Scientific Article

Comparison of a camera-software system and typical farm management for detecting oestrus in dairy cattle at pasture

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Abstract

AIM: To compare the sensitivity, specificity, predictive values and accuracy of detection of oestrus using a novel oestrus detection-strip (ODS) and a camera-software device (CSD) with typical farm management practices of visual observation and use of tail paint in dairy cattle at pasture.

METHODS: Dairy cows (n=480) in a seasonal-calving herd managed at pasture under typical commercial conditions in New Zealand were stratified by age, body condition score and days in milk, then randomly allocated to one of two groups prior to the planned start of mating (PSM). Tail paint was applied to all cows and oestrus detected by visual observation of oestrous behaviour and removal of paint, by farm staff. One group (n=240) was fitted with ODS and also monitored for signs of oestrus using a CSD, while the Control group (n=240) was monitored using tail paint and visual observations only. Cows detected in oestrus were artificially inseminated (AI), and pregnancy status determined using rectal palpation and ultrasonography, 51–52 days after the end of a 55-day AI period. Results of pregnancy diagnosis were used to confirm the occurrence of oestrus, and the sensitivity, specificity, predictive value and accuracy of detection of oestrus compared between oestrus detection methods.

RESULTS: The sensitivity and accuracy of oestrus detection in the Control group, using visual observation and tail paint, were low. Compared with the Control group, detection of oestrus using the ODS and CSD resulted in greater sensitivity (85% *vs* 78%; p=0.006), specificity (99.6% *vs* 98.0%; p<0.001), positive predictive value (PPV; 88% *vs* 51%; p<0.001) and overall accuracy (99.0% *vs* 98.0%; p<0.001). Negative predictive value (NPV) did not differ significantly between groups (99.4% *vs* 99.3%; p=0.28). Pregnancy rate to first service was higher in the CSD group than in the Control group (72% *vs* 39%; p<0.05). Use of the CSD significantly increased the cumulative proportion of cows pregnant to AI over the breeding period (p=0.044).

CONCLUSION AND CLINICAL RELEVANCE: The ODS and CSD was satisfactory for detection of oestrus in seasonal-calving dairy herds grazing on pasture and could improve the sensitivity and accuracy of detection of oestrus in herds where these are low.

KEY WORDS: *Oestrus detection, dairy cattle, automation, camera-software device, oestrus-detection strip, tail paint, reproductive performance*

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Introduction

Detection of oestrus is an important task that needs to be conducted effectively in artificially-bred dairy herds to ensure adequate reproductive performance of the herd. Observing cows for signs of oestrus and inseminating them at the correct time are necessary steps for effective reproductive management. AI was one of the most important agricultural technologies of the 20th Century, and most dairy producers have adopted this technology to maintain competitiveness (Geers et al 1997).

Inefficient reproductive performance in dairy herds is a problem for producers and substantially limits potential profit in dairy enterprises. Increases in the size of herds and milk yield have been implicated as contributors to decreased reproductive efficiency experienced on many dairy farms (Geers et al 1997). The major factor limiting reproductive performance on many farms is failure to detect oestrus in a timely and accurate manner (Senger 1994; Guilbault et al 1998; Fricke 2000). The main method used to detect oestrus in New Zealand is visual observation during feeding and milking times, aided by tail-painting (Macmillan and Curnow 1977; Macmillan et al 1988; Xu et al 1998). In large dairy herds, the brevity of observation per cow limits the effectiveness of this method.

An oestrus detection system was designed (NB Williamson and KJ Butler[1], unpubl. obs.) then developed, to optically and electronically identify and read ODS fixed to the rumps of cows. Early testing demonstrated a high degree of accuracy in automatically identifying the presence of the ODS and automatically determining that paint had been removed from the strips, indicating that cows had been mounted. This system has been patented by Massey University (New Zealand Patent 519743, IPC7, G01N33/74).

The use of computers for monitoring cows and associated technical advances have made automation of detection of oestrus possible. The objective of this study was to test and compare the efficacy and accuracy of detection of oestrus using ODS and a CSD with the typical farm management practices of visual observation and tail-painting combined, in a commercial dairy herd grazed at pasture.

