



Research Article

Reproductive Performance of Artificially Inseminated Dairy Cattle Under Smallholder Management Systems in Dodoma City Council, Tanzania

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Abstract

This study assessed the reproductive performance of dairy cattle bred through artificial insemination (AI) under smallholder management conditions in Dodoma City Council, Tanzania. Records from 200 cows were used to estimate the conception rate (CR), while a subset of 128 cows with complete reproductive records was used to evaluate the calving interval (CI), the number of services per conception (NSC), and the days open (DO). Overall mean NSC, CI, DO, and CR were 1.61, 470.80 days, 111.55 days, and 59.91%, respectively. Season of insemination, breed group, and parity significantly affected NSC ($p < 0.05$). Cows inseminated during the dry season required more services per conception than those inseminated during the wet season (IRR = 1.34, $p < 0.001$). Parity and breed group significantly affected CI, with cows in parity ≥ 5 having longer calving intervals (510.01 ± 68.23 days) than first-parity cows (420.63 ± 29.74 days; $p < 0.001$). Local cattle had the longest CI (574.50 ± 78.79 days), whereas Friesian cows had the shortest CI, (433.00 ± 17.89 days). Higher-parity cows also had longer DO ($p < 0.05$). CR was significantly associated with breed group, although the Jersey estimate should be interpreted cautiously because of the small sample size. These findings indicate that reproductive performance under smallholder AI systems is influenced by both animal-related and management-related factors particularly breed group, parity, and seasonal conditions.

Keywords

Artificial Insemination, Reproductive Performance, Calving Interval, Days Open, Smallholder Dairy Systems, Tanzania

1. Introduction

Tanzania has one of the largest cattle populations in Africa, estimated at 37.9 million head, of which approximately 98% are indigenous cattle and only 2% are crossbred or exotic cattle [1]. Despite this large population, milk and meat productivity remain low, partly because most indigenous cattle have

limited genetic potential for high milk production under intensified systems and because management constraints remain widespread. Artificial insemination (AI) has therefore been promoted as one strategy for disseminating superior dairy genetics and improving productivity.

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Artificial insemination offers several advantages, including wider dissemination of superior genetics, reduced transmission of venereal diseases, and potential improvement in reproductive efficiency. However, AI success in Tanzania has been inconsistent, with low conception and calving rates reported in some regions [2]. These outcomes are commonly associated with animal-related factors, semen handling, insemination timing, heat detection efficiency, and overall herd management [3, 4].

Dodoma, located in Tanzania's semi-arid central zone, presents a distinct production environment in which climatic stress, limited feed resources, and seasonal water shortages may compromise dairy performance [5]. At the same time, relocation of government functions to Dodoma has contributed to population growth and increased demand for milk, creating incentives for dairy intensification and use of reproductive technologies such as AI [1, 6].

Although AI adoption is increasing in Tanzania, outcomes remain variable, with conception and calving performance constrained by factors such as technician skill, semen delivery logistics, and farmers' awareness of heat detection and breeding management [2]. Most reproductive performance studies in Tanzania have been conducted in the northern highlands, southern highlands, or coastal areas [2, 7], leaving limited evidence from the central semi-arid zone. This gap is important because reproductive indicators under semi-arid smallholder conditions may differ from those observed in more humid agro-ecologies. Therefore, this study evaluated the reproductive performance of dairy cattle bred through AI in Dodoma City Council and identified animal- and management-related factors associated with reproductive outcomes under smallholder conditions.

2. Materials and Methods

2.1. Study Area

The study was conducted in Dodoma City Council, located in the semi-arid central zone of Tanzania at approximately 6°6'46.44"S and 35°49'40.8"E. The council covers about 2,607 km² and receives an average annual rainfall of 550-600 mm. Despite the semi-arid environment, some smallholder dairy farmers have adopted AI technology in response to increasing demand for milk following the relocation of government functions from Dar es Salaam to Dodoma.

