Relationship between body condition score and pregnancy rates following artificial insemination and subsequent natural mating in beef cows on commercial farms in New Zealand

F Weik[a]*, JA Archer[b], ST Morris[a], DJ Garrick[a] and RE Hickson[a]

[a]*School of Agriculture and Environment, Massey University, Private Bag 11222, Palmerston North 4442, New Zealand;* [b]*AbacusBio Ltd, PO Box 5585, Dunedin 9054, New Zealand*

**Corresponding author:* Email: f.weik@massey.ac.nz

Abstract

Body condition scoring is an efficient on-farm visual-assessment tool used to describe the energy reserves of animals. Cow body condition score (BCS) at crucial time points throughout the year is likely to influence reproductive performance. The aim of this experiment was to examine the influence of BCS before calving, before mating and at weaning on reproductive performance of mature beef cows. Percentage of cows conceiving to a single artificial insemination (AI) at a synchronised oestrus and pregnancy rate after 49 days of mating were determined for a total of 2,683 individual cows. Cows with a greater than average BCS had greater pregnancy rate to AI than did those with low BCS (P<0.001). The percentage of animals conceiving to AI was on average 54.8% but was lower at 42.5% for pre-mating BCS 4.5 or greater at 64.5% for BCS 9.0 (P<0.001). Cows had greater overall pregnancy rate after 49 days of mating with greater BCS; ranging from 88.3%, 75.7% and 79.7% for BCS 4.5 before calving, before mating and at weaning, respectively, to 93.5%, 93.3% and 93.3% for BCS 8.0 at the same time points. Increasing BCS up to 7 is likely to improve overall pregnancy rate, and most benefit tends to come from improving BCS in lower-conditioned cows to achieve high pregnancy results.

Keywords: beef cows; BCS; reproductive performance; pregnancy rate; artificial insemination

Introduction

Body condition scoring is an easy and efficient tool to assess the energy reserves of livestock which reflects their recent nutritional management. It is used to evaluate energy reserves of the animals based on their body fat and muscle reserves (Bishop et al. 1994; Wagner et al. 1988) and is a better predictor of body fat than is live weight (Russel et al. 1969). The assessment of body condition score (BCS) should not simply reflect the live weight of the animals nor be influenced by factors like gut-fill, mature size or weight of the conceptus in pregnant cows. BCS can be used to evaluate the body reserves of cows at crucial time points throughout the year to improve feed planning, which is known to influence reproductive performance (Morris et al. 2006). Typically, BCS is evaluated through visual assessment that is easily implemented on-farm, without the need for any off-site training or further equipment. In New Zealand BCS in beef cows is typically assessed on a 1-10 (Hickson et al. 2017; Smeaton et al. 2000) or a 0-5 (Morris et al. 2002) scale. A report by Hickson et al. (2017) using the 10-point scale suggested a target BCS of 6 at mating, 7 at weaning and 5 throughout the winter months.

Reproductive performance has been reported as being influenced by BCS, in terms of pregnancy rates or inter-calving interval, in NZ sheep (Kenyon et al. 2014), USA beef cattle (Ciccioli et al. 2003; Renquist et al. 2006) and NZ dairy cows (Buckley et al. 2003). According to Selk et al. (1988) BCS before calving and at the start of mating are the main factors influencing pregnancy rates in beef cows. Similarly, DeRouen et al. (1994) reported a significant positive effect of BCS at calving on subsequent pregnancy rate. However, few studies have been conducted to describe this relationship for beef cows in New Zealand. Morris et al. (2006) reported higher pregnancy rates for cows with greater BCS at joining than for lower-conditioned cows. Tait et al. (2017) indicated that cows that had higher BCS at mating or at pregnancy diagnosis were more likely to have reproductive success.

Artificial insemination (AI) is an efficient reproductive technology with the potential to incorporate favoured genetics into the herd to increase productivity and genetic gain (Vishwanath 2003). AI is widespread within the New Zealand dairy industry, but not yet as well established in beef cow herds (Smeaton et al. 2003). This is mainly due to management issues as beef cattle are not yarded together on a regular basis. One approach to overcome this limitation has been the introduction of oestrus synchronisation. There is scope for a wider use of AI programs within the industry to further improve the beef herd (Morris & Archer 2007). To the authors' knowledge, there is no published literature that examined the relationship between BCS and AI success rate in New Zealand beef cows. However, some studies around the New Zealand dairy industry (Roche et al. 2007) as well as the beef industry outside New Zealand (Ayres et al. 2014; Sprott et al. 1998) have identified higher pregnancy rate to AI for cows with higher than average BCS.

