



# Effect of housing improvement and other factors on the growth of heifer calves on Kenyan smallholder dairy farms

Peter Kimeli<sup>1</sup> · John VanLeeuwen<sup>1</sup> · George Gitau<sup>2</sup> · Luke Heider<sup>1</sup> · Shawn McKenna<sup>1</sup> · Spencer Greenwood<sup>3</sup>

Received: 28 August 2020 / Accepted: 22 December 2020 / Published online: 13 January 2021

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## Abstract

This trial evaluated average daily gain (ADG) effects of heifer calves (< 1 year old) from affordable housing improvements to the roof and flooring on 150 randomly allocated smallholder dairy farms. During the 16-month data collection period, bimonthly farm visits were used to measure weight and other animal- and farm-level factors on the 187 study calves. Multivariable linear regression was used to model ln ADG and ADG during pre-weaning and post-weaning periods, respectively. Median pre-weaning and post-weaning ADGs were 0.307 (interquartile range (IQR): 0.227–0.398) and 0.487 (IQR: 0.354–0.675) kg/d, respectively. In the final pre-weaning model ( $p < 0.050$ ), factors positively associated with ln ADG were calf age at first acaricide application, and total number of calf pens, while factors negatively associated with ln ADG included calf mortality risk over the last 5 years and calf age at first ad lib access to water. In an interaction term, for calves from parity 3+ dams, ADG was lower when milk was fed twice/day than thrice/day, with no difference in calves of lower parity dams. In the final post-weaning model, housing improvements increased ADG by 5.6%. Other factors positively associated with post-weaning ADG were feeding of calf pellets, wheat bran, maize bran, and hay. Calf age at first introduction of concentrate and calf mortality risk over the last 5 years were negatively associated with ADG. In an interaction term, ADG was high when there were faecal coccidia oocysts and when calves had visual or physical contact with their dams, but low when faecal coccidia cysts were present, and these dam-calf connections were absent. In a second interaction term, ADG increased with more calf pens for female principal farmers, while remaining low for male principal farmers. In conclusion, while controlling for other factors of ADG, making affordable calf housing improvements enhanced ADG, particularly during the post-weaning period.

**Keywords** Smallholder · Zero-grazed · Daily weight gain · Housing · Weaning

## Introduction

Best management practices during calf rearing are essential to ensure the availability of future replacement stock (Lanyasunya et al. 2006) and thereby the total herd sustainability (Chang'a et al. 2011; Odero-Waitituh 2017). Appropriate housing for good health and growth of the dairy calf is of vital importance for its future production capacity (Bolt et al. 2017).

Dairy heifer growth rates and body weight at first calving are regarded as important benchmarks in farm management because lower body weight heifers are at a greater risk of dystocia at first calving (Mee 2008), produce less milk, and have a shorter lifespan in the herd (Archbold et al. 2012; McNaughton and Lopdell 2013). It is, therefore, important to understand reasons for growth impairment in calves, especially if they are associated with housing factors that can easily be fixed by farmers themselves.

Methods of rearing dairy calves in Kenya vary considerably from farm to farm. In smallholder resource-limited farms, dairy calves are commonly kept in pens but sometimes they may be allowed to graze or be tethered on natural tropical pastures without protein supplementation. Calves are also often housed poorly, in small pens together with other livestock, particularly small ruminants. As a result of inadequate feeding and poor housing management, stunted growth and high mortality have been reported (Lanyasunya et al. 2006).

✉ Peter Kimeli  
pkimeli@upei.ca

<sup>1</sup> Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, Canada

<sup>2</sup> Department of Clinical Studies, Faculty of Veterinary Medicine, University of Nairobi, Nairobi, Kenya

<sup>3</sup> Department of Biomedical Sciences, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, Canada

Due to decreasing land space and tick infestation of pastures, complete zero-grazing is becoming a common alternative; the animals are housed throughout the year, and feed is provided to them. In such situations, farmers are often unable to produce sufficient fodder because of their smallholdings, and so they have to supplement with forage harvested from public areas or purchased fodder (Rademaker et al. 2016). With complete housing, there is often an excessive accumulation of slurry, presence of uneven and/or hard floors in calf pens and leaking roofs (Nguhiu-Mwangi et al. 2013; Kimeli et al. 2015).

Wide-ranging growth rates of calves have been reported in Kenya. Lanyasunya et al. (2006), in their study on the effect of supplementation on performance of calves in the Nakuru area of Kenya, reported an overall average daily gain (ADG) of 0.338 kg/d, while Gitau et al. (2001) reported a mean ADG of 0.26 kg/d in Central Kenya. Both figures were below 0.4–0.5 kg/d which is the recommended target for smallholder dairy farms in central highlands of Kenya (Lukuyu et al. 2012) and 0.5–0.75, targets for developed countries. In two recent cross-sectional studies, Kathambi et al. (2018) observed an ADG of 0.50 kg/d in calves aged between 1 week and 12 months, while Makau et al. (2018) reported 0.443 kg/d in heifers aged less than 36 months. The latter two studies may have suffered survivor bias; thus, a possible over-estimation is possible. No study has systematically evaluated the smallholder farm impact of calf housing enhancement on ADG while controlling for other related factors of ADG.

Focused prospective studies on calf growth, the housing environment and individual calf parameters are limited in Kenya. The few research studies on this topic (Gitau et al. 2001; Lanyasunya et al. 2006; Thumbi et al. 2013) were largely explorative or based on extensive management systems that are dominated by indigenous breed crosses. Analysis of growth patterns following physical environmental enhancement would be useful for determining the relative importance of housing factors that may affect production efficiency parameters such as ADG.

The objective of our study was to evaluate the effects of practical and affordable calf housing improvement on ADG during pre- and post-weaning periods on smallholder dairy farms.

## Material and methods

### Description of the study area

The study was carried out in Kiambu and Murang'a Counties of Kenya (Fig. 1). These counties experience an average annual environmental temperature of about 18–20 °C and an average rainfall of 962–1195 mm/year. Murang'a County is on  $-0.7957^{\circ}$  S and  $37.1322^{\circ}$  E, and has a human population

of 1,056,640 (KNBS 2019) and area of 2558.8 km<sup>2</sup>, with an altitude of between 914 and 3353 m. Kiambu County is adjacent to the northern border of Nairobi and is on  $-1.1462^{\circ}$  S and  $36.9665^{\circ}$  E, and has a human population of 2,417,735 (KNBS 2019) with an area of 2543.5 km<sup>2</sup> and an altitude of 1200 to 2550 m. Kiambu County is about 40% rural and 60% urban, owing to Nairobi's consistent growth northwards, and it has experienced tremendous growth in dairying due to its ready access to a large urban market and the existence of local milk processing facilities.