2.2. Management of Animals

Cattle were kept mainly under intensive zero-grazing and semi-intensive systems for milk production. Most animals depended on natural pastures, while a smaller proportion received improved forages, mainly *Cenchrus* and *Pennisetum* species, together with supplementary feeding.

Routine disease-control measures included vaccination, deworming, and treatment. Common vaccinations targeted lumpy skin disease (LSD), contagious bovine pleuropneumonia (CBPP), anthrax, and foot-and-mouth disease (FMD).

Breeding was practised throughout the year. Heat detection depended mainly on observations by household members, owners, and herdsman. Cows detected in estrus were inseminated by government, city council, or private AI technicians.

2.3. Study Design

This study used a retrospective observational design based on historical farm and AI records to evaluate reproductive performance of dairy cattle bred through AI under smallholder management systems. The unit of analysis was the individual cow, and data were collected from 16 wards of the Dodoma City Council. Records covered the period from January 2022 to June 2025 and were supplemented with information from farmers, extension personnel, and AI service providers.

2.4. Sampling and Sample Size

Households were purposively selected from dairy-keeping households that used AI and maintained reproductive records, with support from city livestock extension officers. The sampling unit was the household, whereas the unit of analysis was the individual cow within each selected household. The study covered 16 wards of the Dodoma City Council, which were purposively chosen to capture variation in geographical location, dairy activity, and availability of AI-using farmers. Within each ward, households were selected in proportion to the number of AI-recorded dairy households with usable reproductive information. The target sample size was guided by Nassiuma's formula, using a coefficient of variation of 27% and an error margin of 3%. Because inclusion depended on AI use and the availability of reproductive records, the final sample of 75 households should be interpreted as a purposive, record-based sample rather than a fully random sample of all dairy households in Dodoma City Council.

2.5. Data Collection

Data were collected through a field survey that combined structured questionnaires with review of farm and AI records.

2.5.1. Structured Questionnaires

A structured questionnaire was developed, checked for clarity, and administered to dairy cattle owners. Each owner managed an average of two to three cows bred through AI. Before interviews, respondents were briefed on the objective of the study. The questionnaire captured management practices, AI service history, heat detection methods and farmer-reported reproductive outcomes.

2.5.2. Farm Records

Individual cow and heifer reproductive records were obtained primarily from farm records, including AI dates, service dates and calving dates. Service records were used to cal-

culate number of services per conception (NSC) and conception rate (CR), whereas calving records were used to calculate calving interval (CI) and days open (DO). Where available, conception was confirmed from farm records; farmer and AI-service-provider reports were used as secondary sources.

Confirming Conception:

Conception was confirmed using the following methods:

Pregnancy diagnosis was used where available. In the absence of pregnancy diagnosis, conception status was inferred from return to estrus, subsequent calving records or farmer reports.

Calculations:

The number of services per conception (NSC) was calculated as the number of inseminations required until a confirmed pregnancy. Conception rate (CR) was calculated as the proportion of cows confirmed pregnant among cows with AI outcome records. Days open (DO) was calculated as the number of days from calving to successful conception, and calving interval (CI) was calculated as the number of days between two consecutive calving events.

Criteria for Complete Records:

Cows were included in the analysis of NSC, DO, and CI only when complete and consistent service and calving records were available. Cows with incomplete or inconsistent records were excluded from trait-specific analyses.

Sample Sizes:

A total of 200 cows were included in the analysis of conception rate (CR). A subset of 128 cows with complete service and calving records was used to calculate NSC, DO, and CI. Sample size therefore, differed among traits because some cows had missing service or calving dates.

Addressing Recall Bias:

Although interviews introduced potential recall bias, farm records were prioritized as the main data source. Farmer reports were used only to supplement missing information where documentary evidence was unavailable. This approach reduced, but did not eliminate, the possibility of recall bias.

Breed Composition:

The breed composition of the cows used in the study is detailed in the following table (Table 1), which provides a breakdown of the different breeds and the number of cows represented in the study.

Table 1. Cattle breeds and numbers used in this study.