AI	Artificial insemination/artificially inseminated
CSD	Camera-software device
NPV	Negative predictive value
ODS	Oestrus detection-strip(s)
PPV	Positive predictive value
PSM	Planned start of mating

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Materials and methods

Dairy cows (n=404) aged 2–13 years and of mixed breeds (Friesian, Holstein, Jersey, and their crosses), calved >26 days prior to the PSM were used in the study, which was conducted from 06 October to 04 December 2003. Cows that had abnormal reproductive histories (e.g. retained fetal membranes, metritis, abortion, dystocia, vaginal discharge) were excluded. The body condition score of cows ranged from 3.0 to 7.0 (mean 4.0), on a scale of 1–8. Of the selected animals, 93 (23%) were 2-year-old heifers that had recently calved for the first time. Animals were handled using protocols approved by the Massey University Animal Ethics Committee, Palmerston North, New Zealand.

Animals were stratified by age, condition score and days in milk, then randomly allocated to one of two groups, Control and CSD. Forty-nine late-calving cows (cows calved from 06 to 25 October 2003; PSM = 20 October 2003) and 27 newly-purchased cows were added to the trial and alternately allocated to each group, such that the final number of animals in each group was 240. The animals grazed as one herd at pasture and had free access to water. The herd was managed so that the pasture allowance was adequate for maintenance and production requirements, in accordance with usual farm practices. Cows were milked twice daily, starting at 0530 and 1500 hrs, in a rotary-platform milking parlour.

Cows not detected in oestrus by 26 days after the PSM (i.e. on 14 November 2003) were examined by a veterinarian; cows diagnosed as anovular (Control group, n=15; CSD group, n=21) were treated using an intravaginal progesterone-releasing device (Pfizer EAZI-BREED CIDR; DEC International Ltd, Hamilton, NZ) for 8 days, followed by injection of 1 mg oestradiol benzoate (Cidirol; Bomac Laboratories Ltd, Manukau, NZ) at the time of removal of the device, and those that had a corpus luteum present (Control group, n=4; CSD group, n=7) received an intramuscular injection of 2 ml cloprostenol (Estroplan; Parnell Laboratories NZ Ltd, Auckland, NZ). Other cows were treated with a single intra-uterine infusion of 0.5% Lugol's iodine (Alpha Omega Labs, Nassau, Bahamas) (n=2 per group) or unspecified treatments (Control group, n=7; CSD group, n=1).

Tail-painting, ODS and visual observations

Tail paint (Tell Tail oil-based tail paint, fluorescent oestrus detection tail paint; FiL New Zealand Ltd, Mount Maunganui, NZ) was applied to all cows soon after calving, as a strip 18–21 cm long and 5–6 cm wide, posterior to the sacral area covering the mid-line, and evidence of postpartum oestrus recorded. Tail paint was reapplied to all cows at the PSM. Paint was applied using a brush, initially against the direction of the hair and then with the direction of the hair, to achieve a smooth surface (Williamson 1980; Kerr and McCaughey 1984). Diagnosis of oestrus was conducted by farm workers, and cows were considered to be in oestrus when >75% of the tail paint was removed. Cows suspected to be in oestrus were also checked for mounting marks such as skin abrasion and hair removal over the sacrum, in addition to removal of tail paint, before being bred.

Visual observation of oestrous behaviour was also conducted by farm staff over 30–45-minute periods at various times each day, according to typical management practices. Signs of oestrus noted included: standing to be mounted, mounting other cows, head-mounting, clear mucoid vaginal discharge, restlessness, sniffing, licking, chin-resting and chin-rubbing.

The ODS comprised Scotchlite (3M 9920; 3M New Zealand Ltd, Auckland, NZ) reflective strips measuring 150 mm x 50 mm, painted with Zylone sheen black paint (water-based low sheen acrylic; Resene Paint Limited, Palmerston North, NZ), glued to cows using Ados F2 glue (CRC Industries New Zealand Ltd, Auckland, NZ). ODS were placed initially on the sacro-coccygeal area of the rumps of the cows in the CSD group after brushing and glue had been applied to the area. The camera used for the CSD readings was mounted in the milking parlour approximately 120–150 cm above and at right angles to the position of ODS on cows standing on the platform, and at a place where light intensity was most consistent.

Images were captured and analysed at 3-sec intervals, which allowed three frames per cow to be obtained as the rotary platform progressed under the camera. Identities of cows were recorded manually and related to the images obtained. The presence or absence of ODS and proportion of paint removed from the ODS was determined using the CSD for each cow at each milking. Cows were considered to be in oestrus if the ODS was missing or ≥10% of paint had been removed. Strips were maintained once a week during the evening milking by cleaning the very dirty ones and replacing missing ones. The ODS on cows detected in oestrus by the CSD were removed and new ones applied 4 days later.