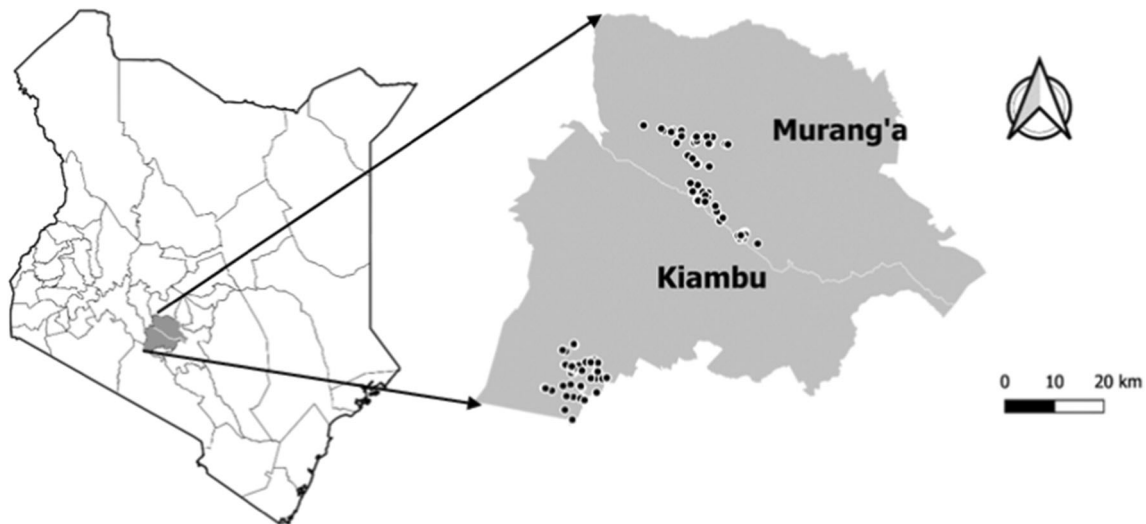
### Study design, sampling method and data collection

This study was a randomised controlled trial, in which calf-pen improvement was implemented on smallholder dairy farms in Kiambu County and control farms were located in neighbouring Murang'a County. Randomisation was achieved at the county level (via a coin toss) to minimise contamination of control group farms, which can happen if they are located in the same area as intervention farms, since housing improvement is something fixable by owners if/when control group farmers visit intervention group farmers, a phenomenon that has been documented in Kenya previously (Kathambi et al. 2019; Richards 2017).

The enrolment of farms to the study was enhanced through a presentation at an information meeting with the farmers via their dairy cooperative society. Farm-level inclusion criteria were as follows: (1) being in the target county; (2) practicing zero-grazing; (3) having at least one unweaned heifer calf aged less than 6 weeks; and (4) having less than ten milking cows. A total of 150 farms, seventy-five from each county, were enrolled in the study over a period of 8 months.

On the initial visit, the principal farmers consenting to participate in the study were asked to respond to a questionnaire covering issues related to the calf characteristics, management practices, farmer training and demographics. The calves were also assessed by observation and thorough physical examination. We then administered calf-pen floor improvements on intervention farms which included (1) filling floor holes if on the ground or repairing wooden slats if on an elevated floor; (2) introduction of rubber mats on the lying area; (3) ensuring a floor gradient for drainage; and (4) patching leaking roofs. The control farms received the same housing improvement (as needed by each farm) after data collection was complete at the end of study period, in appreciation for their participation in the trial.

Each study animal was routinely monitored bi-monthly for up to 6 farm visits, where applicable, to obtain up to a year's worth of data on the study animals. During the follow-up period, July 2018 to October 2019, routine clinical examinations on study calves were conducted. Data on farm management practices, and herd health and veterinary interventions on the herd since the last visit were collected.



**Fig. 1** Map of Kenya showing households that were visited in Kiambu and Murang'a in a randomized controlled trial on the Kenyan smallholder dairy calves

Body weight (kg) via girth measurements (cm) were recorded at recruitment and during all monitoring visits. Faecal samples were also collected per rectum on all visits. Faecal analysis for the presence and counts of coccidia oocysts and helminth eggs was undertaken using a centrifugal faecal flotation method with Sheather's sugar and the McMaster method, as described elsewhere (Kimeli et al. 2020). The initial and bimonthly questionnaires are available upon request.

### Data management and analysis

Questionnaire data were collected using a mobile phone-based data collection platform (Epicollect5®; <https://five.epicollect.net/>), which was then exported to MS Excel 2010 (Microsoft Inc., Sacramento, California, USA) and coded. Laboratory data were added to the Excel spreadsheet, and the combined data were imported to Stata® 15.1 statistical software (StataCorp LLC, College Station, TX, USA) for statistical analyses.

We anticipated that factors associated with the growth of calves pre-weaning were different than for the post-weaning period. Therefore, we modelled factors associated with average daily gain (ADG) in weight for the periods between (1) first and third visits and (2) third and sixth visits. For each animal, therefore, ADG was calculated as the difference between weights measured on (1) the third visit and first visit, divided by the number of days between the visits (model I); and (2) the sixth visit and third visit, divided by the number of days between the visits (model II). When farms had multiple calves, they were monitored and recorded separately in the data.

Descriptive statistics, such as means, standard deviations, median and ranges, were determined for continuous variables, while proportions were calculated for binary and categorical variables. Between-group (counties) differences at baseline

(visit 1) were calculated using independent sample *t* tests and Chi-squared statistics.

Ordinary least-squares linear regression was used in building models using ADG as the outcome of interest. Attempts to use the farm as a random effect (controlling for clustering of calves within farms) did not significantly change the model estimates because there was only one calf per farm for most farms, and therefore it was not utilised. Assessment for normality of ADG was performed using histogram, Q-Q plot and Shapiro-Wilk test. Box-Cox analysis was used to estimate a suitable transformation factor for the ADG outcome in the pre-weaning period. These assessments found that ADG for model I was right-skewed, and a natural logarithm of ADG achieved normality.

In the first regression step, univariable linear regression models for all the predictor variables were fitted into separate models, with those having  $P \leq 0.25$  being eligible for the multivariable analyses. Multicollinearity was then evaluated among the univariable association variables, and one of the correlated predictors was dropped, based on statistical significance unless there was a substantial difference in the biological plausibility. A multivariable model was then built through backward removal, while evaluating for potential confounding. Additionally, a curvilinear relationship was explored for continuous predictors. Two-way interactions between the biologically plausible variables in the final model were tested, and an interaction term was retained if the *P* value of interaction terms was found to be significant at  $P \leq 0.05$ .

Residual analysis was performed to evaluate model assumptions and diagnostics. The normality of residuals was evaluated using histograms, Q-Q plots and normality tests. Homoscedasticity was evaluated by plotting standardised residuals against predicted values, and by using the Breusch-Pagan test. Identification of extreme and influential observations was done by sorting and graphing the standardised

residuals and comparing changes in coefficient estimates and their significance when modelling with and without influential observations. Model fitness was assessed using PRESS statistics (Holiday et al. 1995).

## Results

### Descriptive statistics and univariable analysis

A total of 187 heifer calves from 150 smallholder farms were recruited at different times between July 2018 and February 2019 and followed for up to 477 days, with up to 6 on-farm assessment visits done bimonthly. The number of study farms and candidate calves decreased in subsequent visits due to loss to follow up and late enrolment. One hundred sixty-five animals from 132 farms were evaluated three times, while only 100 animals from 91 farms were assessed and sampled six times (Table 1).