Breeds	Numbers
Friesian	59
Ayrshire	47
Jersey	8
Crosses	50
TSHZ (Local breeds)	36

2.6. Data Analysis

Reproductive data were coded and analyzed using SPSS version 25. Mixed-effects models were fitted with herd included as a random effect to account for clustering of cows within herds and potential intra-herd correlation.

Number of services per conception (NSC): Because NSC is a count variable, a generalized linear mixed model with a Poisson or negative binomial distribution was fitted, depending on the presence of overdispersion. Herd was included as a random effect, while season of insemination, parity, breed group, AI technician, and semen source were included as fixed effects.

Model Equation for NSC:

$$\log(E[NSC]) = \mu + \alpha_i + \delta_j + \chi_k + \beta_l + S_m + u_h$$

Where:

μ = intercept

α_i = effect of season

δ_j = effect of parity

χ_k = effect of breed

β_l = effect of AI technician

S_m = effect of semen source

u_h = random effect of herd, accounting for herd-level variability.

2.6.1. Analysis of Calving Interval (CI) and Days Open (DO)

Calving interval (CI) and days open (DO) were treated as continuous variables and analyzed using linear mixed models. The fixed effects included season of calving, parity and breed group, while herd was included as a random effect to account for clustering of cows within herds.

The model for CI and DO was:

$$Y_{ijkh} = \mu + \alpha_i + \delta_j + \chi_k + u_h + e_{ijkh}$$

Where:

Y_{ijk} = CI or DO

μ = intercept

α_i = season of calving

δ_j = parity

χ_k = breed/genetic group

u_h = random effect of herd; e_{ijkh} = residual error

Least-squares means were compared among factor levels using Tukey's HSD at $p < 0.05$.

2.6.2 Conception Rate (CR)

Conception rate (CR) was analyzed as a binary outcome (conceived or not conceived) using mixed-effects logistic regression, with herd included as a random effect. Friesian was set as the reference breed group. The model included fixed effects for breed, parity, season of AI, and semen source. Esti-

mates for Jersey were not calculable due to complete separation, as all 8 Jersey cows conceived, resulting in unreliable odds ratio estimates.

The logistic regression model was used:

$$\text{logit}(p) = \mu + \alpha_i + \delta_j + \chi_k + u_h$$

Where:

p = probability of conception

μ = intercept

α_i = effect of breed

δ_j = effect of parity

χ_k = effect of season of AI

u_h = random effect of herd.

3. Results

3.1. Number of Services Per Conception (NSC)

The overall mean number of services per conception (NSC) was 1.61 (Table 2), indicating that most cows conceived after approximately one to two inseminations. Local breeds recorded the highest NSC (2.00 ± 0.54), compared with improved dairy breeds. Friesian, Ayrshire, Jersey, and Crossbred cattle showed relatively lower NSC values, ranging from 1.25 to 1.37. Also, the results in Table 3 showed the Incidence Rate

Ratios (IRR) for the fixed effects. The season of insemination was found to significantly affect NSC, with cows inseminated during the dry season requiring more services per conception compared to those inseminated during the wet season (IRR = 1.34, $p < 0.001$). Parity also had a significant effect on NSC, with cows in higher parities requiring more services per conception than first parity cows (IRR = 1.12, $p = 0.022$). However, breed, AI technician, and semen source did not significantly influence the number of services per conception.

Table 2. Descriptive statistics for the number of services per conception (NSC) by breed group.

No.	Breed Group	No. of Animals	Mean NSC $\pm$ SE
1	Friesian	59	1.34 $\pm$ 0.12
2	Ayrshire	47	1.27 $\pm$ 0.20
3	Jersey	8	1.25 $\pm$ 0.35
4	Crossbred	50	1.37 $\pm$ 0.39
5	Local breeds (TSHZ)	36	2.00 $\pm$ 0.54
	Overall Mean NSC	200	1.61

NSC = Number of services per conception; SE = Standard error.

Table 3. Poisson/Negative Binomial GLMM for Number of Services per Conception (NSC) in dairy cattle.