The aim of this study was to evaluate and quantify the relationship of BCS before calving, before mating and at weaning with pregnancy rate to AI and overall pregnancy rate following a 49-day mating period of beef breeding cows on commercial hill-country farms in New Zealand.

Materials and methods

Dataset

The beef progeny test and all related procedures were approved by the AgResearch Ethical Committee.

The dataset consisted of an ongoing beef progeny test (BPT) carried out by Beef + Lamb NZ Genetics on four large-scale commercial farms in New Zealand. The farms are located on North Island (Gisborne, Central Northern plateau, Southern Hawkes Bay) and South Island (North Canterbury) hill country with varying climatic conditions and, therefore, diverging seasonal trait recordings. Data were collected over a period of five years from November 2014 to September 2019. Each year, beef cows were artificially inseminated with semen from New Zealand or foreign bulls. Bull breeds used for mating were Angus, Hereford, Stabilizer, Simmental and Charolais. Data for this experiment was taken from the base population of the BPT, including all cows that built up the population at the start of the progeny test as well as all replacement animals from within the property. Consistent with normal farm practices, animals were typically managed separately in different mobs. However, the overall recording scheme followed the same system for each of those mobs within farm and year. All animals included in this analysis were mixed-aged beef breeding cows (3-10+ years of age) with their second or later calf at foot. BCS and pregnancy data representing a total of 5,484 pregnancy outcomes of 2,683 cows with a total of 16,105 BCS recordings were available for this experiment. All cows in the project were Angus or Hereford. Consistent with normal farm practices, cows failing to conceive were culled following weaning of their calves.

Measurements

BCS was recorded within each herd for all base cows in the dataset on three events throughout the year: pre-calving (July – September), pre-mating (November – January) and weaning (February – April). Timing of these events varied among farms and years, but was consistent for all cows within farm and year. BCS was scored on a 1-10 scale with 0.5 increments (1=emaciated and 10=obese; Hickson et al. (2017)). Birth years were recorded for each cow. All cows included in the analysis were inseminated once by fixed-time AI at a synchronised oestrus before bulls were introduced to the herd, generally two to three days following AI and always less than 21 days after AI. Treatments for oestrus synchronisation were based on a three-yarding protocol for most farms. Cows were given 100 µg of gonadorelin (Ovurelin, Bayer New Zealand Ltd., Auckland, New Zealand) on day 0 and were treated with an intravaginal P4-releasing device (Cue-mate, Bayer New Zealand Ltd., or CIDR, Zoetis New Zealand Ltd., Auckland, New Zealand) from days 0-7. At the day of device removal, cows received 200 µg cloprostenol (Ovuprost, Bayer New Zealand Ltd.) and 200 µg gonadotrophin (Pregnecol, Bayer New Zealand Ltd.). A second treatment of 100 µg of gonadorelin was given on day 10 at the time of AI. One farm used a four-yarding protocol, where the final treatment was conducted the day prior to AI. Bulls remained with the herd for a minimum of seven weeks after AI. Date of AI was recorded with corresponding sire ID. Pregnancy diagnosis (PD) was conducted approximately 90 days after AI using trans-rectal ultrasound by an experienced commercial operator. Fetal age was recorded at pregnancy scanning based on a combination of characteristics. Pregnancy was recorded as either 0 (not pregnant) or 1 (pregnant) at the time of PD.

Data manipulation

Pregnancy rates represent the number of pregnant cows as a proportion of total number of cows with pregnancy records at the time of PD. Day of conception was calculated from the fetal age recorded at PD. A gestation length of 282 days (Burris & Blunn 1952) was assumed to compute probable calving dates based on the fetal age at PD. The interval from this probable calving date to the following AI date was calculated and is referred to as "days from previous calving" (DfPC). The fetal age record was used to determine whether each cow had conceived to AI or natural mating. Cows were defined as conceived to AI when the days between the estimated conception date and AI-Date were less than eight days. Similarly, fetal age records were used to determine pregnancy rate, where cows for which the fetal age indicated they conceived more than seven weeks after AI were recoded as not pregnant to allow calculation of a standardised 49-day pregnancy rate. Age of cows was calculated from their birth year. Cows were grouped according to their age into four categories: 3-year olds, 4-year olds, 5-9-year olds and 10 or more years old. BCS ranks with fewer than five records for each time point were excluded from this study, leaving a range of BCS from 4.0 to 9.0 for further analysis (Table 1).