Tables 2 and 3 report on baseline differences between the intervention and control group farms. Participating farms from Murang'a County had significantly higher owned land acreage but leased less land and earned lower gross income from milk as compared to Kiambu County farms. The differences in bodyweight at enrolment and farmer education level were also statistically significant. However, there was no baseline difference in the number of adults per household, age/gender/marital status of the principal farmer, duration involved in dairy farming, previous attendance of training, floor area of the calf pen, average weaning age, calf breed or dam parity number. Average age at enrolment was 3 ½ weeks, and average weaning age was slightly over 13 weeks, regardless of the group. This weaning age reflects the common weaning age of 3 months in Kenya, and demonstrates that the first two farm visits were recording animal-level information on pre-weaned calves. Therefore, our plan to model pre-weaning ADG for visits 1 to 3 and post-weaning ADG for visits 3 to 6 was appropriate.

**Table 1** Total number of farms and calves (with median weight) at each visit of the study

Visit #	Number of farms	Number of calves	Median calf weight (kg)	Interquartile range
1	150	187	48	44–53
2	145	179	71	57–83
3	132	165	95	79–110
4	126	151	122	104–146
5	112	130	150	116–178
6	91	100	180	145–233

At least two pre-weaning and one post-weaning housing improvement(s) were implemented on all of the 75 intervention farms (Table 4). Rubber mats were provided to all intervention farms to improve softness of the lying area. Fixing the floor gradient to improve liquid drainage (adding dirt to the pen floor more on one side than the other), and fixing holes or slats in the floor were other common fixes applied. Over half of the intervention farms with pre-weaned calves and with post-weaned calves had at least two fixes applied.

The overall ADG of the animals that completed the study was 0.429 kg/d (SD=0.297), with a median of 0.365 kg/d. The calves examined in the pre-weaning period (1st to 3rd visits) had a mean ADG of 0.324 kg/d (SD=0.133; median= 0.307), while the animals examined in the post-weaning period (3rd to 6th visits) had a mean ADG of 0.510 kg/d (SD=0.220; median= 0.487). The mean body weight at recruitment was 46.5 kg/d (SD=8.5) at a mean age of 26.5 days (SD= 17.8), while the mean weight on the sixth (last) visit was 188 kg (SD=58) at a mean age of 356 days (SD=37.8). Figure 2 shows the large variability of bodyweight gains with age among individual calves.

Descriptive statistics and univariable analyses for categorical and continuous variables eligible for multivariable analyses of factors associated with pre-weaning and post-weaning ln ADG and ADG are presented in Tables 5, 6, 7 and 8, respectively. There were 27 and 30 variables meeting the  $p < 0.25$  eligibility cut-off for the pre-weaning and post-weaning multivariable models for ln ADG and ADG, respectively.

### Multivariable linear regression models

#### Model I

In the final pre-weaning model, the following explanatory variables were found to be significantly associated with ln ADG: Education level and Gender of the principal farmers, Dam parity number, Calf frequency of milk feeding, Calf age at first acaricide application, Total number of calf pens, Calf mortality risk over the last 5 years and Calf age at first ad lib access to water (Table 9).

In an interaction term, the relationship between the principal farmer's level of education and ln ADG depended on the gender of the principal farmer. ADG was significantly lower by 31.6% for female than male principal farmers but only when primary education was the highest education level achieved; ADG was similar by principal farmer gender at higher levels of education (Fig. 3).

In a second interaction term, the relationship between dam parity number and ln ADG depended on the frequency of milk feeding. For calves from parity 3+ dams, ADG was lower by 28.1% when milk was fed twice/day than thrice/day; however, there was no ADG difference in calves of lower parity dams (Fig. 4).

**Table 2** Summary of animal and farm characteristics (continuous variables) pre-intervention for 187 calves on 150 Kenyan smallholder dairy farms

Continuous variables	Murang'a County (Control group)			Kiambu County (Intervention group)			P value
	Number	Mean	SD	Number	Mean	SD	
<b>Farmer variables</b>							
# of adults per household	75	2.60	1.39	75	2.87	1.15	0.204
Age of principal farmer (years)	75	53.09	12.71	75	49.96	12.53	0.131
Duration involved in dairy farming (years)	75	19.48	13.75	75	15.55	10.65	0.052
Overall proportion of income from dairy farming (%)	75	47.43	20.79	75	51.37	27.29	0.322
Land size owned by the farmer (acres)	75	2.14	3.19	75	0.73	0.74	<0.001
Land size leased for dairy farming (acres)	75	0.27	0.65	75	0.55	0.67	0.011
Gross income from milk sale (USD) per month	75	213.85	331.65	75	403.35	403.35	0.003
<b>Farm variables</b>							
Floor area of the calf pen (m <sup>2</sup> )	75	3.85	6.00	75	4.27	4.58	0.633
Average weaning age (weeks)	75	13.48	4.90	75	13.17	3.07	0.647
Herd size	75	4.52	3.47	75	6.93	5.32	0.001
<b>Animal variables</b>							
Age at enrolment (days)	89	26.55	15.74	98	24.82	19.55	0.508
Body weight at enrolment (kg)	89	50.97	7.86	98	47.87	8.27	0.010

The coefficients of variables not involved in interactions can be interpreted directly through exponentiation of the coefficients due to the transformed outcome variable of ln ADG. Based on the exponentiated coefficient, ADG increased by 0.6% for every 1-week delay in acaricide application. For number of calf pens, the exponentiated

coefficient showed that ADG increased by 5.3% for every additional calf pen. There was a reduction in ADG by 0.5% for every increased percentage point in mortality risk over the last 5 years. Delayed age at first ad lib access to water was associated with a reduced ADG, by 0.7% for every 1-week delay.

**Table 3** Summary of animal and farm characteristics (categorical variables) pre-intervention for 187 calves on 150 Kenyan smallholder dairy farms

Categorical variables	Category	Murang'a county (control group) % (n/N)	Kiambu county (intervention group) % (n/N)	P value
<b>Farmer variable</b>				
Gender of the principal farmer	Male	49.3 (37/75)	50.7 (38/75)	0.870
	Female	50.7 (38/75)	49.3 (37/75)	
Marital status of the principal farmer	Married	85.3 (64/75)	88.0 (66/75)	0.571
	Single	8.0 (6/75)	4.0 (3/75)	
	Widowed	6.67 (5/75)	8.0 (6/75)	
Attended any dairy farmers training previously	No	41.3 (31/75)	42.7 (32/75)	0.869
	Yes	58.7 (44/75)	57.3 (43/75)	
Education level of principal farmer	Primary	53.3 (43/75)	37.3 (28/75)	0.020
	Secondary	33.3 (25/75)	40.0 (30/75)	
	College/ University	9.3 (7/75)	22.7 (17/75)	
<b>Animal variables</b>				
Calf breed	Friesian	94.4 (84/89)	86.7 (85/98)	0.110
	Ayrshire & Jersey	5.6 (5/89)	12.4 (12/98)	
Dam parity number	1	30.3 (27/89)	23.5 (23/98)	0.544
	2	28.1 (25/89)	27.6 (27/98)	
	≥ 3	41.6 (37/89)	49.0 (48/98)	