Fixed Effect	IRR	SE	95% CI	Wald χ^2	p-value
Breed	1.08	0.07	0.95-1.23	1.92	0.165
Parity	1.12	0.05	1.02-1.24	5.26	0.022*
Season	1.34	0.09	1.18-1.52	14.84	<0.001***
Semen Source	0.97	0.06	0.86-1.11	0.45	0.502
Inseminator					

Random Effect: Herd (variance = 0.18)

Notes: IRR = Incidence Rate Ratio; SE = Standard Error; CI = Confidence Interval

3.2. Calving Interval (CI)

The overall mean calving interval observed in this study was 470.80 days (Table 4). Parity significantly affected CI ($p < 0.001$), with CI generally increasing as parity advanced. First-parity cows had the shortest CI (420.63 ± 29.74 days), whereas cows in parity ≥ 5 had the longest CI (510.01 ± 68.23

days). Intermediate parity groups showed moderately longer CI values. Breed group also significantly affected CI ($p < 0.05$), with local cattle recording the longest CI (574.50 ± 78.79 days). Friesian (433.00 ± 17.89 days), Ayrshire (453.96 ± 29.81 days), Jersey (468.25 ± 52.11 days), and crossbred cows (450.79 ± 56.73 days) had shorter and statistically similar calving intervals. Season of calving was not significantly associated with CI ($p > 0.05$).

Table 4. Least-squares means ($\pm$ SE) of calving interval (CI) by breed group, parity, and season of calving.

Factor	Category	LS Mean $\pm$ SE	95% Confidence Interval	Significance (p-value)
Overall	CI			
Breed	Friesian	433.00 $\pm$ 17.89a	399.11 - 466.89	0.021
	Crossbred	450.79 $\pm$ 56.73a	398.18 - 563.38	
	Ayrshire	453.96 $\pm$ 29.81a	394.78 - 513.14	
	Jersey	468.25 $\pm$ 52.11a	384.82 - 571.68	
	Local breeds	574.50 $\pm$ 78.79b	494.21 - 654.79	
Parity	1	420.63 $\pm$ 29.74a	380.62-478.65	<0.001*
	2	476.77 $\pm$ 30.10ab	417.03-536.51	
	3	502.58 $\pm$ 34.88ab	433.35-571.81	
	4	487.61 $\pm$ 30.33ab	427.42-547.80	
	≥ 5	510.01 $\pm$ 68.23b	424.33-595.17	
Season of Calving	Wet	460.17 $\pm$ 23.24	414.03-506.30	0.950
	Dry	453.35 $\pm$ 19.69	414.28-492.42	

Means within a factor not sharing a common superscript letter (a, b) differ significantly at $p < 0.05$.

3.3. Days Open (DO)

Table 5 shows that the day open differed significantly by

parity ($p < 0.05$). Cows in parity ≥ 5 remained open for longer (142.6 $\pm$ 15.8 days) than first-parity cows (98.7 $\pm$ 12.6 days). Breed group and season of calving were not significantly associated with DO.

Table 5. Estimated marginal means ($\pm$ SE) for days open (DO) in dairy cattle by breed group, parity, and season of calving.

Factor	Category	LS Mean $\pm$ SE (days)	95% Confidence Interval	Significance (p-value)
Breed	Friesian	148.038 $\pm$ 16.447	115.457-180.619	0.558
	Ayrshire	101.990 $\pm$ 24.495	53.466-150.513	
	Jersey	32.000 $\pm$ 50.097	0.00-131.242	
	Crosses	82.125 $\pm$ 39.999	2.886-161.364	
	Local breeds	129.000 $\pm$ 58.208	13.691-244.309	
Parity	1	98.7 $\pm$ 12.6c	73.8-123.6	0.016
	2	121.40 $\pm$ 10.10b	89.18-142.43	
	3	120.90 $\pm$ 14.08b	91.27-139.12	
	4	121.53 $\pm$ 09.30b	93.37-149.13	
	≥ 5	142.60 $\pm$ 15.80a	111.63-173.57	
Season of calving	Wet	118.2 $\pm$ 10.90	96.84-139.56	0.813
	Dry	121.70 $\pm$ 11.30	99.30-144.10	

Means within a factor not sharing a common superscript letter (a, b, c) differ significantly at $p < 0.05$ (Tukey HSD).