Statistical analysis

Binomial regression analysis was performed using R (R Core Team 2019) to evaluate the relationship between pre-calving BCS, pre-mating BCS and BCS at weaning on reproductive performance. Percentage of cows conceiving to a single AI, and pregnancy rate after 49 days of mating, were analysed using logit transformation for categorical data analysis. Age of cow (3, 4, 5-9 and 10+) was considered as a class effect but was not significant for any model and was excluded from the final models. BCS and DfPC were included as covariates for each model. BCS was fitted as a linear and quadratic effect to test for deviation from linearity. The covariates for each model were standardized prior to analysis by subtracting the overall mean and dividing by the standard deviation (SD) (Table 1). A contemporary group (herd:season:mob) and the sire used for AI were fitted as random effects. An ANOVA was conducted to test for significance of the model effects and the form of relationship between the predictor and the response variables. Probabilities of pregnancy rate to AI and pregnancy rate after 49 days of mating were calculated for each level of BCS. In a second approach, BCS was fitted as a fixed effect in each model to estimate least-square means (lsmeans) for each category of BCS. All probabilities and estimates were calculated based on the mean DfPC in this experiment of 71.6 days.

Table 1 Number (n) of cow records for each body condition score (BCS), mean and standard deviation (SD) of BCS and days from previous calving date to first day of mating (DfPC), pregnancy rate to AI (cows pregnant to a single artificial insemination by cows with pregnancy records, %) and 49-day pregnancy rate (cows pregnant after a 49-day mating period by cows with pregnancy records, %) recorded before calving, before mating and at weaning.

	Before calving	Before mating	At weaning
BCS records[a]			
4	57	5	13
4.5	263	30	58
5	539	154	212
5.5	719	305	358
6	1,116	593	717
6.5	736	564	789
7	922	1,023	1,309
7.5	602	874	772
8	389	1,168	841
8.5	86	426	225
9	6	99	135
Total n of records	5,435	5,241	5,429
BCS: Mean ± SD	6.33 ± 1.01	7.14 ± 0.97	6.92 ± 0.97
DfPC: Mean ± SD	71.63 ± 15.74	71.68 ± 15.80	71.63 ± 15.73
49-day pregnancy rate (%)	90.82	91.01	90.88
AI pregnancy rate (%)	54.98	55.43	54.93

[a]BCS was scored on a 1-10 scale with 1=emaciated and 10=obese.

Table 2 Standardized coefficients and standard errors (Estimates ± SE) with P values and unstandardized coefficients (log odds) for all variables in the model to describe the relationship of body condition score (BCS) before calving, before mating and at weaning with pregnancy rate to AI (cows pregnant to a single artificial insemination by cows with pregnancy records) and 49-day pregnancy rate (cows pregnant after a 49-day mating period by cows with pregnancy records) on the logit scale.

Model	Pregnancy rate to AI			49-day pregnancy rate		
	Estimates ± SE	P value	Log odds	Estimates ± SE	P value	Log odds
Model 1 – before calving						
Intercept	0.21 ± 0.07	0.005	-1.9332	2.36 ± 0.07	<0.001	-0.3499
BCS	0.17 ± 0.04	<0.001	0.1660	0.19 ± 0.05	<0.001	0.1833
DfPC[b]	0.24 ± 0.03	<0.001	0.0152	0.34 ± 0.04	<0.001	0.0216
Model 2 – before mating						
Intercept	0.22 ± 0.06	<0.001	-2.4601	2.41 ± 0.06	<0.001	-6.3034
BCS	0.19 ± 0.03	<0.001	0.2000	1.75 ± 0.53	<0.001	1.8072
BCS^2				-1.49 ± 0.54	0.006	-0.1105
DfPC[b]	0.28 ± 0.04	<0.001	0.0175	0.34 ± 0.05	<0.001	0.0215
Model 3 – at weaning						
Intercept	0.19 ± 0.07	0.006	-5.0968	2.42 ± 0.07	<0.001	-5.6681
BCS	1.08 ± 0.33	0.001	1.1186	1.68 ± 0.48	<0.001	1.7366
BCS^2	-0.96 ± 0.33	0.004	-0.0723	-1.46 ± 0.49	0.003	-0.1101
DfPC[b]	0.24 ± 0.03	<0.001	0.0150	0.32 ± 0.05	<0.001	0.0202

[a] Blank cells were not included in the analysis.
[b]Days from previous calving date to first day of mating.