**Table 4** Proportions of 75 and 61 intervention farmers with pre-weaned and post-weaned calves, respectively, that received each of the housing improvements on their Kenyan smallholder farms

	<sup>a</sup> Proportion of 75 farms with pre-weaned calves that received pre-weaning housing improvements	<sup>b</sup> Proportion of 61 farms with post-weaned calves that received post-weaning housing improvements
Type of intervention		
Floor holes or slats fixed	58.7	27.9
Added a rubber mat	100	100
Floor gradient fixed	100	55.7
Roof fixed	33.3	24.6
Number of interventions		
At least one change made	100	100
At least two changes made	100	57.4
At least three changes made	64	34.4
All four changes made	28	14.8

<sup>a</sup> Reference is made to farms that received housing improvements and were under study at first to third visits

<sup>b</sup> Reference is made to farms that received housing improvements and were under study at fourth to sixth visits

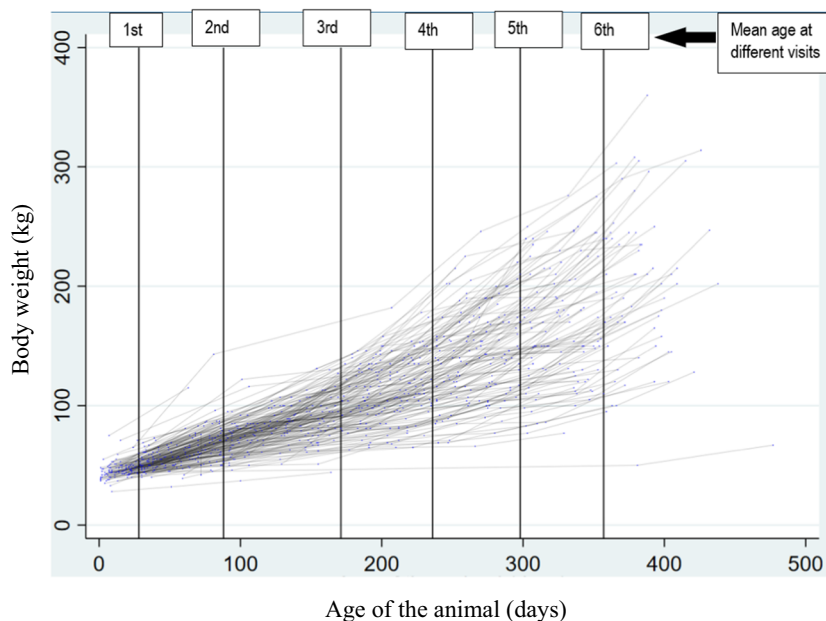
**Model II**

In the final model, the following explanatory variables were found to be significantly associated with post-weaning ADG: housing improvement, age and gender of the principal farmers, total number of calf pens, fed maize bran, fed wheat bran, fed calf pellets, fed hay, age at first introduction of concentrate, dam average daily milk yield in the first 6 weeks, mortality risk over the last 5 years, presence of faecal coccidia oocyst and presence of dam-calf connection by way of having adjacent housing, allowing the calf physical or visual contact with the dam (Table 10).

Calf housing improvement was associated with increased ADG by 0.054 kg/d among the animals on the farms that

received the intervention. An increase in the age of the principal farmer was associated with a decrease of ADG by 0.004 kg/d for every additional year. The calves feeding on maize bran and wheat bran had 0.086 kg/d and 0.079 kg/d better ADG than those not fed maize bran and wheat bran, respectively. Also, calves feeding on calf pellets and on hay had a 0.204 kg/d and 0.077 kg/d increase in ADG, respectively, compared to those not fed calf pellets or hay. Delay in the introduction of concentrate to calves was associated with decreased ADG, by 0.005 kg/d for every 1-week delay. For each additional litre of the dam’s average daily milk yield in the first 6 weeks, there was an increase in ADG of 0.008 kg/d. There was a reduction of ADG by 0.002 kg/d for every increased percentage point in mortality risk over the last 5 years.

**Fig. 2** Growth patterns of 187 calves on 150 Kenyan smallholder farms. The blue dots are the individual weights recorded while the grey lines connect the repeated measurements for each calf



**Table 5** Descriptive statistics and *p* values (<0.25) for Model I (pre-weaning visits) univariable linear regressions for categorical variables associated with ln average daily gain for 165 calves on 132 Kenyan smallholder farms

Variable	Category	% (n/N)	Median ADG	<i>P</i> value
Calf housing improvement	No	51.5 (68/132)	0.32	0.317
	Yes	48.5 (64/132)	0.29	
Highest level of education of the principal farmer	Primary	49.9 (62/132)	0.27	<0.001*
	Secondary	36.4 (48/132)	0.31	
	College/University	16.7 (22/132)	0.38	
Gender of the principal farmer	Male	49.2 (65/132)	0.33	<0.001
	Female	50.8 (67/132)	0.29	
Marital status of the principal farmer	Married	87.1 (115/132)	0.30	0.112
	Single/Widowed	12.9 (17/132)	0.34	
Dam parity number	≤2	55.2 (91/165)	0.33	<0.001
	≥3	44.8 (74/165)	0.29	
Breed of the calf	Friesian	91.5 (151/165)	0.31	<0.001
	Ayrshire/Jersey	8.5 (14/165)	0.25	
Shedding of strongyle-type eggs	No	93.7 (463/494)	0.31	0.194
	Yes	6.3 (31/494)	0.30	
Experience flea infestation	No	73.5 (97/132)	0.31	0.031
	Yes	26.5 (35/132)	0.21	
Feed calves milk replacer	No	94.7 (125/132)	0.31	<0.001
	Yes	5.3 (7/132)	0.21	
Frequency of milk feeding at pre-weaning	Once or twice	84.2 (139/165)	0.30	0.001
	Thrice or four times	15.8 (26/165)	0.37	
Calf weaned at the time of farm visit	No	57.1 (282/494)	0.30	<0.001
	Yes	42.9 (212/494)	0.31	
Feed maize bran	No	70.0 (346/494)	0.30	0.061
	Yes	30.0 (148/494)	0.31	
Feed maize germ	No	66.8 (330/494)	0.30	0.190
	Yes	33.2 (164/494)	0.31	
Fed hay	No	68.4 (338/494)	0.30	<0.001
	Yes	31.6 (156/494)	0.33	
Fed dry maize stalk	No	78.5 (388/494)	0.32	<0.001
	Yes	21.5 (106/494)	0.28	

\*Overall *p* value

There was an interaction between dam-calf connection and the faecal shedding of coccidia oocysts. Compared to when faecal coccidia oocysts were absent, the ADG was reduced by only 0.009 kg/d when there were faecal coccidia oocysts and the calves were allowed to visually or physically connect with the dam; however, ADG was reduced by 0.089 kg/d when faecal coccidia oocysts were present but the dam-calf connection was absent (Fig. 5).

In a second interaction term, the relationship between principal farmer gender and the ADG depended on the total number of calf pens (Fig. 6). ADG was similar (slightly above or below 0.50 kg/d) by principal farmer gender when there were less than four calf pens; however, ADG increased with more calf pens, to

over 0.8 kg/d with more than 6 calf pens, but only when the principal farmer gender was female.