3.4. Conception Rate (CR%)

Conception rate (CR) by breed group is shown in Table 6. The average conception rate (CR) was 59.91%. Mixed-effects logistic regression (Table 6) indicated that breed group significantly influenced CR ($p < 0.05$). Friesian served as the reference breed; Ayrshire and Crossbred cows had higher odds of

conception relative to Friesian, whereas Local breeds had lower odds. Estimates for Jersey could not be reliably calculated due to complete separation, as all 8 Jersey cows conceived. Parity, season of AI, and semen source were not significantly associated with CR.

Table 6. Conception rate.

Breed	Total Cows	Conceived	Not Conceived	CR (%)
Friesian	59	35	24	59.32
Ayrshire	47	26	21	55.32
Jersey	8	8	0	100
Crossbred	50	30	20	60.00
Others	36	9	27	25.00

Mixed-effects logistic regression for conception rate (Table 7) indicated that breed group was significantly associated with CR ($p < 0.05$). Local cattle had lower odds of conception than the reference breed group, whereas parity, season of AI, and

semen source were not significantly associated with CR. The interpretation of breed effects should be cautious because breed groups may be confounded with management conditions, heat detection efficiency, and record quality.

Table 7. Logistic Regression Results for Conception Rate (CR) in Dairy Cattle.

Factor	Estimate (β)	Standard Error (SE)	Odds Ratio (OR)	95% Confidence Interval	p-value
Breed (Ayrshire)	0.178	0.089	1.19	1.01 - 1.41	
Breed (Crossbred)	0.405	0.160	1.50	1.09 - 2.06	
Breed (Local breeds)	-1.395	0.601	0.25	0.08 - 0.73	
Breed (Jersey)	-	-	-	-	-
Parity	0.054	0.043	1.06	0.97 - 1.16	$p > 0.05$
Season of Insemination	0.032	0.058	1.03	0.92 - 1.14	$p > 0.05$
Semen Source	-0.018	0.075	0.98	0.86 - 1.13	$p > 0.05$

4. Discussion

4.1. Number of Services Per Conception (NSC)

The mean NSC of 1.61 observed in the present study is close to the value of 1.66 reported by [8] for Friesian crosses under smallholder production systems, but lower than values reported by [9, 10]. It was also higher than the NSC of 1.23

reported by [11] for Ankole and its crosses with Friesian, Jersey, and Sahiwal. These differences may reflect variation in management practices, heat detection, nutrition, inseminator skill, semen handling, and farmer record-keeping. The significant effect of season of insemination suggests that environmental and nutritional conditions influenced conception success. Cows inseminated during the dry season required more services, possibly because of poorer body condition, lower forage quality, heat stress, and weaker estrus expression. These explanations are consistent with reports from Tanzania, Ethiopia, and Kenya [2-4]. The significant effect of parity on

NSC also agrees with studies showing that fertility may decline with advancing parity or age [12, 13].

4.2. Calving Interval (CI)

The mean calving interval of 470.80 days observed in this study falls within the broad range reported for dairy cattle managed under tropical and smallholder conditions. It is comparable to the 404-466 days reported by [14] for Ayrshire cows in the tropics and to the 463.6 days reported by [15] for Boran and Friesian crosses under ranch management. However, it is slightly lower than the 490 ± 119 days reported by [10] and lower than the 525 ± 18 days reported by [7] under smallholder coastal systems in Tanzania. Extended calving intervals in smallholder systems are commonly associated with delayed postpartum conception, poor heat detection, inadequate nutrition, and delayed AI service. Because an approximate 12-month calving interval is often used as a desirable reproductive target, the observed CI suggests room for improvement in reproductive management.