Results

AI pregnancy rate

The overall percentage of animals conceiving to AI was 54.8%. Cows tended to have greater pregnancy rate (P<0.001) to AI with increasing BCS for all measured time points, ranging from 45.5% (95% CI 40.1-51.0) to 65.7% (95% CI 60.3-70.8) for BCS 4.0-9.0 pre-calving, 40.1% (95% CI 34.3-46.1) to 64.5% (95% CI 60.5-68.3) for BCS 4.0-9.0 pre-mating and 33.1% (95% CI 24.7-42.8) to 57.5% (95% CI 53.7-61.2) for BCS 4.0-8.0 at weaning (Fig. 1). No quadratic relationship between the predictor and the response variable could be identified for pre-calving and pre-mating BCS (P>0.05), however, BCS at weaning showed a significant quadratic (P<0.01) relationship (Table 2). In addition, cows that calved early in the previous mating season had a significantly greater chance (P<0.001) of conceiving to AI the following year.

Forty-nine-day pregnancy rate

The 49-day pregnancy rate for all cows was 90.8%. Pregnancy rate was significantly (P<0.001) associated with

Figure 1 Relationship of body condition score (BCS) before calving (a), before mating (b) and at weaning (c) with pregnancy rate to AI (cows pregnant to a single artificial insemination by cows with pregnancy records); solid line: predicted probabilities from regression analysis, dashed line: 95% CI, dots: least square means for each level of BCS; results are based on an average 71.6 days between previous calving date and first day of mating.