### Model evaluations

In both cases, the model assumptions of normality and homoscedasticity were met. Scatter plots of fitted values and standardised residuals did not depict distinct patterns in the distribution of residuals, with only 3 (model I) and 5 (model II) observations that were outside 2 standard deviations, and these observations were not outliers. The standardised residuals had a good fit on the Q-Q plot. A model fit without these observations had no difference from a model with all observations. Therefore, all

**Table 6** Descriptive statistics and *p* values (<0.25) for Model II (post-weaning visits) univariable linear regressions for categorical variables associated with average daily gain for 100 calves on 91 Kenyan smallholder farms

Variable	Category	% (n/N)	Mean ADG ±SD	<i>P</i> value
Calf housing improvement	No	51.7 (47/91)	0.49±0.20	Baseline
	Yes	48.3 (44/91)	0.53±0.24	0.076
Highest level of education of the principal farmer	Primary	49.5 (45/91)	0.46±0.21	Baseline
	Secondary	35.1 (32/91)	0.52±0.23	
	College/University	15.4 (14/91)	0.62±0.20	<0.001*
Gender of the principal farmer	Male	49.5 (45/91)	0.57±0.22	Baseline
	Female	50.5 (46/91)	0.45±0.20	<0.001
Breed of the calf	Friesian	91.0 (91/100)	0.53±0.21	Baseline
	Ayrshire/Jersey	9.0 (9/100)	0.32±0.18	<0.001
Shedding of coccidia oocysts	No	45.8 (183/400)	0.54±0.23	Baseline
	Yes	54.2 (217/400)	0.48±0.21	0.005
Shedding of strongyle-type eggs	No	85.3 (341/400)	0.53±0.22	Baseline
	Yes	14.7 (59/400)	0.41±0.19	<0.001
Experience flea infestation	No	70.3 (64/91)	0.50±0.21	Baseline
	Yes	29.7 (27/91)	0.54±0.24	0.095
Feed calves milk replacer	No	93.4 (85/91)	0.52±0.22	Baseline
	Yes	6.6 (6/91)	0.37±0.20	<0.001
Calf weaned at the time of farm visit	No	1.3 (5/400)	0.37±0.13	Baseline
	Yes	98.7 (395/400)	0.51±0.22	0.164
Calf fed maize bran	No	69.0 (276/400)	0.49±0.22	Baseline
	Yes	31.0 (124/400)	0.56±0.21	0.003
Calf fed calf pellets	No	97.3 (389/400)	0.51±0.22	Baseline
	Yes	2.7 (11/400)	0.67±0.23	0.017
Calf fed wheat bran	No	85.0 (340/400)	0.50±0.22	Baseline
	Yes	15.0 (60/400)	0.57±0.23	0.023
Calf fed maize germ	No	59.3 (237/400)	0.52±0.23	Baseline
	Yes	40.7 (163/400)	0.49±0.21	0.213
Calf fed hay	No	56.5 (226/400)	0.45±0.19	Baseline
	Yes	43.5 (174/400)	0.58±0.23	<0.001
Calf fed dry maize stalk	No	74.8 (299/400)	0.53±0.22	Baseline
	Yes	25.2 (101/400)	0.46±0.20	0.004
Calf fed dry dairy meal	No	67.0 (268/400)	0.52±0.22	Baseline
	Yes	33.0 (132/400)	0.48±0.22	0.080
Presence of dam-calf connection	No	25.3 (101/400)	0.52±0.21	Baseline
	Yes	74.8 (299/400)	0.51±0.22	0.233

\*Overall *p* value

observations were retained in the final model. The predicted residual error sum of squares (PRESS) statistic was 0.04 for both (Model I) and (model II) which is less than 0.1, suggesting that our final models were good for prediction.

## Discussion

This is the first controlled field trial focussed on calf housing improvement within the zero-grazing system with smallholder

dairy farms. While controlling for other factors associated with ADG in the final post-weaning model, housing improvement was associated with increased ADG by 0.054 kg/d among the calves in the intervention group, which would translate into a 5.4 kg improvement over 100 days or 19.7 kg if applicable over the first year of life. This increased weight is substantial, representing a 10% improvement, assuming calves reach 197 kg by a year of age (average weight in our study calves on their sixth visit was 188 kg). The reasons for these improvements could be because a better roof



**Table 7** Descriptive statistics and *p* values (<0.25) for Model I (pre-weaning visits) univariable linear regressions for continuous variables associated with ln average daily gain for 165 calves on 132 Kenyan smallholder farms

Variable	<i>N</i>	Mean	SD	Median	<i>P</i> Value
Herd size	132	5.9	4.9	4.0	<0.001
Total number of adults in the household	132	2.8	1.3	2	0.070
Number of years involved in dairy farming	132	16.9	12.2	13	0.013
Age at first acaricide application (weeks)	132	16.4	12.9	12	0.250
Age at first deworming application (weeks)	132	17.5	12.7	12	0.013
Total number of calf pens	132	1.4	1.5	1	<0.001
Mortality risk over the last 5 years	132	0.2	0.2	0.1	<0.001
Age at first free access to water (weeks)	132	13.7	13.4	12	<0.001
Frequency of milk feeding per day	132	2.2	0.4	2	0.018
Dam average daily milk yield in the first 6 weeks (L)	165	15.7	6.9	15	<0.001
Age at first introduction of hay (weeks)	132	5.2	5.2	3.5	0.003
Age of the animal during the farm visit (days)	494	95.2	65.9	86.0	0.134

provides a drier area to lie down, and better flooring provides a softer drier area to lie down. Both of these improvements make the lying area more comfortable, leading to a longer lying down time, as found in a companion paper (Kimeli 2020), and therefore higher ADG.

We observed an overall ADG of 0.429 kg/d with a median of 0.365 kg/d during the entire study period. These ADGs are higher than 0.135 kg/d (Thumbi et al. 2013), 0.338 kg/d (Lanyasunya et al. 2006) and 0.260 kg/d (Gitau et al. 2001) that were reported from Western, Nakuru and Central Kenya, respectively. It is however slightly lower compared to 0.50 kg/d (Kathambi et al. 2018) and 0.443 kg/d (Makau et al. 2018) reported from studies conducted in the Meru region of Kenya. Generally, the observed ADG was within 0.4–0.5 kg/d which is the recommended target for smallholder dairy farms in Kenya (Lukuyu et al. 2012) but lower than 0.5–0.75 kg/d, the target for developed countries (Radostits and Blood 1985).

Our study observed a higher ADG over time with 0.324 kg/d pre-weaning and 0.510 kg/d post-weaning. This is contrary to observations by Makau et al. (2018) who reported a general decrease in predicted ADG from about 0.750 g/d at 2 weeks of age to 0.500 g/d and 0.350 g/d for heifers up to 10 and 30 months of age, respectively. Our results may be a typical case of compensatory growth in which the animals accelerate growth after a period of restricted development, mainly due to disease (coccidia infections) and limited feeding during the pre-weaning period (Hornick et al. 2000).