Oestrus was detected in the CSD group using both the CSD system, and visual observation and tail paint, whereas in the Control group only visual observation and tail paint were used.

Inseminations

Cows that were suspected or detected in oestrus at the morning or preceding evening milkings were drafted after the morning milking each day. Regardless of the method of detection used, the farm manager decided which drafted cows were to be inseminated, based predominantly on visual observation and close inspection, especially when a discrepancy occurred between the two methods. Insemination occurred once daily, about 19 h after cows were first detected in oestrus the evening before, and about 4 h after first detection of oestrus in the morning. After 8 weeks of artificial breeding, bulls were introduced to the herd for 4 weeks.

Pregnancy diagnosis and confirmation of oestrus

Pregnancy status was determined using rectal palpation and ultrasound examination 51–52 days after the end of the AI breeding season, and estimated gestational age was used to determine the accuracy of diagnosis of oestrus for cows that became pregnant. When a cow was confirmed to be pregnant to a service on a date recorded in the herd's AI records, that oestrus was regarded as true. Reverse counts of 21 days (± 3 days) and 42 (± 3 days) from inseminations resulting in confirmed pregnancy were also made, and oestrus detected by any method within the date ranges so calculated was also considered to be true. If no oestrus was detected in the calculated date ranges, the insemination was considered to have occurred at the first detected oestrus. No oestrus observed after the confirmed date of conception was considered to be true.

Statistical analysis

Contingency tables were constructed to calculate the sensitivity, specificity, PPV, NPV and accuracy for each detection method, based on the oestrous events that were confirmed from the results of pregnancy diagnosis. Sensitivity was calculated as the proportion of cows that were detected in oestrus that were confirmed as in oestrus from the results of pregnancy testing. Specificity was calculated as the proportion of cows that were determined not to be in oestrus from pregnancy test results that were not detected in oestrus by a detection method. PPV was calculated from the probability that a detected oestrus occurred in a cow that was in oestrus. The NPV was calculated from the probability that non-detection of oestrus occurred for a cow not in oestrus. Overall accuracy was calculated as the measure of the true findings ([true positives + true negatives, i.e. all cases truly identified by a test] / [true positives + false positives + true negatives + false negatives, i.e. the total population]) (Harrison and Braunwald 1987).

Data analysis

Cow age, Body condition score and Days in milk at the PSM were compared between groups using analysis of variance, using SPSS v12.01 for Windows (SPSS Inc, Chicago IL, USA). Calculated sensitivities, specificities, PPV, NPV and accuracies for each detection method (CSD *vs* tail paint plus visual observation) were compared (a) between CSD and Control groups, and (b) within the CSD group, as both detection methods were simultaneously used on cows in that group. Sensitivity, specificity and predictive values were modelled using logistic regression as the log-odds of the probability of the detected status being true, stratified by method of detection, using SAS v8.02 (SAS Institute Inc, Cary NC, USA). Thus, the response was whether or not a cow was detected in oestrus by one of two methods on a particular day, and independent effects were the 2 x 2 strata of true oestrus (1/0) x method of detection. Predicted probabilities and the individual contrasts, to compare sensitivities, specificities or predictive values between methods of detection, were calculated from these four strata for each method of detection. The model also included independent effects for Parity, Body condition score and Days in milk at the PSM. To adjust for repeated observations between subsequent observations of oestrus on the same cow, the identification number of the cow was used as a class statement in the repeated option of PROC GENMOD, running under SAS. In the dataset where the two methods were applied to data from the same cows (i.e. within the CSD group), a matched analysis was run that included method of detection nested within Cow as a repeated effect (Allison 1999). After running each model, the covariate effects of Parity, Body condition score and Days in milk at the PSM were removed stepwise, and the relative changes in model coefficients were calculated. A relative change of >15% was interpreted as a confounding effect for that variable on the sensitivity, specificity or predictive values (Dohoo et al 2003).

Kaplan-Meier survival analysis was used to compare the cumulative proportions of cows not pregnant over time between CSD and Control groups, stratified by cow Age, Body condition score and Days in milk at the PSM, using SAS.

