Field data collection

All the data were collected by a single person (the author), assisted by veterinary/livestock officers from the respective area. Information was collected through questionnaire-guided interviews on farmer demographics, farmers' understanding of cattle infertility, and the reproductive performance of herds and individual animals.

2.4. Data analysis

This study examined the effect of a series of predictor variables on key reproduction-related variables (see Table 6.1). The thirteen predictor variables (see Table 6.1) were selected to encompass a broad range of demographic, practical, and systemic factors that are likely to influence smallholder dairy cattle farmers' understanding and response to infertility in dairy cattle (Kurwijila et al. 2012, Chawala 2020, Ngou et al. 2025).

The collinearity of 13 predictor variables was checked using Spearman's rank correlation, with $\rho>0.7$ being used to indicate collinearity. If collinearity occurred, the variable with the most plausible biological effect was chosen. For each of the four outcomes, the same process was used to identify the final model. Firstly, all 13 predictor variables were tested in a univariable model, with all variables having a P-value ≤ 0.4 being selected for inclusion in a multivariable model, where no further selection was made. The modelling process used for each outcome variable was the same for the univariable and multivariable analyses and is summarised in Table 6.1. For the two cow-level variables (pregnancy status and inter-caving interval), the farm was included as a subject variable and the cow as a within-subject variable to account for clustering within the farm in both univariable and multivariable models.

For all analyses, data are interpreted using the compatibility interval approach; i.e. rather than using p-values to determine a dichotomous outcome, we used 95% confidence intervals to determine the range of values that were compatible with our data under our background statistical assumptions (Gelman & Greenland 2019).

Table 6.1. Predictor and outcome variables selected

Tested predictor variables

Group	Predictor	Categories
Demographics	Region	Arusha, Kilimanjaro, Mbeya, Morogoro, Njombe or Tanga
	Farmer gender	Female or male
	Farmer age (Years)	≤40, 41-60 or ≥61)
	Farmer formal education	None, Primary, Secondary or Higher
	Dairy farm experience (years)	≤10, 11 to 20, 21 to 30 or ≥31
	Herd Size	1 to 2, 3 to 4, 5 to 6 or ≥7
	Breeding method	AI, bull or both
Constraints	High breeding costs	Major, moderate or minor
	Input cost	High or moderate
	Lack of enough land	High or moderate
Fertility issues	Impact of repeat breeding*	Major, moderate or negligible
	Extent of infertility on the farm	Major, moderate and minor
	Selling of infertile animals to other farmers	Agree, neutral and disagree

Tested outcome variables

Outcome	Outcome variable	Statistical model
Ability to identify infertility signs	Score out of 10	Ordinal logistic regression
Failure to produce a calf/year is a sign of infertility	Yes vs. no	Binomial logistic regression
Calving interval (Days)	Ln calving interval	Generalised estimating equation with linear outcome†
Pregnancy status	Pregnant vs non-pregnant	Generalised estimating equation with log outcome†

*Repeat breeding: mating or inseminating an animal multiple times without it becoming pregnant. †Farm used as subject variable and cow as within-subject variable.

3. Results

For the outcome *'ability of the farmer to identify dairy cattle infertility signs'*, seven predictor variables were selected from the univariable analysis: education, experience, herd size, breeding method, breeding cost, perception of infertility extent on their farm and region (see Table 6.2). For all included predictor variables, 95%CI for at least some of the categories included potentially important effects. For example, compared to farmers who had attended university the odds ratio (OR) for a farmer whose highest education was secondary correctly identifying more signs of infertility was 0.84 (0.41–1.72); i.e. our data were compatible with a range of effects from a large decrease in odds and to a smaller but still important increase (and consequently also no meaningful effect).

Of the seven predictor variables, only three, herd size, experience, and region, had at least one category for which the 95%CI excluded 1, i.e. the range of effects with which our data were compatible did not include no effect. For the remaining predictors, all categories had 95%CI that included 1, meaning that the data were compatible with no meaningful effect. Compared to farms with a herd size of ≥7 cattle, all other categories had lower odds of recognising more signs of infertility. However, the data provide only limited support to the hypothesis that, beyond the difference between herds with ≥7 cattle, decreasing herd size was associated with decreased recognition because the large overlap between the CI of the OR for each size category means that although our data are compatible with such an effect, they are also compatible with the opposite. In regard to experience, compared to farmers with ≥31 years of experience, all other categories had higher odds of recognising more signs. For farmers with 11 to 20 years of experience, the 95%CI of the OR ranged from a slight decrease to a substantial increase in odds, so our data are also compatible with no meaningful difference from farmers with ≥31 years of experience. For the regions, compared to farmers in Tanga, all farmers except those in Njombe had higher odds of recognising more signs. Our data for farmers in Morogoro and Kilimanjaro were compatible with effects ranging from a moderate increase in odds (lower CI for OR 1.91 and 1.3, respectively) to a very large increase (5.76 and 9.3, respectively). Farmers in Njombe had lower odds (OR: 0.35) of recognising more signs, ranging from a slight decrease to a large one (CI: 0.15 to 0.80).

Table 6.2: Effect of selected predictors on the ability of Tanzanian smallholder dairy farmers to recognise signs of infertility. Data from 301 farmers across 6 regions of Tanzania

Predictor	Category	Odds Ratio	95%CI	
			Lower	Upper
Formal Education				
	None	1.21	0.33	4.47
	Primary	0.96	0.56	1.64
	Secondary	0.84	0.41	1.72
	Higher	Reference		
Experience (Years)				
	≤10	**3.82**	**1.82**	**8.02**
	11 to 20	2.03	0.96	4.29
	21 to 30	**3.38**	**1.53**	**7.50**
	≥31	Reference		
Herd Size				
	1_2_cattle	**0.22**	**0.11**	**0.44**
	3_4_cattle	**0.37**	**0.19**	**0.70**
	5_6_cattle	**0.45**	**0.23**	**0.89**
	>=7_cattle	Reference		
Breeding Method				
	AI	1.55	0.92	2.60
	Bull	0.55	0.15	2.06
	Both	Reference		
High Breeding Cost				
	Major	1.15	0.53	2.49
	Moderate	0.62	0.38	1.01
	Minor	Reference		
Extent of Infertility Problem on the Farm				
	Major	1.66	0.74	3.69
	Moderate	1.41	0.63	3.14
	Minor	Reference		
Region				
	Arusha	1.56	0.57	4.24
	Kilimanjaro	**2.74**	**1.31**	**5.76**
	Mbeya	1.99	0.42	9.37
	Morogoro	**4.21**	**1.90**	**9.30**
	Njombe	**0.35**	**0.15**	**0.80**
	Tanga	Reference		

Note: Predictors selected from those in Table 6.1 on the basis that for univariable analysis, p≤0.4. Output from an ordinal logistic regression with the outcome being a score out of 10 for identifying signs of infertility correctly.

Example for Interpreting Odds Ratios: The odds of a farmer with experience of ≤10 years getting a higher score than a farmer with ≥31 years of experience were 3.82 times higher than the odds of the farmer with ≥31 years of experience having the higher score

For '*failure to produce a calf in a year (as an infertility sign)*', nine predictors were included in the multivariable analysis (see Table 6.3). For this analysis, the reported ORs are for a farmer correctly identifying that failure to produce one calf a year was a sign of infertility. For all included predictor variables, 95%CI for at least some of their categories included potentially important effects. For example, compared to farmers who perceived that infertility had a minor impact on their farm, the OR for a farmer who perceived it as having a moderate effect was 1.38 (95%CI 0.49 -3.9); i.e. our data were compatible with a range of impact from a moderate decrease in odds to an almost four-fold increase. Of the nine included predictor variables, only four (herd size, breeding method, experience, and region) had at least one category for which the 95%CI from the model was incompatible with no effect.

Compared to farms with a herd size of ≥7 cattle, all other categories had lower odds of recognising failure to produce a calf in a year as a sign of infertility, and our data were compatible with a large effect. For farms with 1-2 cattle, the effect ranged from a small decrease to a large one (i.e. lower and upper CI were 0.1 and 063, respectively). However, for farms with a herd size of 5 to 6 or 3 to 4 cattle, as well as being compatible with a large decrease (lower CI 0.25 and 0.18, respectively), our data were also compatible with no meaningful association (upper CI 1.4 and 1.0, respectively).

Relative to farmers who used both AI and bulls, farmers who used bulls only had lower odds of recognising not achieving a calf-a-year as a sign of infertility, but our data were compatible with a range of outcomes from a large decrease in odds to a small increase (95%CI 0.063 – 1.32). In contrast, for farmers who used AI only, our data were compatible with a range of effects from a moderate increase to a large one (95%CI 1.18 – 4.79). In regard to experience, farmers with less the 31 years of experience had higher odds of correctly recognising failure to produce a calf in a year as a sign of infertility than those with ≥31 years. For farmers with ≤10 and 21-30 years' experience our data were compatible with a range of effects from a moderate increase to a large one (95%CI 1.37 - 12.2 and 1.29 – 10.9, respectively) while for those with 11-20 years our data were still compatible with a large increase (upper 95% CI 4.3) but also a moderate decrease (lower 95%CI 0.56)

Lastly, for region, compared to farmers in Tanga, farmers in all other regions except those in Mbeya had lower odds of correctly recognising failure to produce one calf a year as a sign of infertility. For Morogoro, our data showed effects ranging from a moderate decrease to a very large one (lower and upper 95%CI for OR: 0.099 to 0.8).

Table 6.3: Effect of selected predictors on the ability of Tanzanian smallholder dairy farmers to recognise a failure to produce a calf in a year as a sign of infertility. Data from 301 farmers across 6 regions of Tanzania

Predictor	Category	Odds Ratio	95%CI	
			Lower	Upper
Age (Years)				
	≤40	0.51	0.19	1.41
	41-60	0.54	0.25	1.16
	≥61	Reference		
Experience (Years)				
	≤10	**4.09**	**1.37**	**12.22**
	11 to 20	1.55	0.56	4.30
	21 to 30	**3.74**	**1.29**	**10.87**
	≥31	Reference		
Herd Size				
	1_2_cattle	**0.25**	**0.1**	**0.63**
	3_4_cattle	0.43	0.18	1.0
	5_6_cattle	0.6	0.25	1.43
	>=7_cattle	Reference		
Breeding Method				
	AI	**2.37**	**1.18**	**4.79**
	Bull	0.29	0.06	1.32
	Both	Reference		
High Breeding Cost				
	Major	1.65	0.61	4.48
	Moderate	0.82	0.31	2.14
	Minor	Reference		
High Input Cost				
	Higher	0.52	0.14	1.94
	Moderate	Reference		
Lack of Enough Land				
	Higher	0.7	0.36	1.34
	Moderate	Reference		
Extent of Infertility Problem on the Farm				
	Major	0.81	0.29	2.25
	Moderate	1.38	0.49	3.9
	Minor	Reference		
Region				
	Arusha	0.26	0.06	1.08
	Kilimanjaro	0.56	0.2	1.55
	Mbeya	4.06	0.63	26.1
	Morogoro	**0.28**	**0.1**	**0.8**
	Njombe	0.52	0.16	1.66
	Tanga	Reference		

Note: Predictors selected from those in Table 6.1 on the basis that for univariable analysis, p≤0.4. Output from an ordinal logistic regression with the outcome being failure to produce a calf in a year as a sign of infertility.

For the dependent variable '*pregnancy status'*, six predictors were selected for multivariable analysis (see Table 6.5). For all the included predictor variables, the 95%CI for at least some of the categories encompassed potentially important effects. For instance, compared to farmers who viewed high input costs as a moderate constraint on their farms, those who perceived it as a higher constraint had an OR of 1.26 (95%CI 0.76-2.07). This interval reflects a range of possible impacts, from a small decrease in the proportion pregnant to a marked increase in the odds of pregnancy. Of the six included predictor variables, only three (herd size, experience, and region) had at least one category for which the 95%CI from the model was incompatible with no effect. For herd size, cows on farms that had 1-2, 3-4 or 5-6 cows all had a lower odds of pregnancy than cows on a farm with a herd size of 7 or more. However, it was only on farms with a herd size of 5- 6 that odds of a cow being pregnant had an OR and 95%CI excluding 1 (OR 0.62; 95%CI 0.42-0.91). However, as that CI includes the point estimates of the OR for the other size categories (see Table 6.5), our data do not allow us to make the claim that our OR for the herd size categories are definitely different (Cumming & Finch 2005). Compared to farmers with ≥31 years of experience, cows on farms belonging to farmers in all the other three experience categories had higher odds of pregnancy. For farmers with ≤10 years of experience, the OR included 1 (OR 1.3; 95%CI 0.76-2.23), whereas for the other two categories it did not (see Table 6.5). However, as with herd size, our effect estimates are not precise enough to allow us to distinguish whether the OR for farmers with ≤10 years of experience is different from those of farmers with 11-20 and 20-30 years. Lastly, compared to farms in Tanga, cows in all other regions had higher odds of pregnancy. For cows in Morogoro and Njombe regions, the effects that were compatible with our data ranged from a small increase to a relatively large one (OR and 95%CI were OR 1.82 (1.16-2.84) and 1.86 (1.13-3.07), respectively. Thus, our model suggests that if a farm in Tanga has 40% of its cows pregnant, a farm that was identical but in Morogoro would have 55% of its cows pregnant (95%CI 44 to 65).

Table 6.5: Effect of selected predictors on the pregnancy status of Tanzanian smallholder dairy cows. Data from 1169 cows across 6 regions of Tanzania.

Predictor	Category	Odds Ratio	95%CI	
			Lower	Upper
Age (Years)				
	≤40	1.34	0.86	2.09
	41-60	1.19	0.83	1.72
	≥61	Reference		
Experience (Years)				
	≤10	1.30	0.76	2.23
	11 to 20	**1.77**	**1.04**	**3.01**
	21 to 30	**1.75**	**1.05**	**2.92**
	≥31	Reference		
Herd Size				
	1_2_cattle	0.70	0.44	1.11
	3_4_cattle	0.89	0.59	1.34
	5_6_cattle	**0.62**	**0.42**	**0.91**
	≥7_cattle	Reference		
Breeding Method				
	AI	0.97	0.69	1.36
	Bull	1.49	0.56	3.95
	Both	Reference		
High Input Cost				
	Higher	1.26	0.76	2.07
	Moderate	Reference		
Region				
	Arusha	1.04	0.58	1.88
	Kilimanjaro	1.42	0.95	2.12
	Mbeya	1.48	0.53	4.09
	Morogoro	**1.82**	**1.16**	**2.84**
	Njombe	**1.86**	**1.13**	**3.07**
	Tanga	Reference		

Note: Predictors selected from those in Table 6.1 on the basis that for univariable analysis, p≤0.4. Output from the logistic regression model with the outcome being pregnancy status. Odds ratios (OR) values were derived from a multivariable logistic regression model fitted using generalised estimating equations (GEE) for the clustering effect. An OR of less than 1 indicates lower odds of pregnancy compared to the reference category, while an OR greater than 1 indicates higher odds.