Our study showed that there was an interaction between the highest education level and the gender of the principal farmer (Table 9). The pre-weaning ADG was significantly lower for female than male principal farmers but only when the principal farmer only had primary education. These results are consistent with the findings of Makau et al. (2018) who reported that ADG was lower by 20.7% when the principal farmer was

**Table 8** Descriptive statistics and *p* values (<0.25) for Model II (post-weaning visits) univariable linear regressions for continuous variables associated with average daily gain for 100 calves on 91 Kenyan smallholder farms

Variable	<i>N</i>	Mean	SD	Median	<i>P</i> value
Herd size	91	6.3	5.1	4	<0.001
Age of principal farmer	91	51.3	12.7	52	<0.001
Total number of adults in the household	91	3.0	1.4	3	0.007
Number of years involved in dairy farming	91	17.7	12.5	13	<0.001
Age at first acaricide application (weeks)	91	19.9	11.3	18.3	0.121
Age at first deworming application (weeks)	91	16.9	10.7	12	<0.001
Total number of calf pens	91	1.5	1.7	1	<0.001
Mortality risk over the last 5 years	91	18.4	20.6	12	<0.001
Age at first free access to water (weeks)	91	13.7	14.1	12	<0.001
Frequency of milk feeding per day	91	2.1	0.4	2	0.249
Dam average daily milk yield in the first 6 weeks (L)	100	16.0	7.0	15.5	<0.001
Age at first introduction of concentrate (weeks)	91	6.3	6.3	4	0.004
Age at first introduction of hay (weeks)	91	4.8	4.6	3	0.011

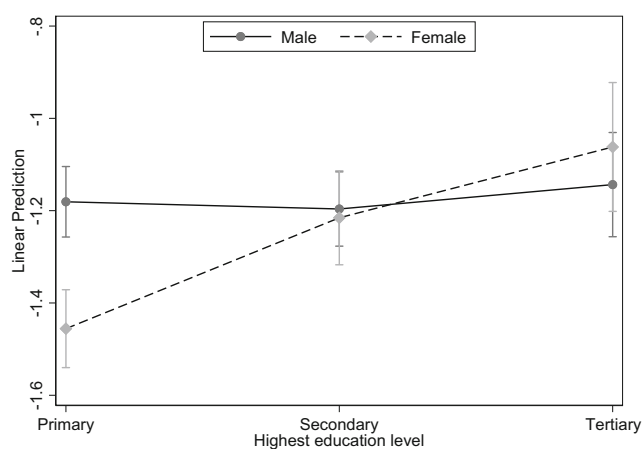
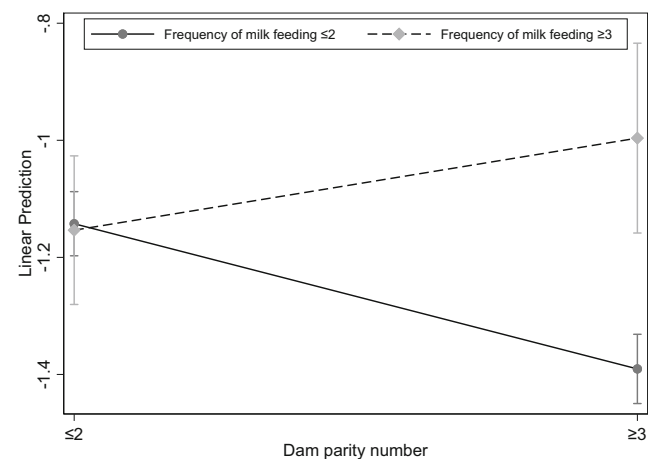
**Table 9** Final linear regression model for pre-weaning ln average daily gain (model I) for 165 calves on 132 Kenyan smallholder farms

Variable	Coefficient	95% CI	P value
Highest level of education of the principal farmer			
Primary	Baseline		0.759*
Secondary	-0.0156	-0.1261, 0.0949	0.782
College/University	0.0372	-0.1006, 0.1750	0.596
Gender of the principal farmer			
Male	Baseline		
Female	-0.2749	-0.3898, -0.1601	<0.001
Highest level of education of the principal farmer * Gender of the principal farmer			
Secondary * Female	0.2559	0.0822, 0.4296	0.004
College/ University * Female	0.3565	0.1493, 0.5637	0.001
Dam parity number			
≤2	Baseline		
≥3	-0.2480	-0.1500, -0.1280	<0.001
Frequency of milk feeding per day			
≤2	Baseline		
≥3	0.0110	-0.0828, 0.2014	0.876
Parity of the dam * Frequency of milk feeding per day			
≥3rd parity * Frequency of milk feeding ≥3	0.4053	0.1882, 0.6224	<0.001
Age at first acaricide application (weeks)	0.0064	0.0032, 0.0096	<0.001
Total number of calf pens	0.0521	0.0322, 0.0720	<0.001
Mortality risk over the last 5 years	-0.0046	-0.0065, -0.0027	<0.001
Age at first free access to water (weeks)	-0.0070	-0.0105, -0.0036	<0.001
Constant	-1.1427		

\*Overall P value

female, compared to male principal farmers or when the male and female were both listed as the principal farmer. Generally, in the Kenyan setup, males are considered the head of the household and can be closely involved in farm activities, if available. However, in many situations where females are the principal farm managers, it means that the male counterpart is

either missing (deceased, separated or divorced) or occupied off the farm (by employment or other activities). Women with only primary education are more likely to have more children (Ouma 2006), requiring more time to manage the household, leaving less time to oversee animal husbandry. Additionally, females with lower education and more children likely have a

**Fig. 3** Interaction plot of the predicted pre-weaning ln average daily gain and 95% CI for gender and education level of the principal farmer, based on the final model of 165 calves in 132 Kenyan smallholder farms**Fig. 4** Interaction plot of the predicted pre-weaning ln average daily gain and 95% CI for dam parity number and frequency of milk feeding, based on the final model of 165 calves in 132 Kenyan smallholder farms

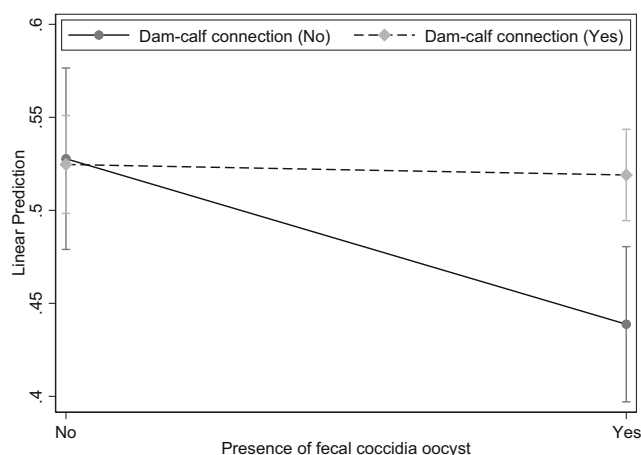
**Table 10** Final linear regression model for post-weaning average daily gain (model II) for 100 calves on 91 Kenyan smallholder farms

