S.L. Vet.J. 2021, 68 (1 & 2) 1 - 9 http://doi.org/10.4038/slvj.v68i1-2.55
Original Research Article

THE RELATIONSHIP BETWEEN LOCOMOTION SCORE AND REPRODUCTIVE PERFORMANCE ON AN UP-COUNTRY LARGE-SCALE COMMERCIAL DAIRY FARM IN SRI LANKA

S. Ekanayake [1*], Y.H.P.S.N. Kumara [2, 3], L. Laven [1], K. Mueller [1], P.G.A. Pushpakumara [3] and R. Laven [1]

[1] *School of Veterinary Science, Massey University, Palmerston North, 4410, New Zealand.*
[2] *School of Agriculture and Environment, Massey University, Palmerston North, 4410, New Zealand.*
[3] *Department of Farm Animal Production and Health, Faculty of Veterinary Medicine and Animal Science, University of Peradeniya, Peradeniya, 20400, Sri Lanka.*

SUMMARY: This study analysed data from a large-scale commercial Up-Country dairy farm, to better understand the impact of lameness on fertility. Over a 12-month period, cattle were locomotion scored five times (every 3 months). Lameness was defined as a locomotion score (LS) of >1 (1-5 scale) and thus included mildly-lame cows. The initial univariate analysis showed that cows which had two LS >1 in the first 180 days after calving and cows which had a LS>1 in the first 90 days after calving had a lower risk of pregnancy and a longer calving-to-conception interval than non-lame (LS=1) counterparts (*p*=0.019 and *p*=0.023 respectively). The multivariate model (Cox-proportional hazard model) identified that, although the hazard of pregnancy was still lower in cows with an LS>1 in the first 90 days after calving, the data were compatible with a reduction in the hazard and no effect (HR=0.68; 95% CI: 0.44-1.07). In contrast, cows that had two LS>1 in the first six months after calving (in both the 0-90- and 90-180-day periods) had a clear negative effect on the hazard of pregnancy. The hazard ratio for twice-lame cows in comparison with non-lame counterparts was 0.44 (95%CI 0.23-0.84), and the median calving-to-conception interval was 133 days longer. Although this data was from only one dairy herd, there is strong evidence that even mild lameness is associated with reduced fertility. Further research is needed from more Sri Lankan herds to better understand the impact of lameness on reproductive performance.

KEYWORDS: Sri Lanka, dairy cattle, lameness, mild lameness, fertility, survival analysis

INTRODUCTION

Managing lameness is a challenge in all dairy nations across the world regardless of the management system employed (Fabian *et al.,* 2014; Green *et al.,* 2014; Kumara *et al.,* 2019). Although the Sri Lankan dairy industry has, for generations, played an important role in the agricultural sector, there is very little published data on dairy cattle lameness in Sri Lanka. This absence of scientific evidence results in a lack of knowledge and awareness regarding dairy cattle lameness among the Sri Lankan dairy community.

One crucial area where data are lacking is the impact of lameness on the productivity of Sri Lankan dairy cows. The report by Kumara *et al.,* (2013) is the only one that the authors are aware of exploring the effect of lameness on reproduction in Sri Lankan dairy cattle. Using data from one high producing, large-scale commercial dairy farm, they reported that the mean calving-to-conception interval (CCI) was 33 days longer in lame than non-lame cows. This dataset needs further analysis as Kumara *et al.,* (2013) did not take into account of when a cow became lame, and the CCI calculation they used does not account for cows that fail to get pregnant or the skewed nature of CCI data (Hudson *et al.,* 2019). The best statistical approach to such data is survival analysis which can simultaneously analyse the combination of whether pregnancy has occurred (binary outcome)

Corresponding Author: S. Ekanayake, email: shashiekanayake01@gmail.com

and when it has occurred relative to calving (continuous outcome) (Lean *et al.*, 2016).

The aim of this study was therefore to re-analyse the dataset collected by Kumara *et al.*, (2013) using survival analysis in order to better characterise the relationship between lameness and reproduction in their study farm.