For '*inter-calving interval (ICI)*', seven predictor variables were included in the multivariable analysis (see Table 6.6). For all the included predictor variables, the 95%CI for at least some of the categories encompasses the potential effects. For instance, compared to farmers who viewed a lack of land as a moderate constraint, those who perceived it as a higher constraint had a longer mean ICI, i.e. 1.05 times higher (95%CI: 0.96-1.16). Thus, if the model predicted that a farm owned by a farmer who viewed lack of land as a moderate constraint had a mean ICI of 500 days, then the model would predict that changing the farmer to one who viewed lack of land as a major constraint would increase ICI to 525 days (95%CI 480 – 580). Of the seven selected variables, only repeat breeding and region had at least one category for which the 95%CI from the model was incompatible with no effect. Compared to farmers who viewed repeat breeding as a negligible constraint, farmers who considered it to have a major or moderate impact had shorter ICI (0.71 (95%CI 0.54-0.93) and 0.67 (95%CI: 0.5-0.89) times, respectively. For region, farms in Kilimanjaro had 1.22 times longer ICI (95% CI: 1.07 to 1.4) than those in Tanga, while those in Njombe were 0.83 times shorter (95% CI: 0.7 to 0.97).

Table 6.6: Effect of selected predictors on the inter-calving interval of Tanzanian smallholder dairy cows. Data from 394 cows across 6 regions of Tanzania

Predictor	Category	GMR	95%CI	
			Lower	Upper
Gender				
	Female	1.11	1.00	1.24
	Male	Reference		
Age (Years)				
	≤40	0.92	0.82	1.03
	41-60	1.00	0.90	1.10
	≥61	Reference		
Breeding Method				
	AI	1.02	0.93	1.11
	Bull	1.06	0.93	1.21
	Both	Reference		
Lack of Enough Land				
	Higher	1.05	0.96	1.16
	Moderate	Reference		
Repeat Breeding				
	Major	**0.71**	**0.54**	**0.93**
	Moderate	**0.67**	**0.50**	**0.89**
	Negligible	Reference		
Selling Infertile Animals to Other Farmers				
	Agree	0.90	0.80	1.01
	Neutral	0.93	0.83	1.04
	Disagree	Reference		
Region				
	Arusha	0.90	0.75	1.08
	Kilimanjaro	**1.22**	**1.07**	**1.40**
	Mbeya	0.93	0.79	1.09
	Morogoro	1.11	0.99	1.26
	Njombe	**0.83**	**0.70**	**0.97**
	Tanga	Reference		

Note: Predictors selected from those in Table 6.1 on the basis that for univariable analysis, p≤0.4. Output from the logistic regression model with the outcome being inter-calving interval.

The GRM (Geometric Mean Ratios) indicates a multiplicative effect relative to the respective reference category in each predictor variable. A value >1 suggests a longer ICI, while a value <1 indicates a shorter ICI compared to the reference. CI represents confidence intervals at the 95% level.

A summary matrix of the influence of the predictor variables on reproductive performance indicators among smallholder dairy farmers in Tanzania is shown in Table 6.7. Of the thirteen predictor variables, only 'region' and 'breeding method' were selected to be included in the multivariable analysis for all four outcome variables, with only 'region' having at least one category where the outcome compared to the reference category was incompatible with no effect in all four models.

Table 6.7. A Summary matrix of the influence of the predictor variables on reproductive performance indicators among smallholder dairy farmers in Tanzania

Predictor	Influenced Dependent variables (✓-Selected, X-Effect)									
	Recognition of infertility signs		Calf a year (Sign)		Pregnancy status		Calving Interval		Total	
	Selection	Effect	Selection	Effect	Selection	Effect	Selection	Effect	✓	X
Region	✓	X	✓	X	✓	X	✓	X	**4**	**4**
Gender							✓		1	0
Age (Years)			✓		✓		✓		3	0
Education	✓								1	0
Experience (Years)	✓	X	✓	X	✓	X			3	3
Herd Size	✓	X	✓	X	✓	X			3	3
Breeding Method	✓		✓	X	✓		✓		**4**	1
High breeding cost	✓		✓						2	0
High cost of inputs			✓		✓				2	0
Lack of enough land			✓				✓		2	0
Repeat breeding							✓	X	1	1
Extent of Infertility Problem on the Farm	✓		✓						2	0
Selling Infertile Animals to Other Farmers							✓		1	0
Total	7	3	**9**	4	6	3	7	3		

Note: This Table presents a summary of predictor variables and their associations with five reproductive performance indicators (dependent/ outcome variables). A check mark (✓) under the 'selection' column indicates that the predictor was selected in the final multivariable model for the respective outcome. A cross (X) under the 'effect' column indicates that the predictor had an OR or GMR which did not include 1. (Note that this does not mean that selected variables without a cross had no effect on the outcome or that the effect on the outcome of the selected variable without a cross is necessarily less than that of the selected variable with a cross – see Tables 6.2 to 6.6 for the effects that are compatible with our data.

4. Discussion

Understanding the factors that affect the fertility of dairy cows on Tanzanian smallholder dairy farms is a crucial prerequisite for their improvement. From the previous surveys of this study, it was clear that there were marked regional differences in farmer demographics as well as their understanding of infertility issues and the reproductive performance of their dairy cattle. Similar regional differences have also been documented in earlier research into farmer knowledge and performance around cattle reproduction. For example, Swai & Karimuribo (2011) and Kashoma & Ngou (2023) both emphasised that the regional context significantly influenced Tanzanian dairy farmers' knowledge and their adoption of reproductive management practices. Similar trends have been observed in a broader East African context, with both Lobago et al. (2006) and Birhanu & Samson (2021) reporting that in Ethiopia, smallholder dairy cattle farmers' awareness of reproductive disorders and overall cattle fertility performance varied substantially by location and Mwanga et al. (2019) detailing variations in breeding decisions in smallholder dairy farmers across different sub-Saharan countries, i.e. Ethiopia. Kenya, Tanzania and Uganda.

However, simply identifying a regional effect is of limited value, as an effect of "region" is simply a proxy for unidentified factors that vary by region and affect farmer knowledge and/or performance. Some of these factors will be factors that we cannot change (such as differences in climate), but others (such as education level) may be amenable to change. Thus, identifying the factors behind regional differences can be useful for developing strategies to improve reproductive knowledge and performance.

The aim of this present study was to use the data collected in the previous parts of the main research in order to establish whether we could identify such factors. This was accomplished by using multiple multivariable analyses to examine the relationship between key predictor variables, related to farmer demographics, perceived constraints, and infertility issues, and four key outcome parameters, two of which were to related farmers awareness and knowledge of infertility (recognition of signs of infertility, and attitude to failing to produce one-calf-a-year), and two which were key reproductive performance measures (ICI and pregnancy status).

Our analysis was a two-stage process: selection of predictors for the multivariable model and an analysis of the results from that model. Both stages provide valuable information about whether our predictors are likely to influence farmer knowledge and reproductive outcomes. The first identifies whether it is plausible that a predictor has a meaningful impact on our outcomes, while the second identifies, after accounting for the other variables in our multivariable model, the effects that are compatible with our data.

Of the six demographic-related predictors (excluding region), age, experience, and herd size were selected for multivariable analysis for at least three of the outcomes. This suggests that these predictors are potentially important in shaping smallholder awareness and practices related to cattle infertility and reproductive performance. In contrast, gender and education level were included in only one multivariable analysis, suggesting that, at least in our dataset, they did not have a consistently strong association with our outcome variables. This does not mean that gender and education have no influence on fertility awareness or reproductive performance. Indeed, previous studies in East Africa suggest otherwise. For example, in regard to gender, Richards et al. (2019) in Kenya, it was shown that female farmers had better calving rates and improved reproductive performance. In Tanzania, studies by Alessandra et al. (2017) and Sikira et al. (2018) showed that access to veterinary services and animal health information differed between males and females, with females facing more difficulties in accessing these resources. For education, in both Kenya and Uganda, better education was linked to better reproductive outcomes (Benon et al. (2015), which may be linked to educated farmers having a better understanding of and being more willing to adopt and use technology (Ingabire et al. 2018, Kashoma & Ngou 2023). Our analysis does not exclude gender and education from having an impact. Thus, while these predictors were not associated with most of the outcome variables in this multivariable analysis, further investigation is needed with a larger or more targeted dataset to draw firmer conclusions.

The farmer’s age was included in the multivariable analysis of three outcomes, i.e. failure to produce a calf in a year, pregnancy status and ICI. For the first two outcomes, our point estimate indicated that younger farmers had better outcomes than farmers in our oldest group (≥61 years), although our data was also compatible with a small decrease in good outcomes. For ICI, our GMR (and CI) were close to zero, but this small variation hides large potential differences in ICI (a GMR of 0.8 and one of 1.2 both indicate a change in ICI of 100 days if the reference ICI is 500 days), so for the impact of age on ICI our data do not provide clear guidance. Elsewhere, the data on the impact of age is variable, at least in reported outcomes. For example, in Sweden, Alvåsen et al. (2018) had more extended reproductive longevity, perhaps because livestock keeping had become a lifestyle rather than a business for them. However, younger farmers can be more active and more open to new technologies (Kosgei et al. 2020, Yap et al. 2025) than older farmers. As our data are not conclusive as to which side of this divide Tanzanian dairy farmers lie, further investigation is needed with a larger or more targeted dataset to draw firmer conclusions about the age of reproductive knowledge/performance.

Experience in smallholder dairy cattle farming was included as a predictor in three multivariable models and was associated with a clear effect across all three outcome variables (see Table 6.7). Notably, farmers with less experience demonstrated a better understanding of the signs of infertility and were more likely to recognise that failing to produce a calf per year was a sign of infertility. This was associated with better reproductive performance (a higher proportion of pregnant cows). This conclusion seems at odds with much of the published literature on East African reproductive performance and experience. Other studies have shown that experienced farmers are better able to report and respond to reproductive problems (Swai & Karimuribo 2011) and to adopt farming technology (Ingabire et al. 2018), with (Mwanga et al. 2019) reporting, across Kenya, Tanzania, Uganda and Ethiopia, that more experienced farmers had better breeding choices and hence improved reproductive performance. Nevertheless, Swai et al. (2014) did highlight that longer experience alone does not guarantee better reproductive outcomes, so we need further investigation around why, in our dataset, the highest level of experience was associated with the poorest outcomes.

Herd size was also included as a predictor in three multivariable models and demonstrated a clear effect across all those variables (see Table 6.7). Conspicuously, smaller farms had poorer reproductive performance, as reflected by lower pregnancy rates. Not all studies have shown a similar effect, Fahey et al. (2002) in Ireland indicated that smaller herd sizes were associated with improved reproductive efficiency. However, all the herds in that study were much larger than seen in the current study (≥34 cows) and other studies in the US and Europe have shown that reproductive efficiency is associated with large herd sizes (Jago & Berry 2011, Löf et al. 2007). For smallholders, it is clear that small herd sizes can limit the opportunities available to them to commercialise and benefit from producing livestock and livestock products (Lubungu 2017, Swai & Karimuribo 2011) and that reproductive performance is one of the key limiting factors preventing smallholders from increasing their herd size (Lubungu 2017). However, as far as we are aware, there are no studies on the impact of herd size and reproductive knowledge/performance. Though studies have assessed the effect of herd sizes on reproductive outcomes like ICI and conception rates (Benon et al. 2015, Löf et al. 2007). Nevertheless, our findings are consistent with the consensus that poor reproductive performance is common on Tanzanian dairy farms.

Although the breeding method was included as a predictor in all four multivariable models, there was only one outcome, i.e. failure to produce a calf within a year, where there was a clear effect on farmers who primarily relied on AI being more likely to recognise this failure as an indicator of infertility. For all the other outcomes, our data were equivocal, consistent with a range of potential effects from poorer to better performances. This does not mean that the breeding method did not influence these other outcomes, just that we cannot draw firm conclusions around the impact of breeding method from this dataset. Other studies from Eastern Africa have suggested that the use of bulls is associated with improved reproductive performance (Kanuya et al. 2014, Kashoma & Ngou 2023) although those studies did not adjust outcomes to account for other differences between farms. Other findings suggest that AI users were more likely to maintain better farm records and have a better understanding of issues related to production, as well as technology adoption (Gargiulo et al. 2018, Ingabire et al. 2018). These mixed findings highlight the complexity of the relationship between breeding method and reproductive outcomes, which may be influenced by additional factors service quality, timing and farm management (Tesfaye et al. 2015, Mekonnen et al. 2010, Jemal et al. 2016).

For the predictors related to farming constraints (i.e. high breeding costs, input costs and lack of enough land) and fertility issues (the impact of repeat breeding, the extent of infertility on the farm and the practice of selling infertile animals to other farmers), each was included at least once in the multivariable models. However, for all of these variables, except for one association, our data are equivocal in regard to their likely impact on the outcomes of the models they are included in. Again, it is important to emphasise that we have not shown that these factors do not have an impact, just that we need more data to better characterise their impact. This is especially important as others have shown an association. For example, Swai et al. (2014) reported that lack of land and high cost of inputs were associated with longer ICI and low conception rates in Tanzania, while challenges related to access to breeding and health services contributed to low calving rates and longer ICI in Malawi (Banda et al. 2012). The only exception to the equivocal finding was repeat breeding with ICI, which showed a clear association. Specifically, farmers who considered repeat breeding a problem on their farm (major or moderate importance) had cows with shorter ICI than those who regarded it as of negligible importance on their farms. This suggests that farmers' recognition of repeat breeding as a problem is an indicator that they are aware of the issue and are more proactive in managing it, perhaps by adopting corrective interventions such as improving heat detection or seeking veterinary advice. Studies have shown large economic impacts of repeat breeding on smallholder dairy farming (Kafi 2022), so this is an area that needs further focus if we are to improve reproductive outcomes on small Tanzanian dairy farms.

The findings of this study clearly demonstrated that region remained a strong and consistent predictor of reproductive outcomes even after accounting for other influential factors such as farmer and farm demographics, understanding of infertility and farming constraints. Region was selected and showed a clear effect in all four multivariable models, which makes it the most impactful predictor in the analysis. This means that regional differences are not only fully explained by other included variables. Rather, it suggests the presence of fundamental region-specific factors involved. Possibly, the presence of factors related to the structure and support systems within the dairy industry, local environment or cultural practices. For instance, questions remain about why a farmer in Tanga differs from that of Morogoro and Kilimanjaro or Njombe, despite being similar in their education and breeding practices. This points out a potential difference in infrastructure, market access, service delivery or farmer organisations. These persistent disparities highlight the critical need for locally specific strategies in improving dairy fertility outcomes and emphasise the importance of deeper investigation into what structural, institutional or management factors drive these regional patterns.