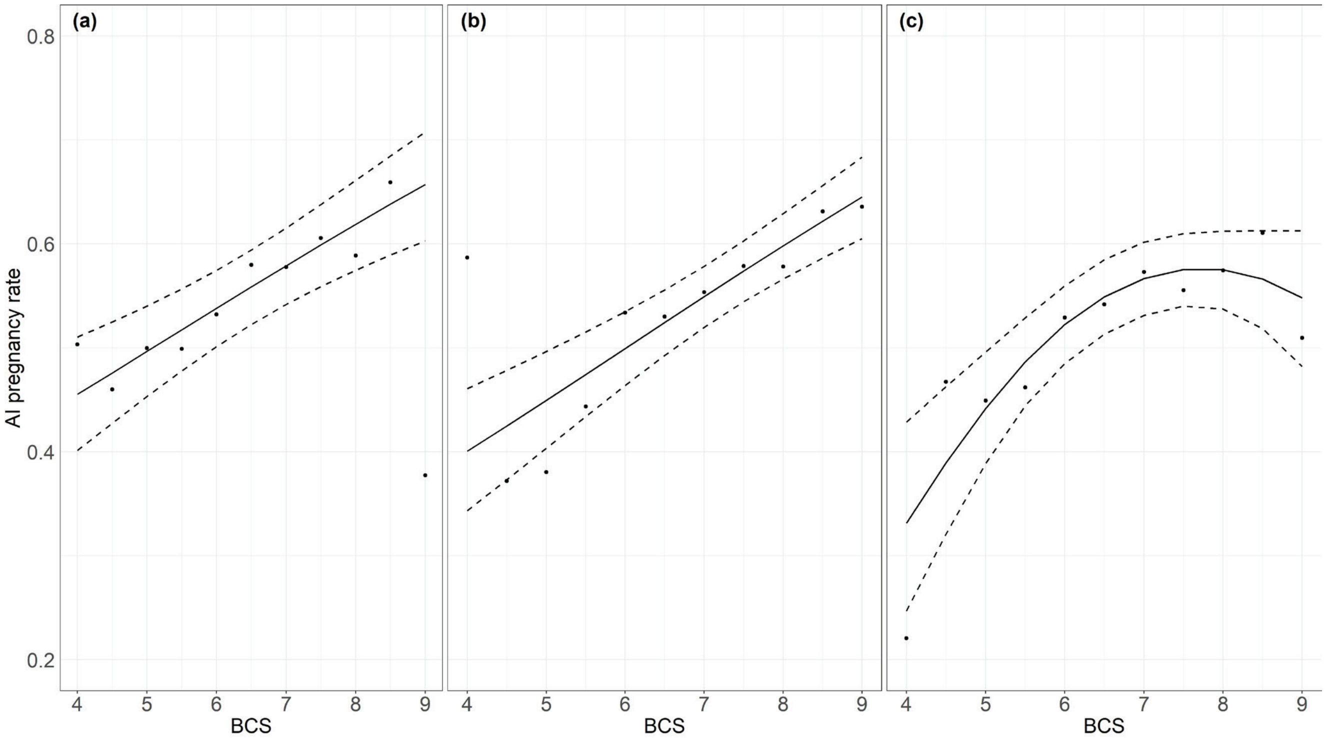
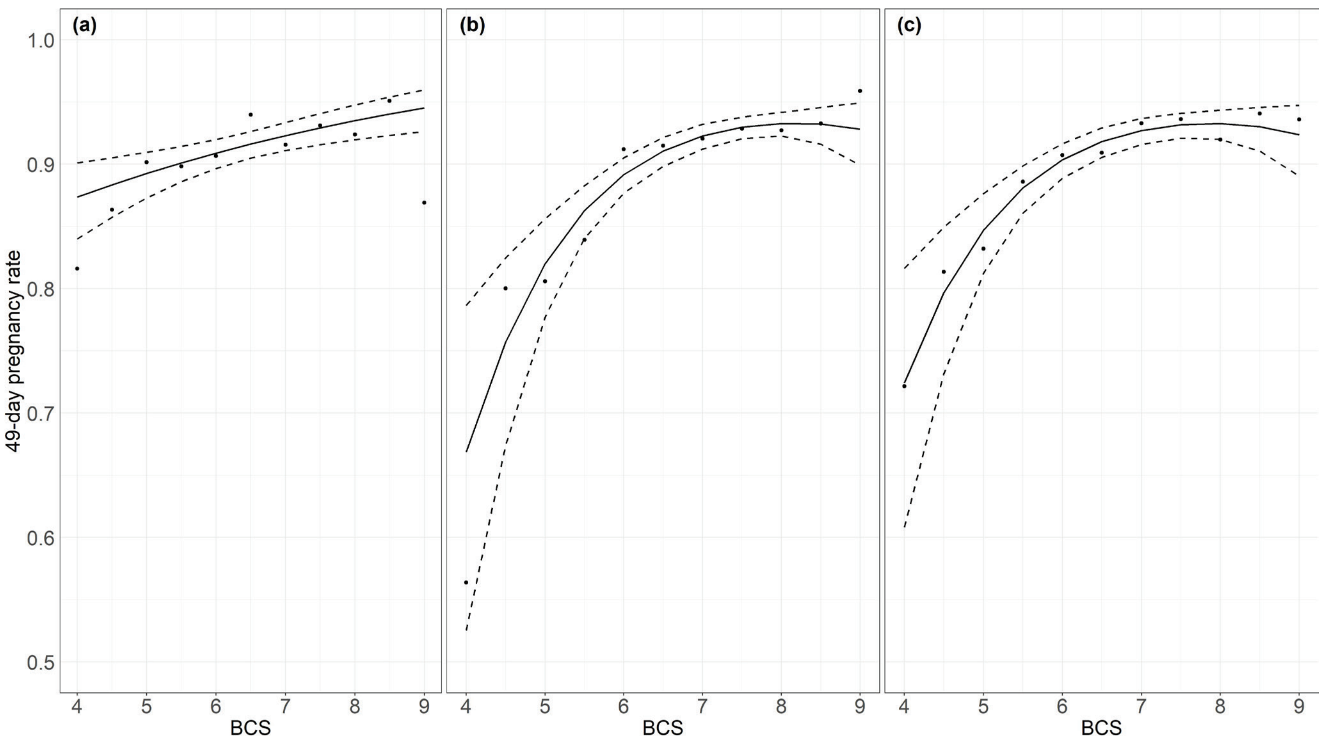


Figure 2 Relationship of body condition score (BCS) before calving (a), before mating (b) and at weaning (c) with 49-day pregnancy rate (cows pregnant after a 49-day mating period by cows with pregnancy records); solid line: predicted probabilities from regression analysis, dashed line: 95% CI, dots: least square means for each level of BCS; results are based on an average 71.6 days between previous calving date and first day of mating.