MATERIALS AND METHODS

This prospective observational study was undertaken on a single, large (600 adult cows) all-year-round calving dairy farm located in the Nuwara Eliya district in Sri Lanka from February 2011- February 2012. The milking herd was approximately 95% Friesian, and 5% FriesianxAyrshire. During the period of the study the average milk production of the farm was approximately 5000 L/day.

Milking cows on the farm were managed as three groups: high producing (early lactation) cows, lower producing (mid to late lactation) cows and first-lactation heifers. High producing cows were managed intensively, being fed a total mixed ration (TMR) and milked three times per day, while the lower producing cows and lactating heifers were managed semi intensively, being fed a mixture of a TMR and grazed grass and being milked twice per day.

The milking herd was locomotion scored on five occasions, every three months from February 2011 to February 2012. Cows were scored using a 1-5 point locomotion score (LS) scale (Sprecher *et al.*, 1997) during evening milking as they exited to the feeding alley from the milking parlour (Table 1). The herd was observed from a distance of 10-15 m, so as not to disturb their natural locomotion and behaviour. In addition, body condition scores (BCS) were recorded using a 1-5 BCS (Ferguson *et al.*, 1994).

Table 1: Locomotion scoring system for dairy cattle (Sprecher *et al.*, 1997).

Score	Clinical Description	Description	Back Posture Standing	Back Posture Walking
1	Normal	Stands and walks normally. All feet placed with purpose	Flat	Flat
2	Mildly lame	Stands with flat back, but arches when walks. Gait is slightly abnormal.	Flat	Arched
3	Moderately lame	Stands and walks with arched back. Short strides with one or more legs	Arched	Arched
4	Lame	Arched back, standing and walking one or more limbs favoured, but at least partially weight bearing.	Arched	Arched
5	Severely lame	Arched back, refuses to bear weight on one limb. May refuse or have great difficulty moving from lying position.	Arched	Arched

The reproductive data (calving date, insemination date(s), and conception date), milk production data (average milk yield per/day/cow) and parity number were extracted from the computer software programme Dairy CHAMP (University of Minnesota, USA). These data, along with locomotion score data and BCS were entered in to a Microsoft Excel spreadsheet (Microsoft Corporation, USA).

Lameness groups

Five groups of cows were created to analyse the association between lameness and reproduction. The five groups are summarised in Table 2. Initially, cows were included in a group based on when, relative to calving, they had been locomotion scored. Cows were included in both Group 1 and Group 2 if they had a LS which had been recorded within 90 days after calving (all cows included in these two groups had only one LS in this period as cows were locomotion scored every 90 days). Cows were included in both Group 3 and Group 4 if they had at least one LS recorded between 0 and 180 days after calving. Groups 3 and 4 thus included all the cows which were in Groups 1 and 2 with the addition of cows which had had a LS recorded between 91 and 180 days after calving, but which had not had a LS recorded between 0 and 90 days after calving. Group 5 cows included all cows which have had a LS recorded between 0 and 90 days after calving and between 91-180 days (i.e., two LS within 180 days after calving).

Once these five groups had been established, lameness definitions were created within each group (see Table 2). For example, in Group 1 a cow was defined as lame if it had a LS>1 between 0 and 90 days after calving, while in Group 2 a cow was defined as lame if it had a LS>1 at any time point during that lactation. A similar process was repeated for cows in Group 3 and 4 (see Table 2). For cows in Group 5, two lameness definitions were created – based on whether a cow has had two or one LS>1 between 0 and 180 days after calving.

Table 2: Summary of the five different lameness definitions used for the analysis.

Lameness Group	Group description		Total cows in group (number lame)
	Population inclusion criterion	Lameness criterion within included population	
Group 1	LS recorded from 0-90 days after calving	LS>1 between 0-90 days after calving	181 (51)
Group 2	LS recorded from 0-90 days after calving	LS>1 at any time† during study	181 (123)
Group 3	At least one LS recorded from 0-180 days after calving	LS>1 between 0-180 days after calving	198 (85)
Group 4	At least one LS recorded from 0-180 days after calving	LS>1 at any time	198 (136)
Group 5	Two LS recorded between 0-180 days after calving	LS >1 once: once-lame LS always>1: twice-lame	173 (once: 59; twice 20)

LS: locomotion score. †, at any time means that the cow was recorded as having an increased LS at any time during the study, i.e. not just the LS which determined whether a cow was eligible for inclusion in a group.