5. Conclusion

The findings of this study revealed a significant association between predictor variables and the four outcome measures, with region emerging as the most influential predictor across all the outcomes, followed by herd size and experience. These results are consistent with earlier findings from this study, all of which demonstrated clear regional disparities in farmers' demographic characteristics, understanding of infertility issues and reproductive performance of their farms. Region had a notable impact on key reproductive outcomes such as pregnancy status and inter-calving interval. Taken together, these findings reinforce the conclusion that regional characteristics must be carefully considered when designing and implementing dairy development strategies. They also highlight targeted, region-specific interventions, rather than broad, uniform approaches to effectively address the unique challenges and realities faced by smallholder dairy farmers in different regions. Furthermore, tailored education and support on infertility awareness and herd management are essential to improving reproductive outcomes in these systems.

6. Declarations

6.1. Authors' contributions

All authors contributed to the study design and conception. Athanas Ngou did the data collection under the guidance of Isaac Kashoma and Richard Laven. Data analysis and interpretation were done by Athanas Ngou, Richard Laven and Timoth Parkinson. The first draft of this manuscript was written by Athanas Ngou, and all authors commented on the versions of the manuscript. All authors read and approved the final document.

6.2. Funding

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6.3. Competing interests

The authors declare that they have no competing interests.

6.4. Data availability

The generated and analysed datasets used in this study are available from the corresponding author upon request.

6.5. Ethics approval

This research was approved by the Ministry of Livestock and Fisheries through the Ethics Review Board of the Tanzania Livestock Research Institute (TALIRI) (reference number TLRI/RCC.21/007) of the United Republic of Tanzania.

6.6. Consent to participate

Informed consent was obtained from all individual participants included in the study.

6.7. Consent to publish

The authors consent to the publication of this article, and participants' permission for publication was obtained where appropriate.

6.8. Competing interests

The authors declare that they have no competing interests.

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7. Reference

Alessandra, G., Distefano, F., Kangogo, D., et al., 2017. Gendered perspectives on smallholder cattle production and health management in three sites in Tanzania. *Journal of Gender, Agriculture and Food Security (Agri-gender),* 2**,** 43-65.

Alvåsen, K., Dohoo, I., Roth, A. & Emanuelson, U. 2018. Farm characteristics and management routines related to cow longevity: a survey among Swedish dairy farmers. *Acta Veterinaria Scandinavica,* 60**,** 1-11.

Banda, L. J., Kamwanja, L. A., Chagunda, M. G., et al., 2012. Status of dairy cow management and fertility in smallholder farms in Malawi. *Trop Anim Health Prod,* 44**,** 715-27.

Benon, K. M., Owiny, D. O., Båge, R., et al., 2015. Managerial practices and factors influencing reproductive performance of dairy cows in urban/peri-urban areas of Kampala and Gulu, Uganda. *Acta Veterinaria Scandinavica,* 57**,** 1-9.

Birhanu, A. & Samson, L. 2021. Knowledge and preventive practices of livestock farmers on infectious causes of reproductive disorders in dairy cows in the Kembata Tambaro zone, southern Ethiopia. *Animal Diseases.* BMC. https://doi.org/10.1186/s44149-021-00014-8.

Chawala, A. R. 2020. Investigation of farmer-led breeding goals and strategies in smallholder dairy farming systems to cope with variation in feed sources and quality.

Cumming, G. & Finch, S. 2005. Inference by Eye: Confidence Intervals and How to Read Pictures of Data. *American Psychologist,* 60**,** 170-180.

Diro, S., Mamo, T., Getahun, W., et al., 2021. Economic loss of dairy cattle poor reproductive performance in central highlands of Ethiopia. *Results of,* 9**,** 248.

Fahey, J., O'sullivan, K., Crilly, J. & Mee, J. 2002. The effect of feeding and management practices on calving rate in dairy herds. *Animal Reproduction Science,* 74**,** 133-150.

Gargiulo, J. I., Eastwood, C. R., Garcia, S. C. & Lyons, N. A. 2018. Dairy farmers with larger herd sizes adopt more precision dairy technologies. *Journal of dairy science,* 101**,** 5466-5473.

Gelman, A. & Greenland, S. 2019. Are confidence intervals better termed "uncertainty intervals"? *BMJ (Clinical research ed.),* 366**,** l5381.

Hudson, C., Cook, J. G. & Laven, R. 2018. Veterinary control of herd fertility in intensively managed dairy herds. *In:* NOAKES, D., PARKINSON, T. & ENGLAND, G. (eds.) *Veterinary Reproduction and Obstetrics.* 10th ed.: Elsevier.

Ingabire, M. C., Yonggong, L., Pesha, J. C. & Hardi, A. 2018. Factors affecting adoption of artificial insemination technology by small dairy farmers in Rwanda: A case of Rwamagana District. *Journal of Economics and Sustainable Development,* 9**,** 46-53. https://core.ac.uk/download/pdf/234648389.pdf.

Jago, J. G. & Berry, D. P. 2011. Associations between herd size, rate of expansion and production, breeding policy and reproduction in spring-calving dairy herds. *Animal,* 5**,** 1626-1633.

Jemal, H., Lemma, A. & Bekana, M. 2016. Assessment of the reproductive performance of dairy cows in smallholder dairy farms using artificial insemination. *Livestock Research for Rural Development,* 28**,** Article 81.

Kafi, M. 2022. Repeat breeding syndrome in dairy cows: is it luckily being solved by itself? *Iranian Journal of Veterinary Research,* 23**,** 93-94.

Kanuya, N., Kessy, B., Bittegeko, S., et al., 2000. Suboptimal reproductive performance of dairy cattle kept in smallholder herds in a rural highland area of northern Tanzania. *Preventive veterinary medicine,* 45**,** 183-192.

Kanuya, N., Mlangwa, J. & Shoo, J. 2014. Constraints associated with the use of Artificial Insemination (AI) and Natural Service (NS) in smallholder dairy herds in Tanga and Morogoro, Tanzania. *Tanzania Veterinary Journal,* 29**,** 9-20.

Kanuya, N. L., Matiko, M. K., Kessy, B. M., et al., 2006. A study on reproductive performance and related factors of zebu cows in pastoral herds in a semi-arid area of Tanzania. *Theriogenology,* 65**,** 1859-74.

Kashoma, I. & Ngou, A. 2023. Insight into the adoption and success of artificial insemination services in smallholder dairy farming systems: A cross-sectional study. *Tanzania Veterinary Journal,* 38.

Kivaria, F., Noordhuizen, J. & Kapaga, A. 2006b. Prospects and constraints of smallholder dairy husbandry in the Dar es Salaam region, Tanzania. *Outlook on Agriculture,* 35**,** 209-215.

Kosgei, J. K., Ng'eno, E. K. & Kibett, J. K. 2020. Factors affecting adoption of dairy cattle milk production technologies in Mosop Sub County, Nandi County, Kenya. *African Journal of Agricultural Research,* 15**,** 140-148.

Kurwijila, L. R., Omore, A. O. & Grace, D. 2012. Tanzania dairy industry overview 2012.

Lobago, F., Bekana, M., Gustafsson, H. & Kindahl, H. 2006. Reproductive performances of dairy cows in smallholder production system in Selalle, Central Ethiopia. *TROPICAL ANIMAL HEALTH AND PRODUCTION,* 38**,** 333-342.

Löf, E., Gustafsson, H. & Emanuelson, U. 2007. Associations Between Herd Characteristics and Reproductive Efficiency in Dairy Herds. *Journal of Dairy Science,* 90**,** 4897-4907.

Lubungu, M. 2017. Factors affecting the livestock herd size among smallholder households in Zambia. *Tropical Animal Health & Production,* 49**,** 1607-1612.

Lucy, M. C. 2001. Reproductive Loss in High-Producing Dairy Cattle: Where Will It End? *Journal of Dairy Science,* 84**,** 1277-1293.

Mekonnen, T., Bekana, M. & Abayneh, T. 2010. Reproductive performance and efficiency of artificial insemination smallholder dairy cows/heifers in and around Arsi-Negelle, Ethiopia. *Livestock Research for Rural Development,* 22, 61.

Mwanga, G., Mujibi, F., Yonah, Z. & Chagunda, M. 2019. Multi-country investigation of factors influencing breeding decisions by smallholder dairy farmers in sub-Saharan Africa. *Tropical animal health and production,* 51, 395-409.

Ngou, A., Laven, R., Parkinson, T., et al., 2025. Understanding Smallholder Dairy Farming in Tanzania: A Cross-Sectional Survey of Farmer Demographics and Management Constraints. Preprint.

Njombe, A., Msanga, Y., Mbwambo, N. & Makembe, N. The Tanzania dairy industry: Status, opportunities and prospects. 7th African Dairy Conference and Exhibition held at Moven Pick Palm Hotel, 25-27 May 2011. Dar es Salaam, 1-22.

Richards, S., Vanleeuwen, J., Peter, S. G., et al., 2019. Impact of mineral feeding on reproductive efficiency on smallholder dairy farms in Kenya. *Livestock Research for Rural Development,* 31.

Roman, L., Olena, B., Nina, D., et al., 2024. Differential diagnosis of chronic infertility in high-yield cows. *Наукові горизонти.* Zhytomyr National Agroecological University.

Shalloo, L., Cromie, A. & Mchugh, N. 2014. Effect of fertility on the economics of pasture-based dairy systems. *Animal,* 8, 222-231.

Sikira, A., Waithanji, E. M., Galie, A. & Baltenweck, I. 2018. Gender aspects in the dairy value chain in Tanzania: A review of literature.

Swai, E., Mollel, P. & Malima, A. 2014. Some factors associated with poor reproductive performance in smallholder dairy cows: the case of Hai and Meru districts, Northern Tanzania. *Livestock Research for Rural Development,* 26, 1-2.

Swai, E. S. & Karimuribo, E. D. 2011. Smallholder Dairy Farming in Tanzania. *Outlook on Agriculture,* 40, 21-27.

Tesfaye, A., Alemayehu, L., Tefera, Y. & Endris, A. 2015. Factors affecting the reproductive performance of smallholder dairy cows in two regions of Ethiopia. *Livestock Research for Rural Development,* 27, Article 46.

Workie, W. Z., Gibson, J. P. & Van Der Werf, J. H. J. 2021. Analysis of culling reasons and age at culling in Australian dairy cattle. *Animal Production Science,* 61, 680-689.

Yap, C. S., Keling, W., Ho, P. L. & Omar, Q. 2025. Technology readiness of farmers in sarawak: The effect of gender, age, and educational level. *Information Development,* 41, 37-47.

Chapter Seven: General Discussion

Transformation of the smallholder dairying in Tanzania

7.0. Introduction

Smallholder dairy farming plays a crucial role in enhancing livelihoods, improving human nutrition and promoting rural development in developing countries such as Tanzania (McDermott et al., 2010). Smallholder dairy farming in Tanzania, however, remains underdeveloped, and is characterised by low-input/low-tech and low-output systems (Hemme & Otte, 2010; Maleko et al., 2018a) that result in low productivity (Brett, 2019). This thesis has generally aimed at providing a research base to underpin the transformation of the Tanzanian dairy industry by better understanding the impact of farmers' demographics upon dairy production, together with key constraints and herd reproductive performance status. It also considers how the results of the present research might be used to guide the transformation of smallholder dairy farming.

7.1. The purpose of the thesis

The thesis has aimed to understand the Tanzanian smallholder dairy industry, including its current performance, challenges and potential. Specifically, it has aimed to assess the demographics of smallholder dairy cattle farms and their farmers, with a focus on the major constraints in farming and breeding practices. A key focus of this has been to examine farmers' understanding of issues related to dairy cattle infertility on their farms and to assess the current reproductive performance of their cattle. To fulfil the latter objective, the thesis has also aimed to develop a simple, effective, and efficient method for assessing the reproductive performance of dairy cattle, particularly in smallholder dairy farming.

7.2. Current vision and opportunities

The vision for smallholder dairying in Tanzania is to transition from its current subsistence system, in which most milk is produced for household consumption with a small surplus sold locally, to a more commercial, market-oriented and sustainable sector (Njombe et al., 2011; Michael et al., 2018; Mbwambo et al., 2019). This will involve making dairying the primary source of income for farmers, rather than a supplementary activity. This goal could be achieved by addressing key challenges that affect Tanzanian farmers, and by adopting successful models for the development of smallholder farming from around the world. There are positive trends towards this goal among Tanzanian smallholder farmers who participated in the present study: for example, the demographics of dairy farmers are changing, with greater involvement of younger individuals and those with formal education than in the past, such that 21% of farmers are under 40 years old, and 93% have formal education. In some regions, such as Morogoro, 68% of smallholder dairy farmers have more than a primary education, including secondary, college, or even university levels. This helps farmers adapt more easily to new practices and technologies, showing increased awareness and investment in the sector. Most importantly, for many farmers, dairying is increasingly viewed not just as a way to ensure household food security but also as a key income source, with many households now prioritising it as their main economic activity. Thus, 77% of respondents considered themselves to be full-time dairy farmers, and 84% depended on dairying as their primary source of income. This indicates a growing reliance on smallholder dairy cattle farming compared to previous reports, in which only 56% (Kashoma & Ngou, 2023) or 32% (Swai et al., 2014) of respondents reported it as their primary source of income.

7.3. Understanding the realities of farmers across the study regions

Acknowledging and integrating farmers' existing practices in policy-making is crucial, and incorporation of this 'bottom up' approach into policy is far more likely to succeed than relying solely on top-down expectations (Makate & Mango, 2017; Phakathi & Sinyolo, 2025). This allows for more effective and sustainable 'bottom-up' farming polices, which empower farmers to contribute their practical, context-specific insights to policy, which boosts the relevance and likelihood of the adoption of such policy (Fujisawa et al., 2015; Ahikiriza et al., 2021). Considering the diversity in locality, farm sizes and the market for milk, as well as the effects of poor fertility and/or reproductive performance of herds, along with other management constraints, these factors could guide the development of sustainable and transformative policies. For example, farmers in Mbeya and Tanga have a proper and sustainable milk market (i.e. due to the existence of a farmers' union in the area), which suggests that it would be easier to disseminate new technology among farmers in those two regions, as they have a single umbrella organisation that brings them together. In contrast, those in other regions are more isolated. On the other hand, although farmers in Mbeya have a common umbrella (UTAMBUZI union), there is limited use of AI technology (i.e. the majority use bulls for breeding), primarily because of the unavailability of an AI service, along with its inefficiency, which has led farmers to abandon the technology (as previously reported Kanuya et al. (2014); Mwanga et al. (2019); Kashoma & Ngou (2023)). Therefore, consideration of such regional differences by dairy development stakeholders is crucial for improving smallholder dairy farming, as it enables tailoring interventions to farmers' specific needs rather than relying on one-size-fits-all solutions (Ahikiriza et al., 2021; Habanabakize et al., 2022).

