Reproduction, Mastitis, and Body Condition of Seasonally Calved Holstein and Jersey Cows in Confinement or Pasture Systems

S. P. Washburn,* S. L. White,* J. T. Green, Jr.,† and G. A. Benson‡
*Department of Animal Science,
†Department of Crop Science,
‡Department of Agricultural and Resource Economics,
North Carolina State University, Raleigh 27695

ABSTRACT

Dairy cows in confinement and pasture-based feeding systems were compared across four spring-calving and three fall-calving replicates for differences in reproduction, mastitis, body weights, and body condition scores. Feeding systems and replicates included both Jersey and Holstein cows. Cows in confinement were fed a total mixed ration, and cows on pasture were supplemented with concentrates and provided baled hay or haylage when pasture supply was limiting. Breeding periods were for 75 d in spring or fall. Reproductive performance did not differ significantly due to feeding system or season. Jerseys had higher conception rates (59.6 vs. 49.5 ± 3.3%) and higher percentages of cows pregnant in 75 d (78.1 vs. 57.9 ± 3.9%) than Holsteins. Cows in confinement had 1.8 times more clinical mastitis and eight times the rate of culling for mastitis than did cows on pasture. Jerseys had half as many clinical cases of mastitis per cow as Holsteins. Only 41 ± 5% of confinement Holsteins remained for a subsequent lactation, starting within the defined calving season compared with 51 ± 5% of pastured Holsteins and 71 ± 5% of Jerseys, respectively. Body weights and condition scores were generally higher for confinement cows than pastured cows, and Jerseys had higher condition scores and lower body weights than Holsteins. In summary, pastured cows had fewer clinical cases of mastitis, lower body condition scores, and lower body weights than confinement cows. Holsteins were less likely to rebreed, had more mastitis, higher culling rates, and lower body condition scores than Jerseys.

(Key words: reproduction, mastitis, confinement, pasture)

Abbreviation key: CONFINE = cows fed TMR in confinement, PASTURE = cows receiving pasture as the primary source of forage plus supplements.

INTRODUCTION

Some evidence shows that pasture-based dairy farming systems can be as profitable as confinement systems that rely on stored forages (Dartt et al., 1999; Hanson et al., 1998). Furthermore, there is interest in seasonal calving herds due to the apparent success of this approach in New Zealand and elsewhere. Interest among some dairy producers in pasture-based dairy production systems has led to questions about comparisons of such systems to the confinement feeding systems that are more prevalent in the United States. Seasonal calving demands a high level of reproductive efficiency if acceptably low cow turnover rates are to be achieved. Also, there may also be potential differences in cow health in comparing pasture and confinement systems. Whole-lactation, multiyear comparisons between pasture-based and confinement dairy systems under US conditions are very limited, and none has been designed to examine seasonal calving within such systems. Some comparison trials have shown differences in favor of pasture systems for reproductive performance (Bela et al., 1995; Phillips, 1990), mastitis, and SCC (Bela et al., 1995; Goldberg et al., 1992), hoof health (Phillips, 1990), and general cow health (Bela et al., 1995). Trials have also shown that pasture-fed cattle tend to have lower BCS compared with confinement-fed cattle (Kolver and Muller, 1998). Other trials have not shown differences between the two systems with SCC (Rust et al., 1995), general herd health (Parker et al., 1993), and BCS (Rust et al., 1995). Goldberg et al. (1992), in a study of 15 Vermont dairy herds, reported that using rotational grazing had some advantage in udder health and milk quality indicators during the grazing season compared with herds of cows kept in confinement. Bela et al. (1995) reported on two Hungarian farms with multiple year comparisons for pastured cows versus cows fed in confinement and found lower SCC, fewer services per conception (1.70 vs. 2.01 ± 0.02), and shorter calving intervals (380 vs. 395 ± 4.2 d) when cows were allowed to graze. In contrast, a 2-yr study in Minnesota (Rust et al., 1995) reported no differences in SCC nor in BCS between cows in confinement versus...
those on pasture. In a single pasture-based dairy herd demonstration in Ohio, Zartman and Shoemaker (1994) reported that involuntary culling was mainly related to reproduction and that the percentage of cows culled for reproduction declined from 40% in the first year to 23, 22, 3, and 12% in yr 2 through 5, respectively.