Note: Group 1 has same population of cattle as Group 2 but used different lameness definitions; Group 3 included the same population of cattle as Group 4 but used different lameness definitions. Groups 3 and 4 include all cows included in Groups 1 and 2 with the addition of cows that had their first LS after calving between 91 and 180 days after calving.

Statistical Analysis

The statistical analysis was performed using SPSS v26 (IBM, USA). For cows which had at least one locomotion score within 180 days of calving, descriptive statistics were created for CCI and the independent variables (average milk yield per day, parity number, BCS nearest to calving) that were thought likely to be associated with CCI.

For each of the five lameness groups, Kaplan-Meier survival analysis was then used to assess the association between the calving to conception interval and lameness. The homogeneity of the survival curves obtained was assessed using a log rank test. In addition, the relative risk of pregnancy before the end of the study period for lame cows compared to non-lame cows was also calculated. For cows in Group 5, this meant that both once-lame and twice-lame cows were compared to never-lame cows.

The correlations between the potential independent variables, i.e., BCS nearest to calving, parity (1st vs. 2nd or greater), lameness status, and average milk yield were analysed using Kendall's rank correlation to ensure that was $\tau < 0.8$, in order to reduce the risk of multicollinearity. For the lameness groups where the log rank test had identified an effect of lameness ($p<0.05$), a multivariate Cox proportional hazard model was then created, with time from calving to conception as the outcome variable and lameness group, BCS nearest to calving, parity (1st vs. 2nd or greater) and average milk yield as the independent variables.

RESULTS

During the study period 1219 LS were recorded of which 824 (68%) were LS1, 319 (26%) LS2, 60 (4.9%) LS3 and 16 (1.3%) LS4. No cows were recorded with LS5. Table 3 summarises the distribution of locomotion scores in the five locomotion scoring sessions and proportion of lame cows (LS>1) and clinically lame cows (LS>2) during each locomotion scoring session.

Table 3: Results of herd locomotion scoring on one herd in Nuwara Eliya district Sri Lanka.

LS Session	Cows scored	Cows LS1	Cows LS2	Cows LS3	Cows LS4	Percentage Cows LS>1	Percentage Cows LS>2
1 (Feb 2011)	265	197	59	6	3	25.7%	3.4%
2 (May 2011)	224	176	40	6	2	21.4%	3.6%
3 (Aug 2011)	254	172	65	14	3	32.3%	6.7%
4 (Nov 2011)	241	135	80	20	6	44.0%	10.8%
5 (Feb 2012)	235	144	75	14	2	39.1%	6.9%

One hundred and ninety-eight cows had at least one locomotion score within 180 days of calving and were therefore eligible for inclusion in the analysis. Of those 198 cows, 164 became pregnant during the study period. The 34 cows which did not become pregnant were a median 414 days from calving (range 280-727 days) at the end of data collection. Sixty-eight of the eligible cows were in their first lactation. Median interval between calving and BCS nearest to that calving was 19 days (range -64 to + 63 days) and median BCS at that time was 2.5 (range 1.5 to 3). Median milk yield of the eligible cows was 21.3 L/day (range 2.6 to 40.6 L/day).

The results of the Kaplan-Meier and relative risk analyses are summarised for the 5 lameness groups in Table 4.

Table 4: Effect of lameness on calving to conception interval and relative risk of pregnancy

Lameness group	Lameness status	N pregnant (%)	RR* (95% CI)	Median CCI (95% CI) days	P-value†
Group 1	Lame	36/51 (71%)	0.81 (0.67-0.98)	198 (142-253)	0.019
	Non-lame	113/130 (87%)		142 (126-158)	
Group 2	Lame	100/123 (81%)	0.96 (0.84-1.11)	157 (128-186)	0.333
	Non-lame	49/58 (84%)		141 (120-162)	
Group 3	Lame	66/85 (78%)	0.90 (0.78-1.02)	160 (112-207)	0.068
	Non-lame	98/113 (87%)		154 (133-175)	
Group 4	Lame	111/136 (82%)	0.95 (0.84-1.09)	169 (134-203)	0.174
	Non-lame	53/62 (85%)		142 (124-159)	
Group 5	Lame once	49/59 (83%)	0.95 (0.83-1.09)	143 (122-163)	0.023
	Lame twice	12/20 (60%)	0.68 (0.48-0.99)	235 (59-410)	
	Non-lame	82/94 (87%)		142 (116-168)	