7.4. Farmers' knowledge of animal sourcing, production constraints and breeding practices

The understanding of smallholder dairy cattle farmers regarding issues related to herd management, particularly infertility and reproductive performance, is fragmented across the study regions. The findings of the present study highlight that the most common source of cattle in their herds was cash purchase, except for the farmers from Mbeya, where gifts from relatives or friends were the predominant source. However, these purchased animals are often brought in with minimal records on reproductive health, as the preferred feature for purchase is current milk production. This could mean that the newly purchased animals have reproductive health issues, which is also attested by another finding of this study that repeat breeding and failure to produce a calf in a year are deemed to be the most impactful limitations on infertility. Purchasing animals from unknown or unregulated sources risks introducing fertility or health problems into herds, either in terms of acquiring individual infertile animals or bringing in animals with infectious diseases that affect fertility. Furthermore, relying on gifts may limit access to improved genetics and/or continuation of informal selection resulting in poor productivity, as the gifted animals are often chosen based on availability or social factors (with little or no selection pressure) and not productivity traits (Okeyo et al., 2015; Nyamushamba et al., 2017). Therefore, education has to be provided to the farmers on the prudent sourcing of dairy cattle, emphasising the need for guidance on safe and strategic cattle acquisition to support herd performance and sustainability: indigenous techniques for animal selection have to be properly guided and supplemented with modern methods for improvement of their genetics and production (Okeyo et al., 2015; Nyamushamba et al., 2017; Karen et al., 2019; Bulcha et al., 2022).

Secondly, the findings demonstrate a huge shift in primary concerns over limitations of productivity from the animal health-related constraints that were formerly dominant (Kusiluka et al., 2006; Kivaria et al., 2006b) towards more management-related ones, such as input cost and the unavailability of enough land and animal feeds. As an example, the practice of delayed post-calving breeding is commonplace amongst some farmers whose aspiration is to increase milk production amount per lactation by extending the lactation length. Delayed breeding also occurs as most farmers plan to program their cows to lactate during the dry season, as the rainy season is always flooded with milk from the traditional keepers, hence a price drop (Schooman & Swai, 2011).

In high-producing cows (≥45 L/d) in developed countries, a delayed post-calving breeding period, or an extended VWP, can contribute to overall profitability (Mecıtoglu, 2022), and extending the calving interval and increasing milking frequency can contribute to higher milk outputs (Österman & Bertilsson, 2003). Also, an extended VWP is associated with a greater chance of the onset of regular ovarian cycles (Ma et al., 2022). However, while extending VWP has these benefits, it may also lead to a decline in milk production once the extended period concludes (Ma et al., 2022). Further, when a cow remains non-pregnant for a longer time, the chances of being culled increase, whilst the value of its pregnancy is higher in early lactation compared to those that conceive later in lactation (Vries, 2006). The present study did not investigate the impact of extended lactation during the dry season; however, because smallholder dairy farming is predominantly a low-input and low-output one (Brett, 2019), with unreliable feed sources during the dry season (Maleko et al., 2016; 2018b). It was probably for that reason that the present study found that repeat breeding and failure to produce a calf in a year were the conditions most widely perceived to affect fertility, probably also showing that breeding is undertaken during the wrong season.

However, further study is needed to investigate the role of feeding as a limiter of smallholder dairy farming. It had been intended to investigate feed supplies, along with along with estimations of blood protein and energy metabolites, as part of this thesis; however, this was thwarted as there were no laboratories for such analysis because of the COVID-19 pandemic (most of the laboratories. in Tanzania, ILRI labs in Kenya and Ethiopia, and South Africa, were yet to resume their operations after the COVID-19 pandemic). Nonetheless, zero grazing or 'cut-and-carry', where forages were harvested daily and brought to the cattle in their shelter, was the most common feeding mode under the zero-grazing system. Similar findings have been reported previously (Urio, 1986; Swai & Karimuribo, 2011); namely, that 'cut-and-carry' uses natural pastures, with fresh forages being obtained from roadsides, highways, and non-cultivated areas such as communal lands, uncultivated fields, communal swamp areas and communal grazing areas. In the present study, tethering animals at pasture was the predominant feeding system in Mbeya (68% of farmers). This could be attributed to the longer periods in the Mbeya region (Busokelo district in particular) when grazing is available, since the area is a cooler highland area (770 to 2865 metres above sea level), which receives 1500 to 2700 mm rainfall per year (Nyunza & Mwakaje, 2012; Makala, 2017). Therefore, focusing on the regional differences while planning for pasture improvements and management is necessary for developing region-specific strategies for smallholder farming.

7.5. Determination of herd reproductive performance indicators

Sustainable management and prosperity of dairy farms are necessary for efficient reproductive performance (Vries, 2006). Smallholder dairy cattle farming has poor performance in terms of both yields and reproductive efficiency (Kanuya et al., 1997; Kanuya et al., 2000; Lyimo et al., 2004; Swai et al., 2007; Chenyambuga & Mseleko, 2009; Shalloo et al., 2014; Allan et al., 2024), as also highlighted by the present study: i.e. the performance of smallholder dairy cattle farmers in the study regions was poor in terms of all the indicators that were evaluated (inter-calving interval (ICI), calving to first service interval (CFSI), first service to conception interval (FSCI), calving to conception interval (CCI) and pregnancy status). The proportion of animal records available for interval-based reproductive performance indicators, i.e. ICI, CFSI, CCI and FSCI, was small, and, overall, the records were of limited reliability. For example, over 70% of animals appeared to have a FSCI of zero, which would actually mean that they all conceived after the first service, which is not true; instead, record-keeping was not properly practiced by the farmers. This is very unfortunate because these indices are the simplest measures for assessing reproductive performance, as they do not require skilled personnel to establish them. However, poor record keeping seems to have been an obstacle for the effective determination of reproductive performance in Tanzania for over 20 years (Kanuya et al., 1997). By contrast, in the present study, direct determination of pregnancy status (i.e. pregnancy diagnosis) was found to be a reliable indicator for determining the reproductive performance of smallholder dairy cattle. Across the regions, the overall proportion of pregnant animals was 46%, with Mbeya and Morogoro leading with 55% and 52% of their animals (i.e. cows and heifers) being pregnant. Also, Morogoro had the highest proportion of pregnant cows (53%), whilst Mbeya had the highest proportion of heifers (53%) that were pregnant. Interestingly, during the farm visits, it was noted that some farmers had pregnant cows/heifers that were not born and raised on the farm but had been purchased and brought in from other farms from within or outside the country. Some of these heifers were bought while pregnant, while others were bought in and later conceived on the farm. This study did not establish the proportion of on-farm and bought-in pregnant animals. Given that pregnancy rates achieved on smallholder farms are generally relatively low, it would be worthwhile investigating both the source of bought-in pregnant animals, and the proportion of each herd that such animals represent. Data from Malawi, where reproductive efficiency is of a similarly low level to that found in the present study (Banda et al., 2012) suggests that, as reproductive efficiency is too low to sustain the necessary herd replacement rate, the purchase of pregnant animals is essential to maintain herd size. It would be interesting to determine whether similar considerations pertain to the acquisition of pregnant animals by the farmers in the present study.

Since pregnancy status was the most reliable indicator of reproductive performance, this study recommends the utilisation of direct pregnancy diagnosis (PD) for the time being, while the record-keeping systems are being improved. However, for this method to be widely utilised, there would need to be a larger pool of people who are competent in pregnancy diagnosis than is presently the case (i.e. due to a lack of veterinary or paraprofessional personnel). Hence, to implement a widespread PD program, a program for capacity-building, perhaps based upon on AI technicians (as well as livestock field officers and veterinarians) developing their pregnancy diagnosis skills. Additional equipment, notably for ultrasound scanning, would enhance the efficiency and accuracy of diagnosis. Additionally, the government and stakeholders might even consider leveraging veterinary students during their internship periods. By coordinating with the Sokoine University of Agriculture, a structured placement program might be implemented to deploy interns to areas with high demand for AI services and other livestock health management demands throughout the country. Supporting these students to remain in the field for the entire internship duration would enhance AI service delivery and sustainability in underserved regions. Studies from both veterinary (Posey et al., 2012; Berrada et al., 2024) and medical (Brodribb et al., 2016; Makate et al., 2021; Seal et al., 2022; McGrail et al., 2023) profession have shown that, high quality rural placement of students increases their chances of staying in the field after their graduation (Seal et al., 2022; McGrail et al., 2023). Other studies showed that students who were trained in dairy internships were more likely to accept dairy-related practice in the USA (Morin et al., 2020). Also, undergraduate rural placements influence the future (postgraduate) studies of a student (Williamson et al., 2012). Therefore, placement of veterinary students could not only help to resolve the problem of insufficient number of veterinarians in the rural areas but also should increase the number of private veterinarians wanting to practice in the rural areas.

The present study also evaluated the influence of farmers' demographics and farm characteristics on various outcome variables via multivariable analysis. The predictors herd size and farmers' experience were notably influential, with both showing clear associations with more than two reproductive outcome variables. Smaller herd sizes were associated with poorer recognition of infertility signs and poorer pregnancy rates: a finding that would be largely as expected, i.e. smaller hers have been associated with poor technical efficiency (Bravo-Ureta & Pinheiro, 1997) and may result into farm losses (Dairy_Farmer, 2023). Interestingly, however, less experienced farmers had better recognition of infertility signs and increased pregnancy rates. Perhaps, in this context, 'experience' could be a proxy for attributes such as youth, enthusiasm and education, which may be lacking in older or less educated farmers. Further, cows whose owners considered repeat breeding as a major or moderate constraint on their farms had shorter ICI than those who considered that it had a negligible impact.

Of all the predictors, the region where a farmer is located had an impact on almost all of the selected reproductive outcomes, indicating the presence of strong regional disparities in reproductive outcomes, which were likely to reflect broader structural, environmental or institutional differences across regions. These findings underline the importance of context-specific approaches, particularly regionally-tailored interventions (rather than uniform solutions to specific challenges), in enhancing reproductive performance among smallholder dairy systems in Tanzania. Some earlier studies in Tanzania also emphasised that the regional context significantly influenced smallholder dairy farmers' knowledge and their adoption of reproductive management practices (Swai & Karimuribo, 2011; Kashoma & Ngou, 2023). Similar trends have been observed in a broader East African context (e.g. Lobago et al. (2006) and Birhanu & Samson (2021) (Ethiopia), and Bebe et al. (2003) (Kenya)). Furthermore, smallholder dairy farmers' awareness of reproductive disorders and overall cattle fertility performance have also been shown to vary substantially by location. Mwanga et al. (2019), who detailed variations in breeding decisions in smallholder dairy farmers across different sub-Saharan countries (Ethiopia, Kenya, Tanzania and Uganda), also reflected that Tanzania farmers are more likely to use bull service over AI. Also, in Malawi only 55% of farmers use AI, and only 39% in farms away from the national semen centre (Banda et al., 2012); a close reflection of the situation in Tanzania

7.6. Upscaling smallholder dairy cattle farming in Tanzania

The present study results highlight that most of the herds are relatively small, such that >70% of the herds have ≤7 dairy cattle per farm. The study also highlights that farms with smaller herds have poor reproductive performance (i.e. lower pregnancy rates). There is relatively little comparative literature on the relationship between herd size and fertility in smallholder farms, although a positive relationship between herd size and fertility in medium-to-large scale dairy herds is well established (Löf et al., 2007; Jago & Berry, 2011) (although, noting that reproductive performance is commonly lower in very large herds, i.e. lower calving rates (Fahey et al., 2002), increased number inseminations per conception (Löf et al., 2007), longer ICI and open days (El-Tahawy, 2017)).

Most farmers in the present study considered that dairy farming was a good source of household cash flow; a similar finding coming from Swaziland, where smallholder dairying has been found to be profitable at the household level (Masuku et al., 2014). However, smaller herds often result in reduced cash flow and hence financial capacity, which in turn narrows the farmers' ability to invest and adopt new technologies to enhance farm performance (Swai & Karimuribo, 2011; Gargiulo et al., 2018). Also, a previous study in Tanzania reported that smallholder dairy cattle farmers are on the disadvantage side in the competition for milk market from the peri-urban and urban medium scale producers (Nyange & Mdoe, 1995). Furthermore, cows in smaller herds have been found to have shorter reproductive longevity because of longer ICI (Löf et al., 2007; Banda et al., 2012). Therefore, for improvement of smallholder dairy farming, increasing herd size would appear to be an important step, as other studies have shown to have improved reproductive performance when herd size exceeds about 30 animals (Fahey et al., 2002; Munira et al., 2023). Thus, as suggested by Banda et al. (2012), there are opportunities to improve smallholder dairy cattle reproductive performance, because ICI have been reported (including in this study i.e. median ICI of 468 days) to be a bit improved i.e. less than 500 days (Chenyambuga & Mseleko, 2009).

Farmers should be educated on the benefits of commercialising their farming, for example, through farmers' unions, since it is easier for them to pull together production resources, which will give them power in the negotiations of the price of their products (Uotila & Dhanapala, 1994; Cheelo & van der Merwe, 2021; Kanire et al., 2024). Additionally, when farmers are together, it encourages other stakeholders to build their interest in investing. For example, it is easier to persuade financial institutions (like the newly established Tanzania Cooperative Bank) to support by providing loans to the community union members rather than to individuals. A good example was observed in the present study, where members of CHAWAMU (in Tanga) and UTAMBUZI (in Mbeya) did not worry much about the availability of buyers of their milk throughout the year (though some had complained that the price was not reflecting the production cost). Conversely, at that same time, individual farmers were unsure not only of the market but also of the price. As mentioned earlier, most farmers from Morogoro, Kilimanjaro, and Njombe prefer to produce milk during the dry season due to milk shortages and hence increased prices. Previous studies also found that improvement of household income and profits from milk and its products was more commonly observed among farmers with cooperative membership (Gupta & Roy, 2012; Jitmun et al., 2020; Toiba et al., 2024) than when they operated as individuals. Furthermore, being a cooperative member increases bargaining power, improves credit access and facilitates technical support, training (Markelova et al., 2009; Ma & Abdulai, 2016; Peng et al., 2022) and access to insurance services (Ma & Abdulai, 2016). Cooperatives also encourage farmers to unite their resources and experiences in exploring new markets to achieve a better price for their milk and thereby improve their livelihood (Chhinh et al., 2022; Israel et al., 2022). Also, collective decision-making is enhanced when farmers are united in the cooperatives (Du & Jiao, 2022; Olson et al., 2023). The beneficial role of cooperatives in training initiatives have been reported in Sri Lanka, aiming at promoting best practices in dairy management of various stakeholders, i.e. extension agents, veterinarians and farmers (Vyas et al., 2020).