The specific objective of this study was to examine differences in reproduction, udder health, and BCS among cows managed in a confinement system compared with cows managed on pasture. Of particular interest was the ability to maintain a seasonal breeding program for Jersey and Holstein cows in the two systems. The multiple-year approach to this study is unique and includes data from complete lactations, two calving seasons, and two breeds in a planned comparison of two distinct dairy management systems.

**MATERIALS AND METHODS**

**Treatments and Design**

This experiment was conducted from March 1995 until November 1998 at North Carolina State University’s Lake Wheeler Road Dairy Educational unit located near Raleigh. This multiple-year study included dairy cows in two feeding systems; a pasture-based system (PASTURE) and a confinement system (CONFINE) using TMR. The project had both spring (4-yr) and fall (3-yr) calving herds with breeding via visual detection of estrus and AI in 75-d periods. Each seasonal herd replicate had 36 cows in PASTURE and 36 cows in CONFINE. The first spring-calving groups included 24 Holsteins and 12 Jerseys. The first two fall-calving groups included 21 Holsteins and 15 Jerseys. In each subsequent set, equal numbers of Holsteins and Jerseys were included. Details of the feeding regimens of the two systems are described by White et al. (2002). Briefly, the PASTURE herds had access to 29 ha of pasture subdivided into 37 paddocks, each containing one or more of several cool- and warm-season grass and legume species to permit grazing year around. PASTURE cows received variable amounts of grain and baled hay or haylage as needed depending upon pasture quality and quantity available. CONFINE cows were housed in a covered free-stall barn with access to an exercise lot and received a TMR with corn and alfalfa silages as the primary forages. Rations were balanced for DMI, CP, ADF, NE\textsubscript{L}, Ca, P, Na, Mg, K, and for trace minerals and vitamins. Calculations were set to challenge production by providing nutrient density above expected production levels by using the DART (Smith et al., 1994) ration program. Jerseys and Holsteins were managed together in both systems, except for two CONFINE replicates where Jerseys and Holsteins were kept separate because of other studies at the dairy unit. Spring- and fall-calving cows were managed as separate groups within each system, except that the various pastures were not assigned to a specific group of cows. During the dry periods, pregnant cows from both CONFINE and PASTURE systems were managed together for 6 to 10 wk and fed rations consisting of corn silage, grass hay, and limited grain.

**Data Collection**

Reproduction data included dates that individual cows were observed in estrus and inseminated within respective 75-d breeding seasons. Conception rates to first and subsequent inseminations and percentages of cows pregnant in 75-d breeding periods were calculated for each breed and treatment group within each seasonal replicate. Breeding periods were from April 1 until June 14 for spring calving groups and from November 1 until January 14 for fall calving groups. Estrous detection was facilitated with use of tail-head paint and androgenized teaser heifers that were rotated weekly between the two systems. Teaser heifers were prepared using 200-mg testosterone propionate (Sigma Chemical Co., St Louis, MO) in 10-ml corn oil injected intramuscularly three times per week for 2 wk before and during breeding seasons. Cows not observed in estrus early in the breeding season were examined via rectal palpation every 2 wk and received prostaglandin F\textsubscript{2α} (25 mg, i.m.) if a corpus luteum was present. Cows within each group were retained in the same group from one year to the next if they rebred successfully within the 75-d breeding period. Cows that did not conceive during the breeding period and cows that were culled for any other reason were replaced with new cows at the beginning of the next calving period. Most replacement cows were first-lactation cows, but some older cows were used.

Indications of clinical mastitis were recorded routinely by personnel at the dairy unit and mastitis treatments were administered based on recommendations of the attending veterinarian. Milk samples were collected monthly and analyzed at the regional Dairy Herd Improvement laboratory (United DHIA, Blacksburg, VA) for SCC using a Fossomatic 360 (Foss Electronic, Slangerupgade, Denmark). Body condition scores were recorded twice each month and body weights were recorded once each month. For BCS, a five-point scale was used with a score of five being obese and a score of one being emaciated (Edmonson et al., 1989). Cows were scored in 0.25-point increments and all scoring was by one individual.