Variable	Coefficient	95%CI	P value
Calf housing improvement			
No	Baseline		
Yes	0.0541	0.0167, 0.0915	0.005
Age of principal farmer	-0.0044	-0.0058, -0.0030	<0.001
Gender of the principal farmer			
Male	Baseline		
Female	-0.1704	-0.2296, -0.1113	<0.001
Total number of calf pens	0.0085	0.0001, 0.0218	0.048
Female principal farmer * Total number of calf pens	0.0666	0.0325, 0.1006	<0.001
Fed maize bran			
No	Baseline		
Yes	0.0863	0.0510, 0.1216	<0.001
Fed wheat bran			
No	Baseline		
Yes	0.0788	0.0330, 0.1245	0.001
Fed calf pellets			
No	Baseline		
Yes	0.2039	0.1074, 0.3005	<0.001
Fed hay			
No	Baseline		
Yes	0.0769	0.0420, 0.1118	0.001
Age at first introduction of concentrate (weeks)	-0.0046	-0.0073, -0.0020	0.001
Dam average daily milk yield in the first 6 weeks (L)	0.0084	0.0053, 0.0114	<0.001
Mortality risk over the last 5 years (%)	-0.0024	-0.0033, -0.0016	<0.001
Presence of faecal coccidia oocyst			
No	Baseline		
Yes	-0.0890	-0.1517, -0.0262	0.006
Presence of dam-calf connection			
No	Baseline		
Yes	-0.0031	-0.0595, 0.0533	0.914
Dam-calf connection * Presence of faecal coccidia oocyst	0.0834	0.0112, 0.1555	0.024
Constant	0.6168		

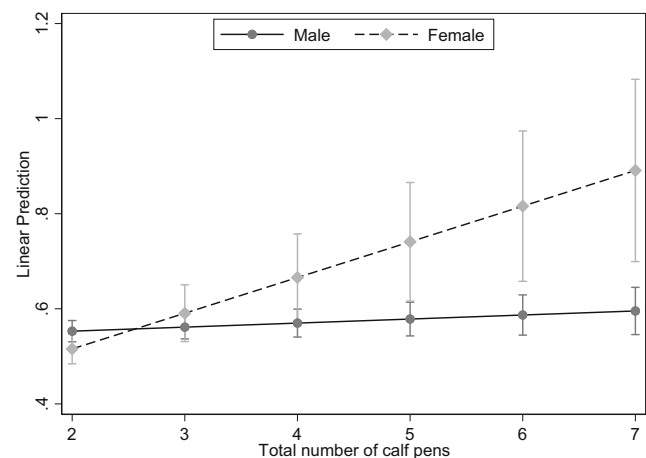
lower socioeconomic status and resource base in order to ensure good housing and nutrition of their calves. It could also be that the women with only primary education have less means to acquire better animals. Overall, ADG improved with increasing education levels, indicating that educated farmers

were likely adopting better management approaches, such as better nutrition, improved housing and disease control.

We also observed an interaction between gender of the principal farmer and total number of calf pens in the post-weaning model (Table 10), where ADG increased with an



**Fig. 5** Interaction plot of the predicted post-weaning average daily gain with 95% CI for the presence of faecal coccidia and dam-calf connection, based on the final model of 100 calves in 91 Kenyan smallholder farms



**Fig. 6** Interaction plot of the predicted post-weaning average daily gain and 95% CI for the gender of the principal farmer and a total number of calf pens, based on the final model of 100 calves in 91 Kenyan smallholder farms

increasing number of calf pens for women while remaining the same for men. We speculate that when women were the principal farmer and farming was their primary source of income, they ensured that the calves were in individual pens for better control over nutrition, hygiene, and bullying, even though it meant more work to keep them clean and well fed because they were in multiple pens rather than all in one pen. Conversely, we observed that men would typically leave multiple animals in one pen because it was quicker to feed the animals and clean only one pen, or not put in the extra effort for good nutrition and hygiene if multiple pens were used. Group housing of calves, especially during the first 1 month of life in suboptimal hygienic conditions, has been shown to have a significantly increased risk of diarrhoeal disease, likely due to increased transmission of enteric pathogens (Curtis et al. 2016). Furthermore, on smallholder dairy farms in developing countries, there is usually a large difference in size between calves on a farm due to the small number of cows on a farm (< 10 cows per farm in our study). Bullying of young calves in group housed pens on such farms is inevitable, leading to lower ADG; therefore, individually housed calves is preferred for better control over nutrition, bullying, and hygiene. Therefore, recent research promoting the benefits of group housing of calves on large farms with cohorts of calves that are approximately the same size (Khan et al. 2016) are unlikely to apply to smallholder dairy farms in Kenya.

The influence of dam parity number on ADG depended on the frequency of milk feeding in our study (Table 9). When the parity number was higher ( $\geq 3$ ), the ADG was higher if the frequency of milk feeding was three times or more. All farmers in this study practiced artificial insemination, but many were using local genetics on younger cows (mainly first and second lactation), which is cheaper at \$5–10 USD per breeding. Conversely, imported genetics were more often used on older cows once the cow fertility is proven to warrant more expensive semen at \$40–150 USD. As a result, the latter calves are likely of high potential, selected for superior performance, including growth rate, which heavily depends on milk quantity offered pre-weaning. It might also be that the higher parity cows were better producers than lower parity cows, and therefore more milk was available to feed the calf and for sale. In their study, Hoseyni et al. (2016) reported that multiparous cows had higher milk production, which was positively correlated with pre-weaning ADG.

Our study revealed that delayed age at first acaricide application was associated with increased ADG (Table 9). Ectoparasites, especially ticks, have been reported to have a significant economic impact on the dairy industry as they cause deleterious effects in cattle bodyweight through blood loss and the transmission of disease-causing agents (Parizi et al. 2012). In exclusively zero-grazing production systems in Kenya, ticks were observed in less than 5% of the calves, compared with over 80% of calves in extensive productive

systems utilizing grazing (Okuthe and Buyu 2006; Gachohi et al. 2012; Omondi et al. 2017). All of our study farmers indicated that they used acaricide spray (mainly synthetic pyrethroids, organophosphate or amitraz) but at a reduced frequency of about once every 2 months, unlike the weekly use in high tick-risk areas. We speculate that delayed acaricide use meant that finances which would have been used for acaricide purchases were utilised elsewhere, including buying of feed and thus improved growth.

We observed that farms that had high mortality risk over the last 5 years had lower ADG (Tables 9 and 10). Previous studies in Kenya showed that tick-borne disease played a minimal role in overall calf mortalities (Gitau et al. 2001); instead diarrhoea was recorded as the most common cause of both morbidity and mortality, at 27% and 22% per year, respectively (Gitau et al. 1994). The diarrhoea was associated with calf care and management factors. In a study on calves in smallholder farms, Chang'a et al. (2010) noticed that about half of the cow-sheds had poor hygiene, with a poor drainage system, and flat floors with potholes. In that study, farmers frequently disposed of the dung and waste materials in the vicinity of the animal housing, which often resulted in unhygienic calf-rearing conditions. These conditions can create situations which impair calf health by overwhelming immunity that, in conjunction with poor nutrition, leads to stunted growth.