With the current herd sizes in Tanzania, it is difficult for these smallholder farmers to engage in dairy farming as a full-time occupation. So, most of them grow crops and keep other animals such as pigs, goats and chickens, with crop cultivation seeming to be the major household economic activity. Therefore, once herd sizes expand, farmers will be more engaged in dairy farming and have more time to observe their animals for various reproductive events. This would improve their income from dairying, via improved production efficiency, as previously reported in the Dominican Republic (Bravo-Ureta & Pinheiro, 1997) showed that technical efficiency was higher on medium-sized than small farms (Bravo-Ureta & Pinheiro, 1997), and because milk from larger herds is often of better quality (lower somatic cell count) than that from smaller herds (Oleggini et al., 2001). Furthermore, reduction of herd size has been reported to contribute to farm losses in a long run (Dairy_Farmer, 2023). The enlargement of farm sizes could be hastened by encouraging younger people to engage in dairy farming. For example, in Eswatini, the involvement of family labour (i.e. children) in farming has been shown to increase technical efficiency (Greyling et al., 2023). This could be attributed to the fact that younger farmers have been reported to have a more business-minded mindset than the more experienced ones, for whom dairy farming is more of a lifestyle and habit than a business (Alvåsen et al., 2018). Also, younger farmers tend to adopt new technology faster than older ones, as the latter tend to stick more to what they are used to; i.e. traditional farming practices (Adekoya & Ajayi, 2000; Ingabire et al., 2018). Additionally, younger farmers might be more active, which makes them more up-to-date with modern farming techniques, including AI. They are also more likely to be more actively involved in the day-to-day activities of the farm, hence resulting in better observation of reproductive events like heat detection as they tend to be more educated and modernized (Khanal, 2010; Ohashi et al., 2024). As an example, a previous study by Brown et al. (2019) found that social expectations have less influence on older farmers, who are more focused on short-term financial performance and are therefore less likely to adopt new technologies related to land use intensification. Older farmers could be more likely to be risk-averse and want to see the benefits demonstrated, which will impact uptake.

7.7. Lessons from other countries

Strategically, Tanzania has appropriate government policies to support the improvement of the smallholder dairy sector. What is lacking is the willingness of the stakeholders to fully utilise these policies, like the livestock masterplan (Michael et al., 2018) and specifically the dairy development plans (Mbwambo et al., 2019). Also, as previously recommended by Kurwijila (1995), when milk processing is well organised (e.g. through cooperative organisations) and equipped with modern technology, it can hugely enhance farmers' access to markets, hence improved household incomes. Since smallholder farms in Tanzania are characterised by smaller herds, this limits their development by reducing cash flow and hindering the adoption of improved technologies and practices essential for enhancing productivity and reproductive efficiency (Akzar et al., 2019). These challenges could be mitigated through the pooling of resources (e.g. by cooperative unions' formulation), alongside targeted training and better access to financial (e.g. micro loans) and technical support, which will result from increased herd size. Reports show that an increased herd size is associated with an increase in the adoption of technologies in Ethiopia (Lilian et al., 2023), Indonesia (Akzar et al., 2019; Toiba et al., 2024) and India (Abbasi & Nawab, 2021). Historically, even in the developed dairy farming countries like New Zealand, a similar process was applied, i.e. increasing the herd sizes, building small factories for refrigeration of butter in the 1880s (Rowarth, 2013). Currently, New Zealand dairy farmers are focusing on the continued improvement of feed for cows of higher breeding worth (Clark et al., 2007). Smallholder farmers in Tanzania are not fully utilizing micro loans due to various factors including limited access, others include lack of information, high interest rates, inadequate credit supply and collateral requirement (Girabi & Mwakaje, 2013; Mwampaghale & Mbogo, 2023).

7.8. Review of the study

This section provides a critical review of the study, focusing on the strengths and limitations of the study design, as well as the mitigation strategies and implications for the interpretation and scope of the study.

7.8.1. Study strengths

One of the major strengths of this study is the incorporation of social behaviour (KAP) and the biological performance of the smallholder dairy farming systems. By linking farmers' knowledge, attitudes, practices and demographic characteristics to reproductive performance indicators, the study moves beyond descriptive analysis. Additionally, the study offers a more comprehensive understanding of the management and performance of dairy cattle in resource-constrained smallholder systems. Such integration of the human and animal dimensions has been emphasised in livestock system research, which highlights the importance of social, economic and biological factors in sustainable smallholder production development (McDermott et al., 2010; Thornton et al., 2010). Studies on KAP related to livestock production and health also demonstrate the influence of farmers' behaviour and social demographic characteristics on management and technology adoption, particularly in smallholder settings (Usman et al., 2020; Kashoma & Ngou, 2023; Mbesa et al., 2024).

This study is also strengthened by its context-specific focus on the smallholder dairy cattle farming system in Tanzania. A production system which somehow underrepresented in the practical reproductive performance research (Allan et al., 2024). This study utilised data collected directly from farmers operating under real-world management conditions, encompassing diverse environmental conditions across the country. This enhances their regional validity and the relevance of the findings to the farmers, livestock service providers and other stakeholders.

Furthermore, this KAP survey provided a clear baseline study and hence facilitated comparison of the findings of this study with similar studies employing behavioural models in agriculture and livestock research from the region and across the globe. Such surveys are widely established tools for identifying behavioural bottlenecks to technology adoption and management improvement, especially in low and middle-income countries where smallholder dairy cattle farming is in practice (Launiala, 2009; Usman et al., 2020).

7.8.2. Study design Limitations and their mitigations

Despite the abundant strengths of the study, there are some study design limitations for acknowledgement. Like, the cross-sectional nature of the study could restrict the ability to establish a causal relationship between KAP variables, management practices and reproductive performance outcomes. While associations were well identified, the temporal direction of these relationships cannot be definitely determined, as both farmer behaviour and reproductive outcomes may be influenced by unobserved prior factors. This was not the case for the present study, as the intention was to establish baseline information on the association in steady or strong causal claims, which is consistent with other practices in such research (Green, 2001).

Also, the study relied partly on self-reported data, especially on demographics and KAP variables, management practices and some farm records. Such information is highly subject to recall bias and social desirability bias, which may result in over-reporting of desirable practices or under-reporting of management constraints. However, this is a well-known limitation of KAP-based research and behavioural surveys (Manderson & Aaby, 1992; Launiala, 2009). In the current study, this was mitigated by involving not only a structured questionnaire, but also all the interviews were conducted by one interviewer (for consistency). Furthermore, the same interviewer had a chance to validate what was reported by the farmers during rectal scanning of animals.

Measurement of reproductive performance under smallholder systems is inherently challenging. This is because of poor record-keeping and reliance on farmer recall for key events, such as calving dates and insemination dates. This may result in measurement errors that potentially attenuate observed associations between management and reproductive outcomes. The current study proposes the use of pregnancy diagnosis as an appropriate measure of reproductive performance under smallholder farming systems. Pregnancy diagnosis reduces reliance on farm records, which are not well-documented in the system.

Although the geographic scope and sample size of the study may limit the direct generalizability of findings beyond similar smallholder systems within Tanzania or East Africa. This was mitigated by the study's multi-regional design. Data were collected from the six key dairy-producing regions of Tanzania. For example, Morogoro and Tanga represent the coastal and sub-humid lowland systems, Mbeya represents high rainfall and hilly environments, while Kilimanjaro, Njombe and Arusha represent cooler highlands and mountainous dairy-producing systems. These regions capture a wide range of climatic, management and production conditions under which smallholder dairy farming is practised.

Variations in the agro-ecological condition, access to services and institutional support may influence the applicability of the results to another context. This study was conducted in six regions representing different ecological zones, i.e. Morogoro and Tanga could represent the coastal areas, while Mbeya is for hilly areas which receive more rain, and Kilimanjaro, Njombe and Arusha are for cold mountainous areas.

7.9. Sample Case Studies

A table of three case studies has been incorporated into the recommendations section to enhance the specificity, practical relevance and contextual grounding of the study findings. Each case study focuses on a distinct regional, production or demographic context identified in the analysis. This allows the provision of the recommendations to be translated into realistic, targeted management and may be policy guidance. The case study draws directly on the study’s observed results and reflects key contrasts observed between regions, production systems and farmer characteristics. By linking the reproductive performance outcomes with KAP and demographic findings for each context, the boxed case studies demonstrate how different combinations of constraints and opportunities shape reproductive efficiency in practice.

Context	Key challenge	Targeted recommendations	Expected outputs
Case 1: Mbeya region			
• Smallholder dairy farming in the region operates under relatively high rainfall and cool highland conditions. • Other features include good forage availability (tethering predominates) with limited access to breeding (AI) and veterinary services at large.	• Inadequate record-keeping (85% had zero FSCI). • Limited access to AI service (bull breeding predominates). • Inadequate oestrus detection.	• Farmers training on oestrous detection and the importance of AI over bull breeding through extension services and model farms. • Promotion of simple record keeping tool, i.e. wall charts and using phones (apps). • Improve the availability and efficiency of the AI service	• Improving farmers' understanding of oestrous detection and better breeding by exploiting AI will improve their animals and allow better use of the favourable feed conditions available in the region.
Case 2: Morogoro and Tanga regions			
• These two regions represent warmer, semi-humid and coastal smallholder dairy systems with great feed fluctuation seasonally and heat stress being a common phenomenon. • This study found that these regions had	• Huge seasonal feed shortages (longer dry and hot seasons). • Inadequate farm record keeping • Inadequate initiatives to improve nutrition (too much	• Promotion of dry season feed conservation (hay, silage and crop residues, i.e. rice straws). • Farmers training on nutrition and pasture farm startups.	• Improving nutrition around breeding will enhance ovulation and hence conception and regular calving.

larger herd sizes (could be triggered by market availability, i.e. closer to Dar Es Salaam)	dependency on natural forages). • Inadequate record keeping.	• Encourage use of affordable energy and protein supplements around breeding and early lactation.	
Case 3: Kilimanjaro, Njombe and Arusha			
• These are cooler highland regions characterised by higher use of improved breeds under intensive management. • In this study, while these regions had higher milk yields had poor reproductive performance.	• Limited understanding on nutritional needs of high-grade cows. • Limited knowledge on infertility issues associated with high milk production. • Inadequate record keeping and reproductive health monitoring.	• Improvements should align with farmers' management capacity • Improve farmers' knowledge on reproductive health • Strengthen the coverage of veterinary and reproductive health services.	• Aligning breed choice and management will improve lifetime reproductive efficiency.

7.10. Further research

This study recommends further research to better understand the underlying reasons behind the observed regional differences. Specifically:

- Qualitative studies are needed to explore how and why farming practices, knowledge, constraints and reproductive performance differ across regions. Such information will provide a valuable context to supplement the quantitative findings.
- Primary research on the nutritional status of smallholder dairy cattle, focusing on the analysis of the nutritional value of the commonly used feeds, particularly their energy and protein content. This could usefully be undertaken alongside the evaluation of animals' corresponding blood metabolites to evaluate the actual nutrient uptake and utilisation in the animals.
- A longitudinal study to track the changes over time while monitoring seasonal transitions, management responses and reproductive performance trends. This will further deepen the understanding of how farmers adopt and cope with environmental and resource challenges throughout the year.

7.11. Conclusion and recommendations

In conclusion, this study, which is the first comprehensive cross-regional study of Tanzanian dairy farming, has found that the fertility of smallholder dairy cattle is generally poor. This infertility appears to be the result of various factors, including farmer demographics and farm characteristics, and farmers' specific understanding of issues related to infertility and poor management, particularly including poor farm record keeping.

The key recommendations emanating from the findings of this thesis for the development of smallholder dairy cattle farming are:

- Differences between regions are significant and should not be overlooked in the creation of policy or practices for improving dairy farming.
- Provision of farmers' education and training on proper farming practice, focusing on oestrus detection, reproductive health and timing of breeding, alongside broadening their knowledge on issues related to dairy cattle infertility, including its causes and prevention. This could be achieved by having a Training Board structured to provide

short, practical and hands-on training courses targeting not only farmers but also farm workers.

- Improvement in record keeping, i.e. support and encouragement should be provided to smallholder dairy cattle farmers on simple ways of keeping farm records (e.g. the use of record books or improvisation of digital technologies (such as apps)). This would not only help them know the progress of their herds, but would also improve the tracking of health, breeding and calving events happening on their farms.

  In this regard, it is important to note the results of the whole herd pregnancy testing, which was a far more reliable indicator of herd fertility status than were any of the available records. Hence at the present time, while awaiting the improvement of farm record keeping systems, the best recommended way to determine reproductive performance in smallholder dairy cattle farming in Tanzania is through the determination of pregnancy status. The personnel and infrastructure requirements to implement this recommendation were discussed above.
- Promoting veterinary extension services through expansion of outreaches, particularly stressing the contribution of poor health and management to infertility, alongside offering a timely reproductive health service.
- Improvement of the overall husbandry practices, with a strong focus upon improvement of nutrition and housing. Poor nutrition is generally the limiting factor to dairy production in developing countries, especially where, as in Tanzania, there is inadequate on farm feed reliability and/or conservation to enable cows to lactate in and through the dry season (Maleko et al., 2016).
- Improving AI service delivery and pregnancy diagnosis (PD) could be a key step towards the better reproductive performance in smallholder dairy herds. For instance, timely AI will increase conception rates while early PD (between 28 to 35 days of post services) allows rebreeding and hence shortening the ICI.
- Encouraging farmers to create/join farmers' cooperative organisations, as this will allow them to pool their resources together and hence have power while negotiating for prices, not only for their products, but also for inputs. Also, membership in such initiatives facilitates access to credit from the financial institutions. It is also through cooperatives starting up small milk processing factories (i.e. for refrigerated milk,

butter and cheese) that herd management will be easier than being an individual farmer.

Implementation of all these should consider the regional variations to ensure their relevance and effectiveness. Finally, the dairy farming sector in Tanzania is entering a key development phase, and the insights from the present study should provide a valuable underpinning to that development.

7.12. References

Abbasi, S., & Nawab, K. (2021). Determinants of the Dairy Technology Adoption by the Rural Milk Producers in District Muzaffarabad, Azad Jammu and Kashmir. *Sarhad Journal of Agriculture*, *37*, 921-929. https://doi.org/10.17582/journal.sja/2021/37.3.921.929

Adekoya, A., & Ajayi, M. (2000). An assessment of farmers' awareness and practices of land management techniques in Iddo Local Government Area of Oyo State. *Journal of Environmental Extension*, *1*, 98-104. https://doi.org/https://doi.org/10.4314/jext.v1i1.2724

Ahikiriza, E., Wesana, J., Gellynck, X., van Huylenbroeck, G., & Lauwers, L. (2021). Context specificity and time dependency in classifying sub-Saharan Africa dairy cattle farmers for targeted extension farm advice: the case of Uganda. *Agriculture; Basel*, *11*(9). https://doi.org/10.3390/agriculture11090836

Akzar, R., Umberger, W., & Peralta, A. (2019). Adoption of multiple dairy farming technologies by the Indonesian smallholder dairy farmers: a latent class analysis approach. 2019 Conference (63rd), February 12-15, 2019, Melbourne, Australia. Accessed on 10th August 2025, from https://ideas.repec.org/p/ags/aare19/285094.html,

Allan, F. K., MacVicar, I. S., Peters, A. R., & Schnier, C. (2024). Systematic map of recent evidence on reproductive performance of cattle in Africa. *Tropical Animal Health and Production*, *56*(7), 218. https://doi.org/10.1007/s11250-024-04074-z

Alvåsen, K., Dohoo, I., Roth, A., & Emanuelson, U. (2018). Farm characteristics and management routines related to cow longevity: a survey among Swedish dairy farmers. *Acta Veterinaria Scandinavica*, *60*, 1-11. https://doi.org/https://doi.org/10.1186/s13028-018-0390-8

Banda, L. J., Kamwanja, L. A., Chagunda, M. G. G., Ashworth, C. J., & Roberts, D. J. (2012). Status of dairy cow management and fertility in smallholder farms in Malawi. *Tropical Animal Health and Production*, *44*(4), 715-727. https://doi.org/10.1007/s11250-011-9972-4

Bebe, B. O., Udo, H. M. J., Rowlands, G. J., & Thorpe, W. (2003). Smallholder dairy systems in the Kenya highlands: breed preferences and breeding practices. *Livestock Production Science*, *82*(2), 117-127. https://doi.org/10.1016/S0301-6226(03)00029-0

Berrada, M., Raboisson, D., & Lhermie, G. (2024). Effectiveness of rural internships for veterinary students to combat veterinary workforce shortages in rural areas. *PLoS One*, *19*(3), 1-19. https://doi.org/10.1371/journal.pone.0294651

Birhanu, A., & Samson, L. (2021). Knowledge and preventive practices of livestock farmers on infectious causes of reproductive disorders in dairy cows in the Kembata Tambaro zone, southern Ethiopia. In *Animal Diseases* (Vol. 1, pp. 1-8): BMC. https://doi.org/10.1186/s44149-021-00014-8.