Reproductive analysis

Parameters of reproductive performance for each group were calculated using DairyWin software (DairyWin 2001 v99.91.148; Massey University, Palmerston North, NZ). Reports of calving, submission, non-return, pregnancy and in-calf rates, as well as analyses of the oestrus return intervals, were conducted. Data were compared between CSD and Control groups using Chi-squared analysis and Fisher's exact test, except for calving to conception interval which was compared between groups using analysis of variance and SPSS. P-values were corrected using the method of Bonferroni to account for multiple comparisons.

Results

Numbers of cows detected in oestrus *vs* not detected in oestrus compared with occurrences of oestrus determined from results of pregnancy testing, and the sensitivity, specificity, predictive values and accuracy of the CSD compared to visual observation and tail paint, are shown in Table 1. Pregnancy was not confirmed in 57/240 (23.8%) cows from the Control group and 27/240 (11.3%) cows from the CSD group, which were omitted from further analysis. The 59 cows not detected in oestrus in the first 26 days after the PSM that received veterinary treatment were distributed about equally between the two groups (Control group, n=28; CSD group, n=31) and were included in analyses. Of the cows detected in oestrus using the CSD, 49 were ignored by the farm staff and not mated, and 49 occurrences of oestrus determined from the results of pregnancy diagnosis were not detected by either the CSD or visual observation/tail paint. There were 171 false-positive diagnoses made by farm staff using visual observation and tail paint that were negative using the CSD (Table 1).

The sensitivity, specificity, PPV and overall accuracy of oestrus detection was higher for the CSD than for visual observation and tail paint, both when records from the same cows were compared within the CSD group and when methods were compared between the CSD and Control groups (Table 1). Comparing only

Table1. Numbers of cows detected in oestrus *vs* not detected in oestrus compared with occurrences of oestrus determined from results of pregnancy diagnosis (PD) for, and associated sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of, a camera-software device (CSD; n=213) *vs* visual observation and use of tail paint by farm staff (Control; n=183) for the detection of oestrus (OD) over a 55-day breeding period using artificial insemination in dairy cows at pasture.

			Result confirmed by PD		Statistics %				
Group[a]	OD method	Result of OD	Oestrus (+)	Oestrus (–)	Sensitivity	Specificity	PPV	NPV	Overall accuracy
Control	Visual observations	Oestrus (+)	201	194	78[b]	98[b]	51[b]	99.3	98[b]
	+ tail paint (farmer)	Oestrus (–)	57	9,665	(CI=73–83)	(CI=97.7–98.3)	(CI=46.0–56.0)	(CI=99.2–99.6)	(CI=97.2–98.7)
CSD	CSD	Oestrus (+)	341	48	85[c,x]	99.6[c,x]	88[c,x]	99.4	99[c,x]
		Oestrus (–)	65	11,209	(CI=80–87)	(CI=99.4–99.7)	(CI=84.0–91.0)	(CI=99.3–99.6)	(CI=98.8–99.2)
	Visual observations	Oestrus (+)	292	219	72[y]	98.1[y]	57[y]	99.0	97[y]
	+ tail paint (farmer)	Oestrus (–)	114	11,038	(CI=67–76)	(CI=97.8–98.3)	(CI=53.0–61.0)	(CI=98.8–99.2)	(CI=96.8–97.4)

[a] Data for both groups were collected twice daily, in the morning and evening, and then pooled into single daily observations for each cow. Cows that did not show evidence of pregnancy were excluded from analysis. Cows that were not milked with the herd on occasions resulted in missing data (52 entries)

[b,c] Statistics differ between Control and CSD groups; p<0.01

[x,y] Statistics differ within the CSD group between CSD and farmer-only methods of oestrus detection; p<0.01

(+) = positive; (–) negative; CI = confidence interval

Table 2. Reproductive performance of cows detected in oestrus by farm staff using visual observations and tail paint (Control) *vs* a camera-software device (CSD) over a 55-day breeding period using artificial insemination in dairy cows at pasture.