Data on other health problems such as lameness, displaced abomasums, and other metabolic diseases were routinely collected and summarized by breed and treatment groups.
Table 1. Reproductive summary across season and year (least squares means ± SE).

<table>
<thead>
<tr>
<th>Group</th>
<th>First-service conception %a</th>
<th>All services conception %a</th>
<th>Cows inseminated within 75 d %a</th>
<th>% of Cows pregnant in 75 d%a</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFINE1 Holsteins</td>
<td>39.0 ± 6.5</td>
<td>44.6 ± 4.7</td>
<td>84.8 ± 3.5</td>
<td>52.8 ± 6.2</td>
</tr>
<tr>
<td>PASTURE2 Holsteins</td>
<td>51.4 ± 6.5</td>
<td>54.5 ± 4.7</td>
<td>87.0 ± 2.9</td>
<td>63.0 ± 5.2</td>
</tr>
<tr>
<td>CONFINE1 Jerseys</td>
<td>60.0 ± 6.5</td>
<td>59.0 ± 4.7</td>
<td>94.8 ± 2.9</td>
<td>75.7 ± 5.2</td>
</tr>
<tr>
<td>PASTURE2 Jerseys</td>
<td>59.0 ± 6.5</td>
<td>60.2 ± 4.7</td>
<td>98.3 ± 2.9</td>
<td>80.5 ± 5.2</td>
</tr>
</tbody>
</table>

*aSignificant breed effect, *P* < 0.05.

1Treatment group of cows fed TMR.

2Treatment group of cows with pasture as the primary forage source.

**Statistical Analyses**

Data were analyzed using GLM procedures in SAS (1997). In preliminary analyses, seasonal differences were small, so each seasonal treatment and breed group was the experimental unit for analyses across years for reproduction and mastitis parameters. In these models, there were a total of 28 observations across the seven seasonal replicates and independent variables included breed, treatment, and the breed × treatment interaction. However, cow was the experimental unit for analyses within season (BCS, BW, SCC). These were analyzed using a model to account for repeated measures across time and included breed, treatment, and the breed × treatment interaction as main effects with date and interactions with date as subplot effects. Categorical data (conception rates and percentages pregnant in 75 d) across all replicates were also analyzed using the CATMOD procedure in SAS (1997) with breed, treatment, and the breed × treatment interaction as independent variables.

**RESULTS**

**Reproduction**

Reproductive performance (Table 1) did not significantly differ by treatment, with overall percentages of pregnancy in 75 d of 64.2 ± 4.1% for CONFINE and 71.7 ± 3.7% for PASTURE groups. Jerseys in both systems did have higher (*P* < 0.05) percentages of cows inseminated (96.5 vs. 85.9 ± 2.2%), conceiving when inseminated (59.6 vs. 49.5 ± 3.3%), and pregnant in 75 d (78.1 vs. 57.9 ± 3.9%) compared with Holsteins. The CATMOD procedure for conception rate and percentage pregnant in 75 d revealed similar breed effects but no differences between PASTURE or CONFINE treatments nor was the interaction of breed with treatment significant.

**Mastitis and Health**

The percentage of cows infected with at least one case of clinical mastitis (Table 2) was higher (*P* < 0.05) in the CONFINE groups than in the PASTURE groups (42.8 ± 3.2% vs. 24.2 ± 3.2%) with Holsteins having a higher incidence than Jerseys (41.2 ± 3.2% vs. 25.8 ± 3.2%, *P* < 0.05). The interaction of breed × treatment was not significant. Similar results are evident when incidences of clinical mastitis are examined over the total number of cows in each breed and treatment replicate (Table 2). Cows in the CONFINE group had 1.8 times as many cases of mastitis per cow as PASTURE cows (0.79 vs. 0.44 ± 0.07) Holsteins had twice the rate of clinical cases as Jerseys (0.81 vs. 0.41 ± 0.07). Culling and death losses attributed to mastitis were also higher for CONFINE cows and for Holsteins. Average SCC scores were not significantly different due to breed (Holsteins: 3.17 vs. Jerseys: 3.04 ± 0.09) or treatment (both CONFINE and PASTURE = 3.10 ± 0.09). However, due to culling and death, most of the 33 cows not completing at least 220 d of lactation were Holsteins (28 of 33), and 18 of those were CONFINE Holsteins, culled primarily for reasons related to poor udder health.