See Table 1 for definition of lameness group and lameness status. RR = relative risk; *, compared to non-lame cows; CCI = calving to conception interval; †, log-rank test

In cows in Group 1 and Group 5, lameness status was identified by the log rank test as having an association with calving to conception interval (p=0.019 and 0.023, respectively). Data from the cows in these two groups were therefore used in two Cox proportional hazard model, the results of which are summarised in Table 5, with the covariate adjusted survival curves presented in Figures 1 and 2.

Table 5: Results from the multivariable Cox-proportional hazard regression model for hazard of getting pregnant for cows in lameness groups 1 and 5.

Lameness group*	Predictor variable	Hazard Ratio (95% CI)
1	Average milk yield (L/cow/day)	1.01 (0.98-1.03)
	Parity (1st vs. 2nd or greater)	0.83 (0.55-1.25)
	Body condition score	1.97 (1.25-3.10)
	Lame status (lame cows vs. non- lame)	0.68 (0.44-1.07)
5	Average milk yield/cow/day	1.00 (0.98-1.03)
	Parity (1st vs. 2nd or greater)	0.77 (0.51- 1.17)
	Body condition score	1.87 (1.17-2.98)
	Once-lame vs. non- lame	0.84 (0.56-1.26)
	Twice-lame vs. non- lame cows	0.44 (0.23-0.84)

* See Table 1 for definition of lameness group and lameness status

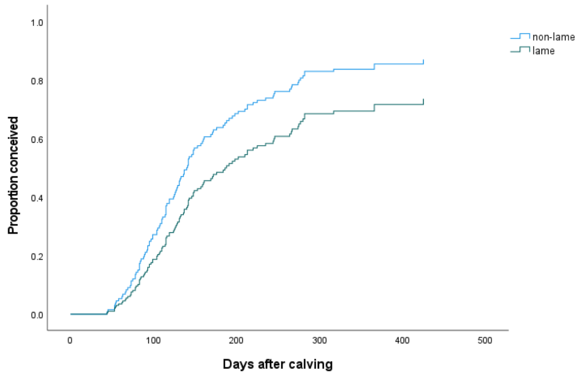

Figure 1: Covariate adjusted survival curve, estimated from the multivariate Cox-proportional hazard model showing the cumulative proportion for CCI for lame and non-lame cows in Group 1 (see Table 1).

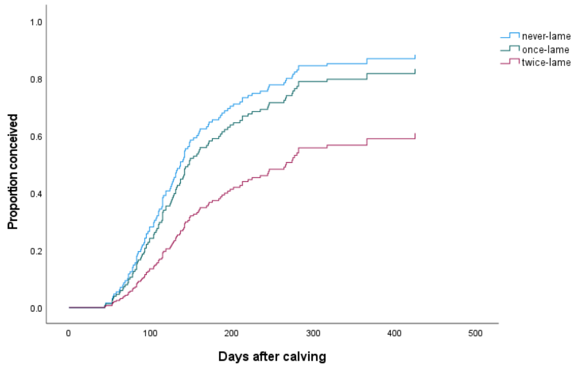

Figure 2: Covariate adjusted survival curve, estimated from the multivariate Cox-proportional hazard model showing the cumulative proportion

for CCI for lame and non-lame cows in Group 1 (see Table 1).