Reproduction monitor	Group		P-value	Target
	Control	CSD		
% Calved <40 days at PSM	26%	19%	0.10	10%
21-Day submission rate	76%	75%	0.92	90%
28-Day submission rate	81%	81%	1.00	92%
Return intervals: 2–17 days	21%	32%	0.007	13%
Return intervals: 18–24 days	64%	56%	0.077	69%
Return intervals: 39–45 days	3%	1%	0.11	7%
Ratio of (18–24-day cyc) to (39–45-day cyc)	22:1	42:1	<0.001	9:1
1st Service 49-day NRR	47%	71%	<0.001	61%
Total services 49-day NRR	57%	74%	<0.001	61%
1st Service pregnancy rate	39%	72%	<0.001	60%
Total services pregnancy rate	46%	70%	<0.001	60%
Services per conception	2.2	1.4	<0.001	1.7
4-week in-calf rate	44%	70%	<0.001	57%
8-week in-calf rate	70%	90%	<0.001	86%
% Not in calf by PSM + 165 days	27%	10%	<0.001	7%
Calving to conception interval	84 days	77 days	<0.001	83 days

PSM = planned start of mating; cyc = cycle; NRR = non-return rate

the results for visual observation and tail paint between cows in the CSD group with the Control group, sensitivity (p=0.13), specificity (p=0.59), PPV (p=0.13), NPV (p=0.28) and overall accuracy (p=0.08) of detection of oestrus were similar. Parity, Body condition score and Days in milk at the PSM were excluded from the final analysis as they did not have a significant effect (p>0.05).

The percentage of cows calved <40 days at the PSM, and both the 21- and 28-day submission rates, did not differ significantly between groups (p>0.10; Table 2). However, the CSD group had higher 2–17-day return rates, first-service and total pregnancy rates to AI, higher 4- and 8-week in-calf rates and fewer services per conception than the Control group (p<0.001). Both the percentage of cows not in calf by the PSM + 165 days, and the cumulative proportions of cows not pregnant over time, controlled for the effects of Age, Condition score and Days from calving to the PSM using survival analysis, were lower in the CSD than in the Control group (Table 2 and Figure 1; p<0.001 and p=0.044, respectively). Thus, detection of oestrus using the CSD significantly improved the proportion of cows that became pregnant to AI, compared with visual observation and tail paint in this study.

Mounting behaviour caused the loss of 72% (245) of the ODS. Of those, 40% were lost after a previous reading of 0% removal of paint, 46% had a previous reading of 1–5% removal of paint, and 14% had a previous reading of 5–10% removal of paint. Thus, 5% loss of paint could be considered indicative of oestrus, since there was an indication that intense mounting behaviour occurred immediately after this point was reached.

Discussion

The objective of this study was to determine the accuracy and efficacy of a novel ODS and CSD for detecting oestrus amongst dairy cows at pasture, and to compare this with the results of the typical farm management practices of visual observation and tail-painting conducted by farm workers. The presence of three concurrent detection systems sometimes created a dilemma for farm staff when deciding which observation of oestrus was correct, which was resolved by the farm manager on each occasion who decided which cows to inseminate based predominantly on visual observation and close physical inspection of each cow. This bias was not controlled for in the present study.

The use of diagnosed pregnancy as a gold standard to confirm the occurrence of oestrus enabled objective comparison of detection methods. If cows were not confirmed pregnant at the time of pregnancy diagnosis, their prior oestrous history could not be confirmed and they were excluded from further analysis. The use of pregnancy to confirm oestrus created a bias in favour of the Control group, as the number of cows in that group that were pregnant (n=183) was considerably lower than in the CSD group (n=213). The design of the study enabled determination of true-negative results on a daily basis, which were consequently lowest for the Control group, thus amplifying the specificity and NPV results. The 98% specificity of oestrus detection in the Control group is relatively high, but still equates to 2% of false-positive diagnoses overall based on visual observation and tail paint. Of the total number of cows in the Control group that became pregnant to AI and were diagnosed as in oestrus by the farm staff, 194/395 (49%) were false-positives compared with 48/389 (12%) of cows that became pregnant and were diagnosed incorrectly as in oestrus using the CSD. These equate to PPVs of 51% and 88% for the Control and CSD groups, respectively (Table 1).

The sensitivity and specificity of detection of oestrus using the CSD were higher than those for the combined use of visual observations and tail paint by farm staff, both within the CSD group and between the CSD and Control groups (p<0.05). Thus, the CSD resulted in increased and more accurate detection of oestrus and, consequently, in higher pregnancy rates to AI, than reliance on visual observations and tail paint as recorded by farm staff, in this herd.