Bravo-Ureta, B. E., & Pinheiro, A. E. (1997). Technical, economic, and allocative efficiency in peasant farming: evidence from the Dominican republic. *Developing Economies*, *35*(1), 48-67. https://doi.org/10.1111/j.1746-1049.1997.tb01186.x

Brett, C. (2019). A new way to boost smallholder dairy productivity in Tanzania. *worldbank. org/voices*. https://blogs.worldbank.org/en/voices/new-way-boost-smallholder-dairy-productivity-tanzania

Brodribb, W., Zadoroznyj, M., & Martin, B. (2016). How do rural placements affect urban-based Australian junior doctors' perceptions of working in a rural area? *Australian Health Review*, *40*(6), 655-660. https://doi.org/10.1071/AH15127

Brown, P., Daigneault, A., & Dawson, J. (2019). Age, values, farming objectives, past management decisions, and future intentions in New Zealand agriculture. *Journal of Environmental Management*, *231*, 110-120. https://doi.org/10.1016/j.jenvman.2018.10.018

Bulcha, G. G., Dewo, O. G., Desta, M. A., & Nwogwugwu, C. P. (2022). Indigenous Knowledge of Farmers in Breeding Practice and Selection Criteria of Dairy Cows at Chora and Gechi Districts of Ethiopia: An Implication for Genetic Improvements. *Veterinary Medicine International*, 1-5. https://doi.org/10.1155/2022/3763724

Cheelo, T., & van der Merwe, M. (2021). What factors influence smallholder farmers' decision to select a milk marketing channel in Zambia? *Agrekon*, *60*(3), 243-252. https://doi.org/10.1080/03031853.2021.1950017

Chenyambuga, S., & Mseleko, K. (2009). Reproductive and lactation performances of Ayrshire and Boran crossbred cattle kept in smallholder farms in Mufindi district, Tanzania. *Livest. Res. Rural Dev*, *21*, 1-7. Accessed on 10th August 2025 from http://lrrd.org/lrrd2021/2027/chen21100.htm.

Chhinh, N., Sok, S., Sou, V., & Nguonphan, P. (2022). Local Engagement in the Agricultural Cooperatives (ACs) Operation in Cambodia. *Sustainability (2071-1050)*, *14*(24), 16515. https://doi.org/10.3390/su142416515

Clark, D. A., Caradus, J. R., Monaghan, R. M., Sharp, P., & Thorrold, B. S. (2007). Issues and options for future dairy farming in New Zealand. *New Zealand Journal of Agricultural Research*, *50*(2), 203-221. https://doi.org/10.1080/00288230709510291

Dairy_Farmer. (2023, Septermber 26). *Cow efficiency is key when working with smaller herds*. Farmers Weekly. Retrieved 2025 August 10 from https://www.farmersweekly.co.nz/farm-management/cow-efficiency-is-key-when-working-with-smaller-herds/?utm_source=chatgpt.com

Du, J., & Jiao, R. J. (2022). Cooperative negotiation in value-driven engineering and systems design: a technical note. *Journal of Engineering Design*, *33*(11), 919-944. https://doi.org/10.1080/09544828.2022.2149179

El-Tahawy, A. S. (2017). Effect of herd size on the productive, reproductive, and economic efficiency of Holstein dairy cows. *Alexandria Journal of Veterinary Sciences*, *55*(1), 21-27. https://doi.org/10.5455/ajvs.277554

Fahey, J., O'Sullivan, K., Crilly, J., & Mee, J. (2002). The effect of feeding and management practices on calving rate in dairy herds. *Animal Reproduction Science*, *74*(3-4), 133-150. https://doi.org/https://doi.org/10.1016/S0378-4320(02)00192-6

Fujisawa, M., Kobayashi, K., Johnston, P., & New, M. (2015). What Drives Farmers to Make Top-Down or Bottom-Up Adaptation to Climate Change and Fluctuations? A Comparative Study on 3 Cases of Apple Farming in Japan and South Africa. *PLoS One*, *10*(3), 1-16. https://doi.org/10.1371/journal.pone.0120563

Gargiulo, J. I., Eastwood, C. R., Garcia, S. C., & Lyons, N. A. (2018). Dairy farmers with larger herd sizes adopt more precision dairy technologies. *Journal of Dairy Science*, *101*(6), 5466-5473. https://doi.org/https://doi.org/10.3168/jds.2017-13324

Girabi, F., & Mwakaje, A. E. G. (2013). Impact of microfinance on smallholder farm productivity in Tanzania: The case of Iramba district. *Asian Economic and Financial Review*, *3*(2), 227, Accessed on August 2024, from https://archive.aessweb.com/index.php/5002/article/view/2988/1471.

Green, E. C. (2001). Can qualitative research produce reliable quantitative findings? *Field Methods*, *13*(1), 3-19. https://doi.org/10.1177/1525822X0101300101

Greyling, J. C., Mdluli, B. B., & Conradie, B. (2023). Farm size and productivity: smallholder dairy production in Eswatini. *Agrekon*, *62*(1), 49-60. https://doi.org/10.1080/03031853.2023.2176896

Gupta, K., & Roy, D. (2012). Gains from coordination in milkfed dairy in Punjab. *Journal of Agribusiness in Developing and Emerging Economies*, *2*, 92-114. https://doi.org/10.1108/20440831211272571

Habanabakize, E., Ba, K., Corniaux, C., Cortbaoui, P., & Vasseur, E. (2022). A typology of smallholder livestock production systems reflecting the impact of the development of a local milk collection industry: case study of Fatick region, Senegal. *Pastoralism: Research, Policy and Practice*, *12*(22). https://doi.org/10.1186/s13570-022-00234-8

Hemme, T., & Otte, J. (2010). *Status and prospects for smallholder milk production: a global perspective. Accessed on 10th August 2025 from http://www.fao.org/3/i1522e/i1522e.pdf*.

Ingabire, M. C., Yonggong, L., Pesha, J. C., & Hardi, A. (2018). Factors affecting adoption of artificial insemination technology by small dairy farmers in Rwanda: A case of Rwamagana District. *Journal of Economics and Sustainable Development*, *9*(12), 46-53. https://core.ac.uk/download/pdf/234648389.pdf.

Israel, B., Majaliwa, D., & Kinala, M. (2022). Contribution of agricultural marketing co-operatives in commercialisation among smallholder maize farmers in Mbozi district, Tanzania. *Journal of Studies in Social Sciences and Humanities*, *8*(1), 98-111.

Jago, J. G., & Berry, D. P. (2011). Associations between herd size, rate of expansion and production, breeding policy and reproduction in spring-calving dairy herds. *Animal*, *5*(10), 1626-1633. https://doi.org/10.1017/S1751731111000516

Jitmun, T., Kuwornu, J. K. M., Datta, A., & Kumar Anal, A. (2020). Factors influencing membership of dairy cooperatives: Evidence from dairy farmers in Thailand. *Journal of Co-operative Organization and Management*, *8*(1). https://doi.org/10.1016/j.jcom.2020.100109

Kanire, E., Msuya, E., & Alphonce, R. (2024). Drivers of dairy farmers' engagement in informal milk markets: Policy implications for developing countries. *Journal of Agriculture and Food Research*, *16*. https://doi.org/10.1016/j.jafr.2024.101128

Kanuya, N., Agger, J., & Pedersen, K. (1997). Assessing the reproductive performance of a Tanzanian dairy herd: the importance of proper record keeping. *Tanzania Veterinary Journal*, *17*(3), 63-71.

Kanuya, N., Kessy, B., Bittegeko, S., Mdoe, N., & Aboud, A. (2000). Suboptimal reproductive performance of dairy cattle kept in smallholder herds in a rural highland area of northern Tanzania. *Preventive Veterinary Medicine*, *45*(3-4), 183-192. https://doi.org/https://doi.org/10.1016/S0167-5877(00)00134-3

Kanuya, N., Mlangwa, J., & Shoo, J. (2014). Constraints associated with the use of Artificial Insemination (AI) and Natural Service (NS) in smallholder dairy herds in Tanga and Morogoro, Tanzania. *Tanzania Veterinary Journal*, *29*(1), 9-20.

Karen, M., John, P. G., Okeyo, M., Joram, M. M., Aynalem, H., Tesfaye, G., Raphael, M., & Stephen, J. K. (2019). Livestock Genomics for Developing Countries – African Examples in Practice. In *Frontiers in Genetics* (Vol. 10): Frontiers Media S.A.

Kashoma, I., & Ngou, A. (2023). Insight into the adoption and success of artificial insemination services in smallholder dairy farming systems: A cross-sectional study. *Tanzania Veterinary Journal*, *38*(1). https://doi.org/10.4314/tvj.v38i1.1

Khanal, A. R. (2010). *Adoption of Breeding Technologies in the US Dairy Industry and their influences on Farm Profitability*. Louisiana State University and Agricultural & Mechanical College.

Kivaria, F., Noordhuizen, J., & Kapaga, A. (2006b). Prospects and constraints of smallholder dairy husbandry in the Dar es Salaam region, Tanzania. *Outlook on Agriculture*, *35*(3), 209-215. https://doi.org/https://doi.org/10.5367/000000006778536819

Kurwijila, L. (1995). Milk Marketing and processing options for smallholder dairy co-operative organisations: the case of Serengeti and Mwakaleli dairy co-operatives in Tanzania.

Kusiluka, L., Karimuribo, E., Mdegela, R., Kampaga, A., Bundala, A., Kivaria, F., Kabula, B., Manjurano, A., Turuka, F., & Loken, T. (2006). Constraints associated with production in smallholder dairy farms in the eastern coastal zone of Tanzania. *Bulletin of animal health and production in Africa*, *54*(4), 286-296. https://doi.org/https://doi.org/10.4314/bahpa.v54i4.32779

Launiala, A. (2009). How much can a KAP survey tell us about people's knowledge, attitudes and practices? Some observations from medical anthropology research on malaria in pregnancy in Malawi. *Anthropology Matters*, *11*(1).

Lilian, K., Louise, M., Henrietta, L. M., Johanna, F. L., Gizachew, G., Adane, M., Stefan, B., James, L. N. W., & Ndungu, S. N. (2023). Adoption of dairy technologies in smallholder dairy farms in Ethiopia. In *Frontiers in Sustainable Food Systems* (Vol. 7): Frontiers Media S.A.

Lobago, F., Bekana, M., Gustafsson, H., & Kindahl, H. (2006). Reproductive performances of dairy cows in smallholder production system in Selalle, Central Ethiopia. *Tropical Animal Health and Production*, *38*(4), 333-342. https://doi.org/10.1007/s11250-006-4328-1

Löf, E., Gustafsson, H., & Emanuelson, U. (2007). Associations Between Herd Characteristics and Reproductive Efficiency in Dairy Herds. *Journal of Dairy Science*, *90*(10), 4897-4907. https://doi.org/10.3168/jds.2006-819

Lyimo, Z., Nkya, R., Schoonman, L., & Van Eerdenburg, F. (2004). Post-partum reproductive performance of crossbred dairy cattle on smallholder farms in sub-humid coastal Tanzania. *Tropical Animal Health and Production*, *36*(3), 269-279.

Ma, J., Burgers, E. E., Kok, A., Goselink, R. M., Lam, T. J., Kemp, B., & van Knegsel, A. T. (2022). Consequences of extending the voluntary waiting period for insemination on reproductive performance in dairy cows. *Animal Reproduction Science*, *244*, 107046. https://doi.org/https://doi.org/10.1016/j.anireprosci.2022.107046

Ma, W., & Abdulai, A. (2016). Does cooperative membership improve household welfare? Evidence from apple farmers in China. *Food Policy*, *58*, 94-102. https://doi.org/10.1016/j.foodpol.2015.12.002

Makala, A. (2017). *Mbeya region inverstment opportunities*. Mbeya Region: Regional Commissioner, Mbeya Retrieved from https://mbeya.go.tz/storage/app/media/uploaded-files/mbeya%20region.pdf

Makate, C., & Mango, N. (2017). Diversity amongst farm households and achievements from multi-stakeholder innovation platform approach: lessons from Balaka Malawi. *Agriculture & Food Security*, *6*(1), 37.

Makate, M., Ledwith, T., Robinson, S., Broderick, I., Miller, S., & Bell, J. (2021). Training and retention in rural and remote Australia: Examining the association between GP vocational training placements and subsequent practice location in Western Australia. *Journal of Rural Studies*, *86*, 346-356. https://doi.org/10.1016/j.jrurstud.2021.06.019

Maleko, D., Msalya, G., Mwilawa, A., Pasape, L., & Mtei, K. (2018a). Smallholder dairy cattle feeding technologies and practices in Tanzania: failures, successes, challenges and prospects for sustainability. *International Journal of Agricultural Sustainability*, *16*(2), 201-213. https://doi.org/10.1080/14735903.2018.1440474

Maleko, D., Msalya, G., Mwilawa, A., Pasape, L., Owiro, N., Ochuodho, J., Rachuonyo, H., Gohole, L., Tarus, J., & Ooko, L. (2016). Overview of feed resources condition and feeding practices among the smallholder dairy farmers in Tanzania. Fifth African Higher Education Week and RUFORUM Biennial Conference 2016," Linking agricultural universities with civil society, the private sector, governments and other stakeholders in support of agricultural development in Africa, Cape Town", South Africa, 17-21 October 2016,

Maleko, D., Ng, W.-T., Msalya, G., Mwilawa, A., Pasape, L., & Mtei, K. (2018b). Seasonal variations in the availability of fodder resources and practices of dairy cattle feeding among the smallholder farmers in Western Usambara Highlands, Tanzania. *Tropical Animal Health and Production*, *50*(7), 1653-1664. https://doi.org/10.1007/s11250-018-1609-4

Manderson, L., & Aaby, P. (1992). An epidemic in the field? Rapid assessment procedures and health research. *Social Science & Medicine*, *35*(7), 839-850. https://doi.org/10.1016/0277-9536(92)90098-B

Markelova, H., Meinzen-Dick, R., Hellin, J., & Dohrn, S. (2009). Collective action for smallholder market access. *Food Policy*, *34*(1), 1-7. https://doi.org/10.1016/j.foodpol.2008.10.001

Masuku, B., Masuku, M., & Belete, A. (2014). Economic efficiency of smallholder dairy farmers in Swaziland: An application of the profit function. *Journal of Agricultural Studies*, *2*(2), 132-146.