BCS before calving, before mating or at weaning (Table 2), with a higher proportion of cows conceiving at greater BCS. Cows with a greater than average BCS had greater pregnancy rates; ranging from 87.4% (95% CI 84.0-90.1) to 94.5% (95% CI 92.6-96.0) for BCS 4.0-9.0 pre-calving, 66.9% (95% CI 52.5-78.7) to 93.3% (95% CI 92.3-94.2) for BCS 4.0-8.0 pre-mating and 72.4% (95% CI 60.8-81.6) to 93.3% (95% CI 92.0-94.4) for BCS 4.0-8.0 at weaning (Fig. 2). Pre-mating BCS and BCS at weaning followed a quadratic function with little increase in pregnancy rate for BCS above 7. In contrast, pre-calving BCS was linearly related to 49-day pregnancy rate. Forty-nine-day pregnancy rate increased ($P<0.001$) as the time increased between the preceding probable calving date and the first day of mating.

Discussion

AI pregnancy rate

Nutritional status has been demonstrated to influence reproductive performance in beef cows (Sprott et al. 1998; Whitman 1975). BCS as a measure of nutritional status can, therefore, be manipulated in order to improve reproductive performance. From a management perspective, a high percentage of cows conceiving early in the breeding season is desired and may subsequently lead to higher calf weaning weights (Lesmeister et al. 1973).

Regression analysis showed a positive association between BCS and pregnancy rate to AI, indicating that a higher BCS would result in a greater proportion of cows conceiving to AI early in the mating season. The form of relationship between BCS before calving and before mating and the pregnancy rate to AI was linear. This implies that any increase in BCS around calving and before mating would result in improved pregnancy rate to AI. Ayres et al. (2014) found that Zebu beef cows were more likely to conceive to first mating by AI when they were at their greatest BCS at parturition. Similarly, studies on dairy cows reported a positive effect of higher BCS at calving on pregnancy rate at first mating by AI (Roche et al. 2007), while cows in poor condition at parturition tended to have lower pregnancy rates (Lopez-Gatius et al. 2003). Ayres et al. (2014) did not identify a relationship between BCS around mating and AI conception rate, whereas Roche et al. (2007) reported a significant effect.

Results from this experiment support the conclusion that beef cows need to be in BCS of at least 6, around the time of calving and/or mating, to achieve approximately 50% conception to a single synchronised AI, and that greater BCS will likely lead to further improvements in conception rate. Adequate number of days between previous calving and the start of mating and good BCS at calving has been demonstrated to increase the probability of oestrus (Sprott et al. 1998; Whitman 1975). In agreement with this, our experiment showed that an increase in time from previous calving results in greater pregnancy rate to AI at the start of mating, indicating that cows that calved early were more likely to conceive to AI at the following breeding.

Forty-nine-day pregnancy rate

The mean pregnancy rate reported by McFadden et al. (2005) was 91% for a total of 1,005 beef cow herds in New Zealand and matches the findings of this study with an overall pregnancy rate of 90.8-91.0% across all herds and years.

Several studies have described the relationship between pre-calving BCS and BCS around mating on pregnancy rate. Pre-calving BCS had a significant effect on 49-day pregnancy rate in this experiment, which agrees with the findings of DeRouen et al. (1994) and Selk et al. (1988), however, neither Morris et al. (2006) nor Tait et al. (2017) found an effect of calving BCS on pregnancy rate. Pre-mating BCS and BCS at weaning were significantly related to 49-day pregnancy rate in the current study. Renquist et al. (2006) and Morris et al. (2006) demonstrated an increase in pregnancy rate for higher BCS at joining, whereas Tait et al. (2017) did not report a significant relationship of BCS at joining or PD with pregnancy rates.