The current study revealed that ADG was reduced when calves were delayed in their first ad lib access to drinking water (Table 9). Water provision has been associated with early rumen and microbiome development, feed intake, weight gain and immune response (Senevirathne et al. 2018). Wickramasinghe et al. (2018) observed that the provision of drinking water immediately after birth could improve the growth and development of calves pre- and post-weaning, potentially by stimulating rumen development, thus increasing nutrient availability. Therefore, early water provision is of great benefit to calves and should be encouraged. Unfortunately, it is a common perception among farmers that ad lib water access to calves will lead to calves drinking a lot of water all at once, leading to hemolysis and hemoglobinuria. Young bucket-fed calves can drink excessive quantities of water if offered to them in the way they usually receive their milk because the limit of their consumption in that circumstance is governed not by satiety, but by the physical limit of the capacity of the gut (Njoroge et al. 1999). However, calves do not overdrink water when it is available ad lib from birth.

The age at first introduction of commercial concentrate supplements (e.g. calf starter with at least 18% protein) to calves had a significant impact on weight gain (Table 10). Calves that received at least a handful of concentrate early in life performed better than those in which concentrate administration was delayed. Previous reports have shown that incorporating starter diets for young calves at an early age is the

best approach for improving both rumen papillae development and subsequent performance to attain a favourable growth rate (Bach et al. 2007; Khan et al., 2011; Reddy et al. 2017).

Our study showed that calves provided calf meal/pellets, maize bran, and wheat bran had greatly improved ADG (Table 10). Calf meal/pellets are commercial supplements that are high in crude protein (18–22%) but may be too expensive for some smallholder farmers. Both wheat and maize bran are milling by-products and can vary in quality, depending on the proportions of the outer skins, germ (fat-rich) and endosperm that are in the products (Mlay et al. 2005). Chemical analyses of similar cattle feed in Pakistan have shown that maize bran has 89% dry matter, 14.0% crude protein and 12.0% crude fibre, while wheat bran has 89% dry matter, 13.1% crude protein and 11.3% crude fibre (Tahir et al. 2002). These chemical analyses confirm that wheat bran and maize bran can be important alternative sources of supplemental protein for ruminants, although they are lower in crude protein than calf meal or pellets. While no other studies could be found demonstrating effects of bran feeding on ADG in calves, a feeding trial has shown that adding wheat bran to a forage diet increased dry matter intake and milk yield, and improved the energy balance (Erlt et al. 2017). Therefore, bran feeding should be encouraged if farmers are not feeding any grain to preweaned calves because they cannot afford calf pellets. Wheat bran and maize bran are inexpensive and readily available in the Kenyan market. There is, however, a need to investigate further the optimal amount of bran to feed, and what are the benefits accrued when bran is mixed with other available by-products such as maize germ, cotton seed cake and sunflower seeds.

The study showed that calves whose dams produced high milk yield at the time of recruitment had higher predicted ADG (Table 10). This result is consistent with the findings of Addisu et al. (2010) who reported a significant positive association between ADG and milk yield traits. It is likely that farmers were consistently providing more milk to calves whose dams had ample milk for calf consumption, household consumption, and sales to acquire much needed income.

Our study found that improved ADG post-weaning was associated with calves with dam-calf connections—rearing a calf in a pen adjacent to her dam with physical or visual contact with her dam (Table 10). The dam-calf connection system best mimics the natural situation and allows free behavioural expression and thus improved welfare (Johnsen et al. 2016). Although there are controversies surrounding dam-calf physical contact at younger ages due to the potential spread of infectious disease and parasites (Gebeyehu et al. 2018; Kimeli et al. 2020), our study showed increased ADG post-weaning if a dam-calf connection was present compared to calves completely secluded from the dam with no physical or visual contact, especially if coccidia shedding was occurring.

Decreased predicted ADG was observed in calves that were positive for faecal coccidia oocysts (Table 10). Coccidia are known to destroy the lining of the intestine, causing inefficiency of nutrient absorption and decreased appetite, which is detrimental to the growth (Coffin 2018). Farmers should be encouraged to consider coccidia control programs, including starter feed with coccidiostats (which are currently uncommon in Kenya) and improved calf hygiene and daily sanitation to remove faeces, thereby decreasing the environmental load of oocysts in the local environment.

A limitation to our study was that county location and intervention grouping were collinear, leading to a possible confounding effect of the county. Although there was a baseline mean difference between groups in a few of the variables (Tables 2 and 3), we believe that the groups were comparable for the study objectives since most of the important variables in the final models were not statistically significantly different between the groups at enrolment. Furthermore, the variables that were found to be statistically significantly different between the two groups at enrolment were controlled for in the models: (1) ADG controlled for body weight at enrolment; (2) number of calf pens in the model controlled for herd size and/or farm size/income; and (3) farmer education in the model controlled for farmer education level at enrolment. Randomisation at the farm level would have been ideal for minimizing the possible effects of selection bias, information bias and confounding. However, randomisation within the county was impractical in the current study since the interventions involved easily fixable housing improvement, which could be implemented by the control farmers if they visited intervention farms, which would have contaminated the control group farms, as we observed in other cow comfort intervention trials in Kenya (Kathambi et al. 2019; Richards 2017). We chose the small amount of residual confounding from county level randomisation after confounding controls in the models over the large amount of contamination from farm level randomisation observed first-hand in our previous Kenyan smallholder dairy farm trials.

## Conclusion and recommendation

The growth of calves from birth to 1 year was generally within the recommended smallholder targets for zero-grazing farms in Kiambu and Murang'a Counties, but below the internationally expected performance targets. The positive effect of calf housing improvements on post-weaning ADG was significant, even after controlling for other factors in the final model, suggesting that housing factors have long-term impacts on the growth of calves. ADG was also found to have associations with management factors such as frequency of milk feeding, age at first acaricide application, age at first access to ad lib water, concentrate supplementation of various types, and

presence of a dam-calf connection. Additionally, farmer traits such as education level, gender and age were associated with the growth performance. One animal-level factor was associated with ADG, coccidia oocyst shedding. We recommend that farmers should implement housing improvements, coccidia control, and early water and concentrate provision, and construct more calf pens with at least visual contact between calves and dams. Farmers and animal health professionals should be trained with an emphasis on the identified factors to ensure better calf health and growth. Further study should quantify the long-term effects of improved housing on reproduction indices and lactational performance, such as age at first calving and milk yield during the first lactation.

**Acknowledgements** This research was made possible with the financial support of the Sir James Dunn Animal Welfare Centre and University of Prince Edward Island. The funders had no role in the design, conduct or writing of the research.

The authors would also like to gratefully acknowledge the support of Kiambu and Murang'a County governments, local dairy cooperative societies, and farmers who graciously allowed us into their farms. Further, thanks are given to Charles Muraguri and Isaac Karuri who were field assistants, and Edith Keya and Beatrice Mutende who processed the faecal samples.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval and farmer consent** This study was approved by the Research Ethics Board and the Animal Care Committee of the University of Prince Edward Island (#6007717). The study was explained orally to all participants, and signatures for informed consent were obtained from all the participants in the study.

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