Mbesa, B., Makindara, J., Kadigi, M., Majubwa, R., & Madege, R. (2024). Effect of training on knowledge, attitude, and practice on the use of hermetic storage technologies among smallholder farmers in Tanzania. *African Journal of Empirical Research*, *5*(2), 881–893-881–893.

Mbwambo, N., Nigussie, K., & Stapleton, J. (2019). Dairy development in the Tanzanian livestock master plan. *Gates Open Res*, *3*(628), 628. https://doi.org/https://doi.org/10.21955/gatesopenres.1115533.1

McDermott, Staal, S., Freeman, H., Herrero, M., & Van de Steeg, J. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science*, *130*(1-3), 95-109. https://doi.org/https://doi.org/10.1016/j.livsci.2010.02.014

McGrail, M. R., Gurney, T., Fox, J., Martin, P., Eley, D., Nasir, B., & Kondalsamy-Chennakesavan, S. (2023). Rural medical workforce pathways: exploring the importance of postgraduation rural training time. *Human Resources for Health*, *21*(31). https://doi.org/10.1186/s12960-023-00819-3

Mecıtoglu, G. Y. (2022). The effect of early or late breeding on milk production in high producing lactating dairy cows. *Livestock Studies*, *62*(1), 1-6. https://doi.org/https://doi.org/10.46897/livestockstudies.1077787

Michael, S., Mbwambo, N., Mruttu, H., Dotto, M., Ndomba, C., da Silva, M., Makusaro, F., Nandonde, S., Crispin, J., & Shapiro, I. (2018). Tanzania Livestock Master Plan (2017/2018-2021/2022). *United Republic of Tanzania, Ministry of Livestock and Fisheries*.

Morin, D. E., Molgaard, L., Royster, E., Johnson-Walker, Y. J., & Fetrow, J. (2020). Prior Experience, Career Intentions, and Post-Graduate Positions of Veterinary Students Who Participated in an 8-week Dairy Production Medicine Course. *Journal of Veterinary Medical Education*, *47*(3), 275-289. https://doi.org/10.3138/jvme.1117-163r

Munira, S., Romance, M., Khan, M. U., Kabir, A., Rahman, M. M., Sarder, M. J. U., & Haque, M. H. (2023). Genetic and Managerial Factors Affecting the Conception Rate of Cows in Rajshahi City Corporation Area of Bangladesh. *European Journal of Veterinary Medicine*, *3*(5), 5-10. https://doi.org/https://doi.org/10.24018/ejvetmed.2023.3.5.113

Mwampaghale, A. A., & Mbogo, C. (2023). Challenges facing accessibility of agriculture financing in Tanzania: a case study of TIB development bank limited and CRDB Bank PLC. *International Journal of Research and Innovation in Social Science*, *7*(3), 1222-1242.

Mwanga, G., Mujibi, F., Yonah, Z., & Chagunda, M. (2019). Multi-country investigation of factors influencing breeding decisions by smallholder dairy farmers in sub-Saharan Africa. *Tropical Animal Health and Production*, *51*, 395-409. https://doi.org/https://doi.org/10.1007/s11250-018-1703-7

Njombe, A., Msanga, Y., Mbwambo, N., & Makembe, N. (2011, 25-27 May). The Tanzania dairy industry: Status, opportunities and prospects. 7th African Dairy Conference and Exhibition held at Moven Pick Palm Hotel,

Nyamushamba, G. B., Mapiye, C., Tada, O., Halimani, T. E., & Muchenje, V. (2017). Conservation of indigenous cattle genetic resources in Southern Africa's smallholder areas: turning threats into opportunities — A review. In *Asian-Australasian journal of animal sciences* (Vol. 30, pp. 603-621): Asian-Australasian Association of Animal Production Societies.

Nyange, D., & Mdoe, N. (1995). Dairy industry in Tanzania and the prospect for small scale milk producers. Workshop on Strategies for Market Orientation of Small Scale Milk Producers and their Organisations, Morogoro (Tanzania), 20-24 Mar 1995,

Nyunza, G., & Mwakaje, A. G. (2012). Analysis of Round Potato Marketing in Tanzania. *International Journal of Business and Social Science*, *3*(23).

Ohashi, T., Saijo, M., Suzuki, K., & Arafuka, S. (2024). From conservatism to innovation: The sequential and iterative process of smart livestock technology adoption in Japanese small-farm systems. *Technological Forecasting & Social Change*, *208*. https://doi.org/10.1016/j.techfore.2024.123692

Okeyo, M., Olivier, H., Young-Jun, K., & Seoae, C. (2015). African Indigenous Cattle: Unique Genetic Resources in a Rapidly Changing World. In *Asian-Australasian journal of animal sciences* (Vol. 28, pp. 911-921): Asian-Australasian Association of Animal Production Societies.

Oleggini, G. H., Ely, L. O., & Smith, J. W. (2001). Effect of Region and Herd Size on Dairy Herd Performance Parameters. *Journal of Dairy Science*, *84*(5), 1044-1050. https://doi.org/10.3168/jds.S0022-0302(01)74564-X

Olson, F., Schweiss, K., Gutierrez, K., & DeBalsi, B. (2023). Cooperatives: Rethinking the Epic Tale of a Radical Venture Form. In *Bleeding-Edge Entrepreneurship: Digitalization, Blockchains, Space, the Ocean, and Artificial Intelligence* (Vol. 16, pp. 117-136): Emerald Publishing Limited.

Österman, S., & Bertilsson, J. (2003). Extended calving interval in combination with milking two or three times per day: effects on milk production and milk composition. *Livestock Production Science*, *82*(2-3), 139-149.

Peng, Y., Wang, H. H., & Zhou, Y. (2022). Can cooperatives help commercial farms to access credit in China? Evidence from Jiangsu Province. *Canadian Journal of Agricultural Economics*, *70*(4), 325-349. https://doi.org/10.1111/cjag.12320

Phakathi, S., & Sinyolo, S. (2025). Integrating Indigenous and Modern Knowledge Systems for Household Food Security in the Smallholder Irrigation Schemes in South Africa. In *Integrating Indigenous and Scientific Knowledge for Sustainable Food Systems in Africa: The Plug-In Principle* (pp. 29-46). Springer.

Posey, R. D., Hoffsis, G. F., Cullor, J. S., Naylor, J. M., Chaddock, M., & Ames, T. R. (2012). Preparing Students for Careers in Food-Supply Veterinary Medicine: A Review of Educational Programs in the United States. *Journal of Veterinary Medical Education*, *39*(3), 257-262. https://doi.org/10.3138/jvme.0112-012R

Rowarth, J. S. (2013). Dairy cows: economic production and environmental protection. *Ecosystem services in New Zealand-conditions and trends. Manaaki Whenua Press, Lincoln, NZL*, 85-93.

Schooman, L., & Swai, E. (2011). Marketing, handling and physical quality of raw marketed milk in Tanga region of Tanzania. *Livestock Research for Rural Development*, *23*(9), 13-19.

Seal, A. N., Playford, D., McGrail, M. R., Fuller, L., Allen, P. L., Burrows, J. M., Wright, J. R., Bain-Donohue, S., Garne, D., Major, L. G., & Luscombe, G. M. (2022). Influence of rural clinical school experience and rural origin on practising in rural communities five and eight years after graduation. *Medical Journal of Australia*, *216*(11), 572-577. https://doi.org/10.5694/mja2.51476

Shalloo, L., Cromie, A., & McHugh, N. (2014). Effect of fertility on the economics of pasture-based dairy systems. *Animal*, *8*, 222-231. https://doi.org/10.1017/S1751731114000615

Swai, E., Kyakaisho, P., & Ole-Kawanara, M. (2007). Studies on the reproductive performance of crossbred dairy cows raised on smallholder farms in eastern Usambara mountains, Tanzania. *Livestock Research for Rural Development*, *19*(5), Article 61. https://doi.org/http://www.lrrd.org/lrrd19/5/swai19061.htm

Swai, E., Mollel, P., & Malima, A. (2014). Some factors associated with poor reproductive performance in smallholder dairy cows: the case of Hai and Meru districts, Northern Tanzania. *Livestock Research for Rural Development*, *26*(6), 1-2.

Swai, E. S., & Karimuribo, E. D. (2011). Smallholder Dairy Farming in Tanzania. *Outlook on Agriculture*, *40*(1), 21-27. https://doi.org/10.5367/oa.2011.0034

Thornton, P. K., Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., & Toulmin, C. (2010). Livestock production: recent trends, future prospects. *Philosophical Transactions of the Royal Society B. Biological Sciences*, *365*(1554), 2853-2867. https://doi.org/10.1098/rstb.2010.0134

Toiba, H., Rahman, M. S., Hartono, R., & Retnoningsih, D. (2024). Improving dairy farmers' welfare in Indonesia: Does cooperative membership matter? *Annals of Public & Cooperative Economics*, *95*(4), 1003-1019. https://doi.org/10.1111/apce.12471

Uotila, M., & Dhanapala, S. (1994). Dairy development through cooperative structure.

Urio, N. A. (1986). On-farm research on utilization of crop residues by smallholder dairy farmers in Hai district, Tanzania. *Towards Optimal Feeding of Agricultural Byproducts to Livestock in Africa*, 17.

Usman, O. A., Abel, B. E., Erika, G., Abubakar Bala, M., Ana, M., Roberto, M. L. R., Aliyu, W., Bryony, A., Erik, M., Ruth, A., Gabriel, V., & Alasdair, J. C. C. (2020). Knowledge, Attitudes and Practices of Veterinarians Towards Antimicrobial Resistance and Stewardship in Nigeria. In *Antibiotics* (Vol. 9, pp. 453-453): MDPI AG.

Vries, A. d. (2006). Economic value of pregnancy in dairy cattle. *Journal of Dairy Science*, *89*(10), 3876-3885. https://doi.org/10.3168/jds.S0022-0302(06)72430-4

Vyas, D., Nelson, C. D., Bromfield, J. J., Liyanamana, P., Krause, M., & Dahl, G. E. (2020). MILK Symposium review: Identifying constraints, opportunities, and best practices for improving milk production in market-oriented dairy farms in Sri Lanka. *Journal of Dairy Science*, *103*(11), 9774-9790. https://doi.org/10.3168/jds.2020-18305

Williamson, M., Wilson, R., McKechnie, R., & Ross, J. (2012). Does the positive influence of an undergraduate rural placement persist into postgraduate years? *Rural and Remote Health*, *12*(2), 177-185. https://doi.org/https://search.informit.org/doi/epdf/10.3316/informit.346032927862484

Appendix One

Dairy Cattle Infertility Survey Questionnaire

Consent Statement

1. **English version**

KAP SURVEY – Smallholder Dairy Cattle Infertility

INTRODUCTION

Hello, my name is Athanas Ngou, a PhD student from Massey University. I am conducting a study to better understand infertility in dairy cattle and how smallholder dairy farmers perceive and manage this issue. I would like to ask you a few questions about your knowledge, attitudes, and practices (KAP) regarding dairy cattle infertility. This survey will take approximately 30 minutes to complete. It is confidential, i.e. your name and address will only be recorded for possible future follow-up but will not be linked to your responses. Participation is entirely voluntary. You may choose to skip any question or stop the interview at any time without penalty.

Do you agree to participate in this survey?

☐ Yes ☐ No

(If "No", please stop the interview. End of survey)

PURPOSE OF THE SURVEY

The purpose of this KAP survey is to assess how smallholder dairy farmers understand and respond to dairy cattle infertility. The study aims to identify knowledge gaps, attitudes, and on-farm practices related to infertility, and to explore how farmers protect their animals from infertility-related risks. The information collected will help guide future education and intervention efforts. Once the findings are available, we plan to use them to inform community discussions and share results with key stakeholders such as the Ministry of Livestock and Fisheries Development, community leaders, and farmer groups. Our goal is to support positive changes in dairy management and improve reproductive performance in smallholder dairy herds.

2. Kiswahili version

DODOSO LA KAP – Ugumba/Utasa kwa Ng'ombe wa Maziwa wa Wafugaji Wadogo

UTANGULIZI

Habari! Jina langu ni **Athanas Ngou**, mwanafunzi wa Shahada ya Uzamivu (PhD) kutoka Chuo Kikuu cha Massey, New Zealand. Ninafanya utafiti ili kuelewa vizuri tatizo la ugumba/utasa kwa ng'ombe wa maziwa, na namna wafugaji wadogo wanavyolielewa na kulikabili. Ningependa kukuuliza maswali machache kuhusu uelewa, mtazamo na mienendo yako (KAP) kuhusu ugumba/utasa wa ng'ombe wa maziwa. Dodoso hili litachukua takribani dakika 30 kukamilika. Maelezo yako yatabaki kuwa ya siri – jina na anwani yako zitatumika kwa ajili ya ufuatiliaji wa baadaye tu, lakini hayatatajwishwa pamoja na majibu yako. Ushiriki wako ni wa hiari kabisa. Unaweza kuamua kutojibu swali lolote au kusitisha ushiriki wakati wowote bila madhara yoyote.

Je, unakubali kushiriki katika dodoso hili?

☐ Ndiyo ☐ Hapana

(Kama jibu ni "Hapana", tafadhali sitisha mahojiano. Mwisho wa dodoso)

LENGO LA DODOSO

Lengo la dodoso hili ni kutathmini namna wafugaji wadogo wa ng'ombe wa maziwa wanavyoelewa na kushughulikia tatizo la ugumba/utasa kwa ng'ombe. Utafiti huu unalenga kubaini pengo la maarifa, mitazamo, na tabia zinazofanyika shambani kuhusu ugumba/utasa, pamoja na kuchunguza jinsi wafugaji wanavyolinda mifugo yao dhidi ya athari za ugumba/utasa. Taarifa zitakazokusanywa zitatumika kuelekeza juhudi za mafunzo na uingiliaji wa kisera kwa siku za mbele. Mara matokeo yatakapopatikana, tutayatumia kuanzisha majadiliano ya kijamii, na kuyawasilisha kwa wadau muhimu kama vile Wizara ya Mifugo na Uvuvi, viongozi wa jamii, na vikundi vya wafugaji. Lengo kuu ni kuchochea mabadiliko chanya katika usimamizi wa ng'ombe wa maziwa na kuboresha uzazi katika mashamba ya wafugaji wadogo.