The PPV increased when the sensitivity of detection of oestrus in a herd increased, and the NPV increased when the number of true-negative observations of non-oestrus in a herd increased (Cordoba et al 2001). The CSD had a higher PPV (p<0.001) but

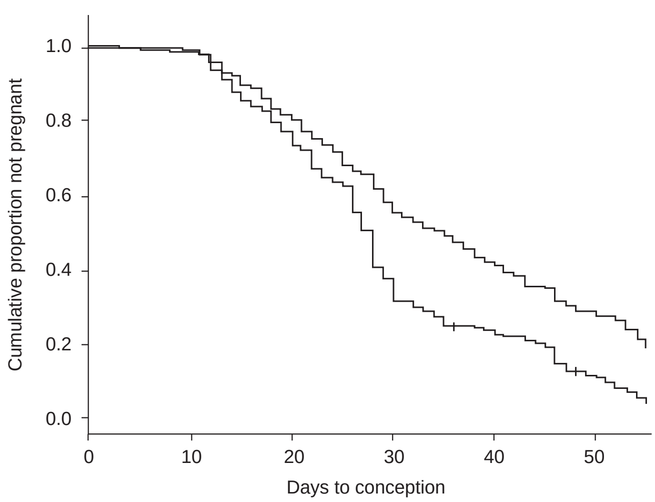

Figure 1. Kaplan-Meier survival analysis of the cumulative proportion of cows not pregnant each day from 10 days before until 55 days after the planned start of mating (PSM), for cows detected in oestrus using a camera-software device (n=240; eligible cows for analysis n=213; lower line) or visual observations and tail paint (Control group; n=240; eligible cows for analysis n=183; upper line), stratified by Age, Days from calving to the PSM and Body condition score.

similar NPV (p=0.28) compared with visual observation and tail paint in the present study, indicating that the CSD had a higher probability of detecting cows that were in oestrus but not of excluding cows that were not in oestrus. The percentage of cows for which 2–17-day return intervals were recorded was high for both the CSD (32%) and Control groups (21%) compared with the target of 13%. The ultimate decision on whether or not to submit cows for AI rested with the farm manager, who ignored CSD results on at least 49 occasions. The higher sensitivity of the CSD and subsequent re-detection of cows that had previously been submitted (erroneously) for AI may have contributed to the higher proportion of 2–17-day return intervals for the CSD compared with the Control group (p=0.007). Higher pregnancy rates for the CSD *vs* the Control group are consistent with inaccurate detection of first oestrus by farm staff followed by accurate detection of true oestrus by the CSD. More accurate detection of genuine short (8–10-day) cycles (Fagan and Roche 1988; Tegegne et al 1993; Burke et al 1994) by the CSD may also have contributed to the higher number of 2–17-day return intervals recorded for this group compared with controls.

The CSD gave false-positive readings when ODS were extremely dirty and not detected, resulting in them being recorded as missing. If an ODS was wet, it occasionally gave false readings because of the reflection caused by the water. However, a high rate of true-positive (85%) and low rate of false-negative (0.6%) results combined to demonstrate a higher overall accuracy of oestrus detection for the CSD compared with visual observation and tail paint interpreted by farm staff, despite these known false readings.

Loss of ODS appeared to be caused by intense mounting activity as well as shedding of the winter coat, despite brushing cows before application. The time allowed for applying strips, while the cows were on the rotary milking platform during milking, may have been inadequate to achieve satisfactory adhesion. From the data that were recorded, the majority of ODS showed 1–5% of paint had been removed at the milking before the strips were lost.

Reproductive performance indicators on the farm used in this study were mostly well below target, and the farm had a history of non-pregnancy rates as high as 25% in previous seasons. This may have resulted, in part, from inaccurate detection of oestrus, including errors of omission, and early false-positive diagnoses in the current study. The potential for gains in reproductive performance due to increased accuracy of oestrus detection using a method such as the CSD was high on this farm, and differences attributed to the use of the CSD compared with visual observation and tail paint may not be so evident on farms with better reproductive management.

In conclusion, the sensitivity, specificity, PPV, NPV and accuracy of detection of oestrus using a novel ODS and CSD method were higher than for visual observation and tail paint in this study. The ODS and CSD system detected more oestrous events that were subsequently confirmed as true from the results of pregnancy diagnosis, and fewer false-positive oestrous events than visual observations by farm staff and use of tail paint. Despite low submission rates, both the pregnancy and in-calf rates achieved using the ODS and CSD system were above target and significantly greater than those of control cows managed under typical commercial conditions. These results indicate potential for this novel method of oestrus detection to increase pregnancy rates to AI in commercial dairy herds, particularly in herds in which the accuracy of oestrus detection is otherwise low.

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