Pre-mating BCS and BCS at weaning were quadratically related to 49-day pregnancy rate in the current experiment. Improving condition around mating to BCS 7 is beneficial whereas further increase is unlikely to result in greater pregnancy rates. This outcome could explain the absence of a significant relationship between BCS at joining and PD on pregnancy results reported by Tait et al. (2017), as the cows in their study were all above BCS 6, and based on the results found in this experiment, a strong response would have been unlikely. Compared to the curvilinear trend for pre-mating BCS and BCS at weaning, pre-calving BCS followed a linear relationship. This indicates that increasing pre-calving BCS would result in higher pregnancy rates without a detrimental effect of very high BCS. This finding concurs with Renquist et al. (2006), who also reported a quadratic relationship between BCS around breeding and a linear relationship between BCS at calving on pregnancy rates. This experiment outlines an optimum BCS between 6 and 7 at mating and weaning, whereas overall higher pre-calving BCS would be advantageous. From a commercial perspective, this demonstrates the value of separating lower-conditioned cows and increasing their feed levels to ensure sufficient BCS gain. However, increasing BCS before calving is associated with higher feed costs for grazing cows compared to after calving when more feed is becoming available as a response to increased pasture growth in early spring. The results found in this experiment tend to agree with industry targets outlined by Hickson et al. (2017), which seem to be adequate guidelines to improve pregnancy results.

Compared among pre-calving BCS, pre-mating BCS and BCS at weaning, the pre-mating BCS tends to be the most valuable in predicting pregnancy rates and might therefore be a key point for achieving pregnancy rate targets. Those findings coincide with those of Renquist et al. (2006) who identified a greater variation in pregnancy rate being explained by BCS at breeding compared to BCS at calving. Nevertheless, BCS at weaning is often the only measurement available for New Zealand farmers in their day-to-day practices. Cows that are in better condition at weaning may be more likely to have gained or at least maintained condition over the mating period compared with cows that were in poorer condition at weaning. This could explain why those cows with greater BCS at weaning were more likely to have conceived during the mating period.

Pre-calving BCS did have an influence on 49-day pregnancy rate in the current experiment, but the slope of the relationship at lower BCS was greater before mating than before calving. This suggests that the focus for management should be to ensure that cows achieve a minimum BCS of 6 to 7 at time of mating. Based on the relationship persisting through to weaning, it seems that it is likely that maintaining target BCS of 6 to 7 at least across the mating period may also improve 49-day pregnancy rates.

Conclusion

This study quantified the relationship of BCS before calving, before mating and at weaning with AI and 49-day pregnancy rate. Increasing BCS tends to be advantageous to achieve higher pregnancy rates. The linear relationship between BCS and AI pregnancy rate suggests that aiming for the highest possible BCS before calving and before mating would lead to improved outcomes from AI programmes. For overall pregnancy rate (after 49 days of natural mating post-AI), the curvilinear relationship with BCS suggests that most value can be obtained by reducing the percentage of low-conditioned cows in the herd.

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References

Ayres H, Ferreira RM, Torres-Júnior JRS, Demétrio CGB, Sá Filho MF, Gimenes LU, Penteado L, D'Occhio MJ, Baruselli PS 2014. Inferences of body energy reserves on conception rate of suckled Zebu beef cows subjected to timed artificial insemination followed by natural mating. Theriogenology 82: 529-536. doi 10.1016/j.theriogenology.2014.04.026.

Bishop DK, Wettemann RP, Spicer LJ 1994. Body energy reserves influence the onset of luteal activity after early weaning of beef cows. Journal of Animal Science 72: 2703-8. doi 10.2527/1994.72102703x.

Buckley F, O'Sullivan K, Mee JF, Evans RD, Dillon P 2003. Relationships among milk yield, body condition, cow weight, and reproduction in spring-calved Holstein-Friesians. Journal of Dairy Science 86: 2308-2319. doi 10.3168/jds.S0022-0302(03)73823-5.

Burris MJ, Blunn CT 1952. Some factors affecting gestation length and birth weight of beef cattle. Journal of Animal Science 11: 34-41. doi 10.2527/jas1952.11134x.

Ciccioli NH, Wettemann RP, Spicer LJ, Lents CA, White FJ, Keisler DH 2003. Influence of body condition at calving and postpartum nutrition on endocrine function and reproductive performance of primiparous beef cows. Journal of Animal Science 81: 3107-3120. doi 10.2527/2003.81123107x.

DeRouen SM, Franke DE, Morrison DG, Wyatt WE, Coombs DF, White TW, Humes PE, Greene BB 1994. Prepartum body condition and weight influences on reproductive performance of first-calf beef cows. Journal of Animal Science 72: 1119-1125. doi 10.2527/1994.7251119x.

Hickson RE, Morris ST, Thomson BC. 2017. Beef Cow Body Condition Scoring. https://beeflambnz.com/knowledge-hub/PDF/beef-cow-body-condition-scoring [accessed 20 March 2020].