For Group 1 cows, lame cows took 50 days longer to get pregnant than non-lame cows (194 vs. 144 days, respectively). However, there was no clear effect of lameness on hazard of pregnancy, as although the study HR for lame cows compared to non-lame cows was 0.68, the 95% CI went from a large negative effect to a small positive one (0.44 to 1.07). In contrast, for Group 5 cows, there was a clear effect of having two scores of LS>1 on hazard of pregnancy; HR was 0.44 compared to non-lame cows with the data being compatible with a true HR being between 0.23 (a large negative effect) and 0.84 (a moderate negative one). Twice-lame cows took 133 days longer to get pregnant than never-lame cows (275 vs. 144 days, respectively), while once-lame cows took only 1 day longer to become pregnant than non-lame cows (145 days vs. 144 days)

In both models, the only other predictor variable shown to have a clear association with hazard of pregnancy was BCS nearest to calving. In the model for lameness group 1, an increase in BCS nearest to calving of one unit increased the hazard of getting pregnant by 1.97 times (95% CI: 1.25 to 3.10). In the model for lameness group 5, the equivalent effect of an increase BCS on the hazard of getting pregnant was 1.87 (95% CI: 1.17 to 2.98).

DISCUSSION

Although the 1-5 locomotion scoring system introduced by Sprecher *et al.,* (1997) defines all scores >1 as lame, most studies evaluating the impact of lameness using this scoring system have used a score of >2 as indicating lameness (Sprecher *et al.,* 1997; Espejo *et al.,* 2006; Somers *et al.,* 2015; Ratanapob *et al.,* 2020; Hut *et al.,* 2021). However, of the LS recorded for this study, the proportion that were >2 was only 6.2%, so we used LS>1 as our lameness definition.

The initial univariate analysis showed that cows that had a LS>1 in the first 90 days after calving had a lower risk of pregnancy and a higher median CCI than cows that had a LS of 0 during that period. However, in the multivariate model, although the hazard of pregnancy was still lower in lame cows, the data were compatible with both a reduction in the hazard and no meaningful effect. In contrast, both the univariate and the multivariate analyses showed a clear negative association between being lame twice in the first six months after calving and hazard of pregnancy. For the multivariate analysis, the HR for twice-lame cows compared to non-lame cows was 0.44 (95%CI 0.23-0.84), and median CCI was 133 days longer.

This finding is consistent with previous data showing that lameness has a negative impact on dairy cow reproduction (Huxley, 2013; Ekanayake *et al.,* 2019). However, most of the studies reviewed by those authors focused on clinical lameness or LS equivalent to >2 on a 1-5 scale, so would have included the majority of cows categorized as lame in the current study as non-lame. Only four published studies by Sood and Nanda, (2013); Olechnowicz, (2015); Orgel *et al.*, (2016) and O'Connor *et al.*, (2020) looked at the impact of mild-lameness on dairy cows fertility. Of those studies only Orgel *et al.*, (2016) found that mildly lame cows had reduced reproductive performance compared to non-lame cows. They reported that cows observed as mildly lame in their third month of lactation had 18 days longer CCI (120 vs. 102 days, P=0.002) than non-lame cows. This effect is much smaller than the 133 days increase in CCI seen in this study in cattle that had an LS>1 on two occasions between days 0 and 180 after calving. This may, at least in part be because of differences in study design. Orgel *et al.*, (2016) monitored LS on a monthly basis (as opposed to the 3-month gap between observations used in this study), so cows identified as mildly lame in the present study are likely to have had more persistent gait changes than those identified as mildly lame by Orgel *et al.*, (2016), and persistence of increased LS is likely to increase the impact of that increased LS (Archer *et al.*, 2010). Persistence of lameness is likely to lead to a greater impact. This is particularly applicable to the twice-lame cows who were recorded as having a LS≥2 on two occasions, 3 months apart. There were also differences in the definition of the non-lame cows; Orgel *et al.*, (2016) compared their LS2 cows to cows that had a LS1 in the same month (irrespective of previous or subsequent LS) whereas for lameness group 5 cows in our study, a non-lame cow was a cow that had LS1 on both occasions. Perhaps the most important difference was that Orgel *et al.*, (2016) included only LS2 cows in their analysis, whereas in the present study our analysis included cows from score 2 to score 4. Indeed, of the 20 cows included in the twice-lame group only 10 had LS2 on both occasions. However the 133-day difference in CCI reported in the current study was much larger than any of the differences attributed to LS>2 by Orgel *et al.,* (2016), and when the data were re-analysed using only the 10 cows that had LS2 on both occasions, the log rank test still identified a difference between twice-lame and non-lame cows (p=0.002) (No difference in median CCI could be estimated as only 4/10 cows became pregnant). Nevertheless, although the data strongly suggest that the hazard of pregnancy is lower compared to non-lame cows, with such a small number of cows in the twice-lame group, the 95% confidence of any estimate intervals are wide (see Table 3), so further data are required to better establish the likely effect of mild persistent lameness on CCI on this and similar farms in Sri Lanka. Such data should be collected on a more regular basis to minimise the number of cows which elevated LS between scoring events and to better establish the true duration of apparently persistent mild lameness.