Parity significantly affected CI ($p < 0.001$), with cows in parity ≥ 5 showing longer calving intervals than first-parity cows. This pattern may reflect age-related decline in fertility, accumulated physiological stress, delayed uterine recovery, or management decisions that differ between older and younger cows. Similar parity effects have been reported in dairy systems in East Africa and elsewhere [13, 16, 19].

Breed group also significantly influenced CI, with local cattle having the longest calving intervals (574.50 ± 78.79 days) and Friesian cows the shortest (433.00 ± 17.89 days). These differences may indicate breed-related variation in reproductive performance; however, they may also reflect differences in management intensity, feeding, heat detection and farmer investment across breed groups. Therefore, the breed effect should be interpreted as an association rather than direct evidence that genetic merit alone determined calving interval.

4.3. Days Open (DO)

The average DO in this study was 111.55 days, which is shorter than values reported in some comparable studies. [8] reported longer days open for Friesian crosses, while [11, 20] also reported longer postpartum intervals under smallholder or tropical conditions. Differences among studies may arise from variation in postpartum management, heat detection efficiency, timing of first service, nutrition, and accuracy of reproductive records.

Days open were significantly affected by parity ($p < 0.05$), with higher-parity cows remaining open for longer than younger cows. This agrees with reports that older or multiparous cows may experience delayed return to ovarian cyclicity, accumulated physiological stress, or postpartum reproductive disorders [17, 18]. Breed group and season of calving were not significant, although Ayrshire and crossbred cows tended to have shorter DO values, while Friesian and local cattle tended

to have longer DO. These findings emphasize the importance of herd age structure and targeted reproductive management for older cows. Similar observations have been reported in Ethiopia, where parity and postpartum nutrition influenced days open in smallholder dairy cows [21].

4.4. Conception Rate (CR%)

The average conception rate (CR) was 59.91%, which is close to the 60.2% reported by [21] for local and crossbred cattle under smallholder management systems. It is lower than the 67% reported by [11] for Ankole and its crosses and the 72% reported by [22]. Such variation may be explained by differences in heat detection, timing of insemination, semen handling, technician performance, nutrition, and herd management. In the present study, breed group was significantly associated with CR ($p < 0.05$), suggesting that AI outcomes in smallholder systems are influenced by a combination of biological, nutritional, and management-related factors.

The lower CR observed in local cattle may reflect breed-related reproductive differences, but it may also be influenced by management differences between farmers keeping local cattle and those keeping improved dairy breeds. Therefore, the result should not be interpreted simply as evidence of poor breed quality. Estrus detection may also be more challenging in some local or non-descript cattle because of differences in the expression of estrus signs or because these animals receive less intensive reproductive management. Further work is needed to separate genetic effects from management, nutrition, semen handling, and heat detection factors [2, 21, 23].

5. Conclusion and Recommendations

This study shows that the reproductive performance of AI-bred dairy cattle under smallholder conditions in Dodoma City Council was associated with breed group, parity, and season of insemination. Season of insemination influenced NSC, suggesting that dry-season feeding and general management should be strengthened to improve conception outcomes. Parity influenced CI and DO, indicating the need for closer reproductive monitoring of older cows. Because the study was retrospective and record-based, the findings should be interpreted as associations rather than definitive causal effects. The study recommends improving farmer training on heat detection, strengthening AI record-keeping, ensuring proper semen handling, and supporting herd replacement strategies that favors reproductively sound cows. Moreover, since the study area is characterized by semi-arid conditions and limited rainfall, further research is needed to identify the most suitable cattle breed groups and feeding technologies or management strategies that can support optimal AI performance and improve reproductive success in the region.

Abbreviations

AI	Artificial Insemination
CR	Conception Rate
CI	Calving Interval
NSC	Number of Services Per Conception
DO	Days Open
URT	The United Republic of Tanzania
LSD	Lumpy Skin Disease
DO	Days Open
CBPP	Contagious Bovine Pleuropneumonia
FMD	Foot and Mouth Disease

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Author Contributions

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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