Kenyon PR, Maloney SK, Blache D 2014. Review of sheep body condition score in relation to production characteristics. New Zealand Journal of Agricultural Research 57: 38-64. doi 10.1080/00288233.2013.857698.

Lesmeister JL, Burfening PJ, Blackwell RL 1973. Date of first calving in beef cows and subsequent calf production. Journal of Animal Science 36: 1-6. doi 10.2527/jas1973.3611.

Lopez-Gatius F, Yaniz J, Madriles-Helm D 2003. Effects of body condition score and score change on the reproductive performance of dairy cows: a meta-analysis. Theriogenology 59: 801-812. doi 10.1016/s0093-691x(02)01156-1.

McFadden AM, Heuer C, Jackson R, West DM, Parkinson TJ 2005. Reproductive performance of beef cow herds in New Zealand. New Zealand Veterinary Journal 53: 39-44. doi 10.1080/00480169.2005.36467.

Morris CA, Archer JA 2007. Application of new technologies in New Zealand for beef cattle and deer improvement. New Zealand Journal of Agricultural Research 50: 163-179. doi 10.1080/00288230709510289.

Morris ST, Kenyon PR, Burnhham DL 2002. A comparison of two scales of body condition scoring in Hereford x Friesian beef breeding cows. Proceedings of the New Zealand Grassland Association 64: 121-123.

Morris ST, Morel PCH, Kenyon PR 2006. The effect of individual liveweight and condition of beef cows on their reproductive performance and birth and weaning weights of calves. New Zealand Veterinary Journal 54: 96-100. doi 10.1080/00480169.2006.36619.

R Core Team 2019. R: A Language and Environment for Statistical Computing.

Renquist BJ, Oltjen JW, Sainz RD, Calvert CC 2006. Relationship between body condition score and production of multiparous beef cows. Livestock Science 104: 147-155. doi 10.1016/j.livsci.2006.04.004.

Roche JR, Macdonald KA, Burke CR, Lee JM, Berry DP 2007. Associations among body condition score, body weight, and reproductive performance in seasonal-calving dairy cattle. Journal of Dairy Science 90: 376-391. doi 10.3168/jds.S0022-0302(07)72639-5.

Russel AJF, Doney JM, Gunn RG 1969. Subjective assessment of body fat in live sheep. The Journal of Agricultural Science 72: 451-454. doi 10.1017/S0021859600024874.

Selk GE, Wettemann RP, Lusby KS, Oltjen JW, Mobley SL, Rasby RJ, Garmendia JC 1988. Relationship among weight change, body condition and reproductive performance of range beef cows. Journal of Animal Science 66: 3153-3159. doi 10.2527/jas1988.66123153x.

Smeaton DC, Bown MD, Clayton JB 2000. Optimum liveweight, feed intake, reproduction, and calf output in beef cows on North Island hill country, New Zealand. New Zealand Journal of Agricultural Research 43: 71-82. doi 10.1080/00288233.2000.9513410.

Smeaton DC, Harris BL, Xu ZZ, Vivanco WH 2003. Factors affecting commercial application of embryo technologies in New Zealand: a modelling approach. Theriogenology 59: 617-634. doi 10.1016/S0093-691X(02)01244-X.

Sprott LR, Harris MD, Richardson JW, Gray AW, Forrest DW, Northcutt-Dolezal S, Cundiff LV 1998. Pregnancy to artificial insemination in beef cows as affected by body condition and number of services. The Professional Animal Scientist 14: 231-235. doi 10.15232/S1080-7446(15)31835-0.

Tait IM, Morris ST, Kenyon PR, Garrick DJ, Pleasants AB, Hickson RE 2017. Effect of cow body condition score on inter-calving interval, pregnancy diagnosis, weaning rate and calf weaning weight in beef cattle. Proceedings of the New Zealand Society of Animal Production 77: 23-28.

Vishwanath R 2003. Artificial insemination: the state of the art. Theriogenology 59: 571-584. doi 10.1016/S0093-691X(02)01241-4.

Wagner JJ, Lusby KS, Oltjen JW, Rakestraw J, Wettemann RP, Walters LE 1988. Carcass composition in mature hereford cows: estimation and effect on daily metabolizable energy requirement during winter. Journal of Animal Science 66: 603-612. doi 10.2527/jas1988.663603x.

Whitman RW 1975. Weight change, condition and beef-cow reproduction. PhD. Dissertation Colorado State University. Fort Collins.