For Group 1 cows (cows with one LS between 0 and 90 days after calving), there was a 50-day difference between the CCI of cows that had LS ≥2 and those which had LS 1. This difference was again much bigger than any difference reported by Orgel *et al.,* (2016), even though of the total 51 lame cows during 0-90 days after calving, 43 had an LS = 2 which represented mild lameness in our study. However, in contrast to the twice-lame cows, the data were compatible with no effect of mild lameness; i.e. our study lacked the power to identify an increase in CCI of 50 days as different from 0. This lack of power was also an issue in the studies by Sood and Nanda (2013) and Olechnowicz (2015) who found no effect, but would also not have been able to identify an increase in CCI of 50 days as different from 0. Clearly a 50-day increase in CCI is economically important, so further data are required to better establish the likely effect of early mild lameness on CCI on this and similar farms in Sri Lanka.

This research was undertaken on one dairy farm, which in Sri Lanka is considered to be a large scale, intensive, commercial dairy farm. This farm is not representative of most dairy farms in Sri Lanka. Therefore, our conclusion that mild lameness affects fertility needs confirming with further research on more farms (even for other intensive Sri Lankan dairy farms).

CONCLUSION

This analysis study has shown that on this herd even mild lameness was associated with poor fertility. This prospective study found a univariate association between the hazard of pregnancy and mild lameness (LS>1) in the first 3 three months after calving, and between chronic lameness (two LS>1) during the first six months after calving. Accounting for differences in age, BCS around calving and milk production, cows with LS>1 at both examinations in the first six months after calving had markedly lower fertility than cows which had no scores>1. Further research is needed from more Sri Lankan herds to better establish the likely impact of lameness on reproductive performance.

ACKNOWLEDGEMENTS

The authors would like to thank to the owner of the "Ambewela dairy farms", Mr. Harry Jayawardena, and all the farm staff members for their great support during the period of one year of data collection.

REFERENCE

Zheng, R., Xie, S., Lu, X., Sun, L., Zhou, Y., Zhang, Y., Wang, K. (2018). A Systematic Review and Meta-Analysis of Epidemiology and Clinical Manifestations of Human Brucellosis in China. *BioMed Research International*, 1–10. doi:10.1155/2018/57129

Archer, S.C., Green, M.J., Huxley, J.N. (2010). Association between milk yield and serial locomotion score assessments in UK dairy cows. *Journal of Dairy Science*, **93**, 4045-4053. DOI:3168/jds.2010-3062.

Ekanayake, S., Laven, L., Mueller, K., Huxley, J., Laven, R. (2019). Impact of Lameness on Reproduction and Milk Production in Dairy Cattle. A review of abstracts from International Ruminant Lameness conferences (2002-2017). *Proceedings of 20th International symposium and 12th International conference on lameness in Ruminants*, Tokyo, Japan, 2019.

Espejo, L.A., Endres, M.I., Salfer, J.A. (2006) Prevalence of Lameness in High-Producing Holstein Cows Housed in Freestall Barns in Minnesota. *Journal of Dairy Science*, **89**, 3052-3058. DOI:10.3168/jds.S0022-0302(06)72579-6.

Fabian, J., Laven, R.A., Whay, H.R. (2014). The prevalence of lameness on New Zealand dairy farms: A comparison of farmer estimate and locomotion scoring. *The Veterinary Journal,* **201**, 31-8, DOI:10.1016/j.tvjl.2014.05.011.