Section A: Farmer demographics (Please check the box of your preferred answer)

1. Who is the head of the family?
   a) ☐Father
   b) ☐Mother
   c) ☐Other
2. Please specify if you have selected other. ……………………….
3. What is the type of your family?
   a) ☐Monogamy
   b) ☐Polygamy
   c) ☐Single parent
   d) ☐Widow
   e) ☐Widower
   f) ☐Single
4. Are you the sole person responsible for making decision on-farm management?
   a) ☐Yes
   b) ☐No

Section B: Farming information

5. What is the size of your farm size (number of cattle)?
   a) ☐1-2 cattle
   b) ☐3-4 cattle
   c) ☐5-6 cattle
   d) ☐7-8 cattle
   e) ☐9-10 cattle
   f) ☐≥10 cattle
6. How many people are looking after the animals? ……………
7. Please specify the details of all the people looking after animals

S/N	Name	Sex (M/F)	Age (years)	Duty/position (Father, Mother, Child Relative, Employee)	Family /Employee	Involvement (Part/ Full-time)	Experience (months/years)	Highest education (STD 7, O – Level, A – Level, College, University or No formal education)

8. How long have you been in the dairy industry?
   a) ☐0< 1 year
   b) ☐1-5 years
   c) ☐5-10years
   d) ☐10-15 years
   e) ☐>15 years
9. What was the source of your first dairy cow?
   a) ☐Cash purchase.
   b) ☐Gift from relatives or friends.
   c) ☐NGO/government schemes, i.e. HIT.
   d) ☐Commercial banks
   e) ☐Home bred.
   f) ☐Home bred + purchase.
   g) ☐Others
10. Please specify if you have selected other. ……………………………..
11. Is dairy farming your primary source of income?
    a) ☐Yes
    b) ☐No

12. If the answer above is No, what other sources of income do you have? (Please circle the preferred answer)

Income Source	**Major**	**Moderate**	**Minor**	**Not at all**
Crop farming	1	2	3	4
Business	1	2	3	4
Employment	1	2	3	4

13. Do you have other animal species on the farm?
    a) ☐Yes
    b) ☐No
14. If yes, name them, please: ……………………
15. Which dairy breeds do you have?
    a) ☐Friesian
    b) ☐Jersey
    c) ☐Ayrshire
    d) ☐Crosses
    e) ☐Others
16. Please list other breeds present in your farm. ……………………………………
17. Composition of the cattle on the farm (please write their number)

Category	Number
Cows	
Heifers	
Bulls	
Others (please specify):	

18. How do you milk your cows?
    a) ☐Hand milking
    b) ☐Machine
    c) ☐Both
    d) ☐Not started
19. How many calves do you expect per year? ………………
20. At what age do you wean your calves?
    a) ☐2 months
    b) ☐3 months
    c) ☐Four months
    d) ☐≥ 5 months
    e) ☐Never had one
21. Have you ever attended a course on dairy farming (husbandry and disease control)?
    a) ☐Yes
    b) ☐No
22. If yes, when was the training conducted?
    a) ☐<1 year ago
    b) ☐1-2 years ago
    c) ☐3-4 years ago
    d) ☐5 years ago
    e) ☐>5 years ago

23. Can you rank the general constraints of dairy farming? (Please circle the preferred answer)

Constraint	Very highly significant	Important	Moderate	Minor	Of little importance	Not at all
Unavailability of feeds (quantity and quality)	1	2	3	4	5	6
Lack of money to buy inputs	1	2	3	4	5	6
Lack of enough land	1	2	3	4	5	6
Unpredictable milk market	1	2	3	4	5	6
Diseases	1	2	3	4	5	6
Unavailability of breeding service (bulls/AI)	1	2	3	4	5	6
High cost of inputs	1	2	3	4	5	6

Section C. Breeding practice and heat detection

24. Do you have any cattle breed preference?
    a) ☐Yes
    b) ☐No
25. If yes, please list your priorities. …………………
26. Which features do you consider while selecting a breed? (Please circle the preferred answer)

Feature	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Milk production	1	2	3	4	5
Disease resistance	1	2	3	4	5
Body size (Small or large)	1	2	3	4	5
Easy handling	1	2	3	4	5
Easy to conceive	1	2	3	4	5

27. Which breeding method do you use in your farm?
    a) ☐Natural service
    b) ☐Artificial insemination
    c) ☐Both
28. If using natural service, who owns the bull?
    a) ☐Myself
    b) ☐Neighbours
    c) ☐Community bulls
    d) ☐Other
29. Please specify other bull owners (if selected other in Qn 28). ………………………
30. If using AI, how easy do you get the service.
    a) ☐Immediately after calling the AI technicians.
    b) ☐Regularly
    c) ☐Irregular with some interruptions on weekends and holidays
    d) ☐Other
31. Please specify, how easy to get the AI service (if selected other in Qn 30). ……………………….

32. How long does it take for the AI technician to arrive at your farm after requesting the service?
    a) ☐1 to 3 hours
    b) ☐4 to 6 hours
    c) ☐7 to 9 hours
    d) ☐10 to 12 hours
    e) ☐More than 12 hours
33. How often do cows come on heat?
    a) ☐Every 7 days
    b) ☐Every 14 days
    c) ☐Every 21 days
    d) ☐Every 28 days
    e) ☐Don't know.
    f) ☐Other
34. Please specify the time. ……………………………………..
35. Which heat signs do you normally observe before breeding your cattle? (Please circle the preferred answer)

Sign	**Most observed**	**Observed**	**Sometimes observed**	**Not observed**
Mounting others	1	2	3	4
Stand to be mounted	1	2	3	4
Vulva discharge	1	2	3	4
Bellowing (noise making)	1	2	3	4
Restless	1	2	3	4
Sleeping	1	2	3	4
Off fed	1	2	3	4
Milk drop	1	2	3	4
Other	1	2	3	4

36. Other heat sign observed (please list). ……………………………………….
37. What are the constraints for successful breeding in your farm? (Please circle the preferred answer)

Constraint	**Major**	**Moderate**	**Minor**	**Not at all**	**Never used**
Unavailability of AI service	1	2	3	4	5
Unavailability of Bull	1	2	3	4	5
Poor heat detection	1	2	3	4	5
Cow not showing heat	1	2	3	4	5
High breeding cost	1	2	3	4	5
Bull located at far distance	1	2	3	4	5
Other	1	2	3	4	5

38. Please list other constraints for successful breeding in your farm. ………………………………..
39. Where do you normally monitor your cows for heat detection?
    a) ☐At paddocks
    b) ☐At milking pallor
    c) ☐In house

40. How frequently do you monitor your cattle for heat detection?
    a) ☐Once per day
    b) ☐Twice a day
    c) ☐Once per month
    d) ☐Not checking at all
    e) ☐Other
41. Please specify other frequency for heat observation. ……………………………………………

Section D. Farm feeding and nutrition

42. Which cattle rearing system you are using?
    a) ☐Intensive
    b) ☐Extensive
    c) ☐Semi intensive
    d) ☐Other
43. Please specify the other rearing system. ……………………………………………………………
44. What is the source(s) of feed for your cattle? (Please circle the preferred answer)

Source of feed	**Major**	**Moderate**	**Minor**	**Not at all**
Fodder plot at farm	1	2	3	4
Cut fodder from outside	1	2	3	4
Bought fodder	1	2	3	4
Crop residues	1	2	3	4
Natural pastures (roadside and swamp areas)	1	2	3	4
Conserved feeds (hay + silage)	1	2	3	4
Grazing and stall feeding	1	2	3	4

45. What are you feeding your animals during the dry/wet season? (Please check your preference)

Feed type		**Wet season**	**Dry season**
a)	Grasses		
b)	Concentrates		
c)	Minerals		
d)	Silage		
e)	Other		

46. Please specify the other type of feed. ……………………………………..

47. Do you supplement your dairy cattle?
    a) ☐Yes
    b) ☐No

48. If yes, which supplement do you give? (Please circle the preferred answer)

Feed supplement	Major	Moderate	Minor	Not at all
Mineral concentrate	1	2	3	4
Energy concentrate	1	2	3	4
Protein concentrate	1	2	3	4
Other	1	2	3	4

49. What is the source of concentrate you feed your animals? (Please circle the preferred answer)

Source	Major	Moderate	Minor	Not at all
Homemade / compounded at home	1	2	3	4
Buy from vendors	1	2	3	4
Other	1	2	3	4

50. Please specify the other sources of concentrates. ………………………………………………

51. Which group of cattle do you normally supplement? (Please circle the preferred answer)

Cattle group	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Dry cows	1	2	3	4	5
Lactating cows	1	2	3	4	5
Pregnant heifers	1	2	3	4	5
Sick cows	1	2	3	4	5

Section E. Farmers knowledge and attitude on dairy cattle infertility

52. In your opinion, which of the following statements defines infertility? (Please circle the preferred answer)

Definition	Correct	Incorrect	Not sure
Reduced fertility	1	2	3
Failure to produce calf per year	1	2	3
Producing small amount of milk	1	2	3
Abortion	1	2	3
Retained foetal membranes	1	2	3
Death	1	2	3
Stillbirths	1	2	3
Diarrhoea	1	2	3
Purulent valvular discharges	1	2	3
Suffering from reproductive diseases	1	2	3

Suffering from mastitis	1	2	3
Dystocia	1	2	3
Repeat breeding	1	2	3

53. Have you ever encountered infertility in your farm?
    a) ☐Yes
    b) ☐No
    c) I don't know.
54. If yes, which have you experienced? (Please circle the preferred answer)

Encountered infertility	**Major**	**Moderate**	**Minor**	**Not at all**
Reduced fertility	1	2	3	4
Failure to produce calf per year	1	2	3	4
Producing small amount of milk	1	2	3	4
Abortion	1	2	3	4
Suffering from reproductive diseases	1	2	3	4
Diarrhoea	1	2	3	4
Suffering from mastitis	1	2	3	4
Dystocia	1	2	3	4
Retained foetal membranes	1	2	3	4
Stillbirths	1	2	3	4
Death	1	2	3	4
Repeat breeding	1	2	3	4

55. Do you consider infertility as a problem in your farm?
    a) ☐Yes
    b) ☐No
56. If yes (question above), to what extent? (please circle the preferred answer)
    a) ☐Major
    b) ☒Moderate
    c) ☐Minor
    d) ☐Not at all

57. In your opinion, which of these are causes of infertility? (Please circle the preferred answer)

Cause	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Improper farm record keeping	1	2	3	4	5
Diseases	1	2	3	4	5
Poor nutrition and housing	1	2	3	4	5
Poor oestrus detection	1	2	3	4	5
Proper calf rearing	1	2	3	4	5
Uterine infections	1	2	3	4	5
Embryonic or foetal mortality	1	2	3	4	5
Mycotoxins	1	2	3	4	5
Use of pedigree bulls	1	2	3	4	5
Improper use of hormones, i.e. PGF2α	1	2	3	4	5

58. Which type of cattle are mostly affected by infertility? (Please circle the preferred answer)

Cattle group	Mostly	Somehow	Not at all
Cows	1	2	3
Heifers	1	2	3
Bulls	1	2	3
Calves	1	2	3

59. Which breed of dairy cattle on your farm is more prone to infertility? (Please circle the preferred answer)

Breed	Mostly	Somehow	Not at all
Friesian	1	2	3
Ayrshire	1	2	3
Jersey	1	2	3
Indigenous	1	2	3
Crossbreed	1	2	3

60. What are the signs of infertility you normally experience in your farm? (Please circle the preferred answer)

Sign	Correct	Incorrect	Not sure
Anoestrus	1	2	3
Uterine infections	1	2	3

Diarrhoea	1	2	3
Purulent valvular discharge	1	2	3
Abortion	1	2	3
Retained foetal membranes	1	2	3
Suffering from mastitis	1	2	3
Stillbirths	1	2	3
Dystocia	1	2	3
Reduced milk production	1	2	3
Repeat breeding	1	2	3

61. What are pre-disposing factors of infertility in dairy cattle? (Please circle the preferred answer)

Factor	**Major**	**Moderate**	**Minor**	**Not at all**
Premature breeding of heifers	1	2	3	4
Use of incompetence AI technician	1	2	3	4
Use of incompetence bull	1	2	3	4
Old age	1	2	3	4
Poor nutrition	1	2	3	4
Lack of regular reproductive check	1	2	3	4

62. In which season of the year, you are most likely to encounter infertility in your farm?
    a) ☐Dry season
    b) ☐Wet season
63. What are the impacts of infertility in dairy cattle? (Please circle the preferred answer)

Impact	**Major**	**Moderate**	**Minor**	**Not at all**
Failure to produce calf in a year	1	2	3	4
Increased production costs	1	2	3	4
Fast growth	1	2	3	4
Reduced milk production	1	2	3	4
Culling	1	2	3	4
Death	1	2	3	4

64. What do you do when you have an infertile cow in your farm?

Action	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
Sell to other farmers	1	2	3	4	5

Slaughter the animal	1	2	3	4	5
Treat the animal by myself	1	2	3	4	5
Report to the veterinary service provider	1	2	3	4	5

Section F. Farmers practice on dairy cattle infertility

65. Do you have veterinary service in your farm?
    a) ☐Yes
    b) ☐No
66. If yes, who is providing the service? (Please circle the preferred answer)

Service provider	Major	Moderate	Minor	Not at all
Veterinarian	1	2	3	4
Vet Paraprofessional	1	2	3	4
Vet-paraprofessional assistant	1	2	3	4
Community animal health worker (CAW)	1	2	3	4

67. Which veterinary services you normally obtain from the service provider? (Please circle the preferred answer)

Service	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Disease management	1	2	3	4	5
Reproductive health check	1	2	3	4	5
Artificial Insemination	1	2	3	4	5
Routine procedures, e.g. dehorning, deworming and hoof trimming	1	2	3	4	5

68. Have you ever managed infertility by using traditional method(s)?
    a) ☐Yes
    b) ☐No
69. If yes, which traditional method(s) have you used? (Please list them). ……………………………….
70. What do you do to prevent infertility in your farm? (Please circle the preferred answer)

Preventive measure	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Proper farm record keeping	1	2	3	4	5
Use of artificial insemination	1	2	3	4	5
Routine reproductive examination	1	2	3	4	5
Use programmed breeding, i.e. use of hormones	1	2	3	4	5
Disease prevention/control	1	2	3	4	5

Proper breeding programme	1	2	3	4	5
Proper feeding	1	2	3	4	5

Section G: Farm address

1. Farm no: ………………………….
2. Farm/ owner name: ……………………………….
3. Physical address:
    - Region: …………………………………………………
    - District: …………………………………………………
    - Ward: ……………………………………………………
    - Village/street: ………………………………………
4. Mobile number: ………………………………………..……
5. Location:
    - Latitude (x. y °)
    - Longitude (x. y °)
    - Altitude (m)
    - Accuracy (m)
6. WhatsApp no: …………………………………
7. Email: ……………………………………..……………
8. Location (GPS): ……………………………………………

THANK YOU

END OF SURVEY