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

Green, L.E., Huxley, J. N., Banks, C., Green, M.J. (2014). Temporal associations between low body condition, lameness and milk yield in a UK dairy herd. *Preventive Veterinary Medicine,* **113**, 63-71. DOI :10.1016/j.prevetmed.2013.10.009.

Hudson, C., Cook, J.G., Laven, R. In: D. Noakes., T. Parkinson, G. England (2019). *Veterinary Reproduction and Obstetrics* (10th Edtn). W.B. Saunders, Chapter 25, 467-484.

Hut, P.R., Hostens, M.M., Beijaard, M.J., van Eerdenburg, F.J.C.M., Hulsen, J.H.J.L., Hooijer, G.A., Stassen, E.N., Nielen, M. (2021). Associations between body condition score, locomotion score, and sensor-based time budgets of dairy cattle during the dry period and early lactation. *Journal of Dairy Science,* **104**, 4746-4763. doi:10.3168/jds.2020-19200.

Huxley, J.N. (2013). Impact of lameness and claw lesions in cows on health and production. *Livestock Science*, **156**, 64-70. DOI:10.1016/j.livsci.2013.06.012.

Kumara,S.N., Jayakantha, M.A.K., Abeysinghe, A.M.P., Sanjeewa, M.A., Laven, R.A., Pushpakumara, P.G.A. (2019). The relationship between lameness, milk production and fertility in lactating dairy cows in two dairy farms of Sri Lanka. *Proceedings of 20 th international symposium and 12 th International conference on lameness in Ruminants,* Tokyo, Japan.

Kumara,Y.H.P.S.N., Abeysinghe, A.M.P., Sanjeewa, M.P.K., Pushpakumara, P.G.A. (2013). Relationship between Lameness and Productive and Reproductive Performance in Milking herd of an Upcountry Dairy Farm. *Proceedings of 65 th Annual Scientific Sessions of Sri Lanka Veterinary Association,* Gannoruwa, Sri Lanka.

Lean, I.J., Lucy, M.C., McNamara, J,P., Bradford,B.J., Block, E., Thomson, J.M., Morton, J.M., Celi ,P., Rabiee, A.R., Santos, J.E.P., Thatcher, W.W., LeBlanc, S.J. (2016). Recommendations for reporting intervention studies on reproductive performance in dairy cattle: Improving design, analysis, and interpretation of research on reproduction. *Journal of Dairy Science*, **99**, 1-17, doi:10.3168/jds.2015-9445.

O'Connor, A., Bokkers, E.A.M., Boer, I.J.M., Hogeveen, H., Sayers, R., Byrne, N., Ruelle, E., Shalloo, L. (2020). Associating mobility scores with production and reproductive performance in pasture-based dairy cows. *Journal of Dairy Science*, **103**, doi:10.3168/jds.2019-17103.

Olechnowicz, J. (2015). Associations between different degrees of lameness in early lactation and the fertility of dairy cows. *Medycyna Weterynaryjna*, **71**, 36-40.

Orgel, C., Ruddat, I., Hoedemaker, M. (2016). Prävalenz von Lahmheiten unterschiedlichen Grades in der Frühlaktation von Milchkühen und deren Einfluss auf Fruchtbarkeitsparameter. *Tierarztl Prax Ausg G Grosstiere Nutztiere*, **44**, 207-217.

Ratanapob, N., Thiangtum, W., Rukkawamsak, T., Srisomrun, S., Panneum, S., Arunvipas, P. (2020). The relationship between lameness and reproductive performance in dairy cows raised in small holder farms, Thailand. Songklanakarin *Journal of Science and Technology*, **42**, 766-770.

Somers, J., Huxley, J., Lorenz, I., MLO, D., Grady, L. (2015). The effect of lameness before and during the breeding season on fertility in ten pasture based Irish dairy herds. *Proceedings of 18th International symposium and 10thconference on Lameness in Ruminants,* Valdivia, Chile.

Sood, P., Nanda., A.S. (2013). Lameness in cross breed cows; prevalance, host level, risk factors and reproductive performance. *Indian Journal of Animal Science*, **83**, 3793-3782.

Sprecher, D.J., Hostetler, D.E., Kaneene, J.B. (1997). A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance. *Theriogenology*, **47**, 1179-1189, 1997.