During the first seasonal replicate of the project, six of 24 Holstein cows in the PASTURE group experienced lameness, which was attributed to sharp-edged gravel in the travel lanes. However, the cows were able to form trails within the lanes that were free of the sharp gravel, and so lameness was only a transient problem. No PASTURE Jersey cows experienced lameness. One PASTURE Jersey cow died of frothy bloat while grazing alfalfa in the first year (1995), and six other cows were treated for mild cases of bloat using an oral drench alfalfa in the first year. A commercial product was briefly included in the concentrate ration to prevent bloat, but its use was discontinued because the cost was deemed uneconomic compared with changing management strategies. Improved management practices using limited access grazing for 1 to 2 d to adapt cows to nearly pure stands of alfalfa or clover subsequently prevented problems with bloat. Incidence of other disease and health problems such as displaced abomasums and culling due to feet and leg problems were very low and did not differ between treatments.

Because of culling related to reproduction, mastitis, and other health factors, an average of only 41 ± 5% of
Table 2. Mastitis summary across season and year (least squares means ± SE).

<table>
<thead>
<tr>
<th>Group</th>
<th>Cows infected g,h</th>
<th>Infections/cow (all cows)g,h</th>
<th>Mastitic cows culled/died %a,b</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFINE1 Holsteins</td>
<td>51.0 ± 4.5</td>
<td>1.06 ± 0.10</td>
<td>9.7 ± 1.6</td>
</tr>
<tr>
<td>PASTURE2 Holsteins</td>
<td>31.4 ± 4.5</td>
<td>0.57 ± 0.10</td>
<td>1.6 ± 1.6</td>
</tr>
<tr>
<td>CONFINE1 Jerseys</td>
<td>34.6 ± 4.5</td>
<td>0.51 ± 0.10</td>
<td>3.4 ± 1.6</td>
</tr>
<tr>
<td>PASTURE2 Jerseys</td>
<td>17.0 ± 4.5</td>
<td>0.30 ± 0.10</td>
<td>NONE</td>
</tr>
</tbody>
</table>

*a*Significant breed effect, *P* < 0.05.

*b*Significant treatment effect, *P* < 0.01.

*c*Treatment group of cows fed a TMR.

*d*Treatment group of cows with pasture as the primary forage source.

CONFINE Holsteins remained in their respective group for their next lactation starting within the defined seasonal calving period. That compared to 51 ± 5% of PASTURE Holsteins and 71 ± 5% and 72 ± 5% for Jerseys, respectively. Again, breed effects were significant (*P* < 0.05), but treatment and the interaction of treatment with breed were not significant.

**Body Condition and BW**

The average BW during the study were 583 ± 11 kg for CONFINE Holsteins, 568 ± 7 kg for PASTURE Holsteins, 419 ± 9 kg for CONFINE Jerseys, and 387 ± 5 kg for PASTURE Jerseys with significant (*P* < 0.05) effects of breed in each seasonal replicate. Although CONFINE cows had numerically higher average BW in each of the seven seasonal replicates, the groups differed significantly (*P* < 0.05) in BW only for spring 1995, fall 1995, and fall 1997. Cows typically lost weight in early lactation and regained it later such that there were significant effects across time (data not shown), but there were no breed × treatment interactions.

In all replicates except spring 1995, Jersey cows were scored with higher body condition (*P* < 0.05) than were Holsteins. Also, PASTURE cows had lower (*P* < 0.05) average BCS over a lactation period than CONFINE cows except for fall 1997 (Table 3). Significant interactions involving time included treatment × date (*P* < 0.05) for each replicate as the patterns of BCS across lactations varied with treatment (Figures 1 and 2). Other interactions (breed × date, breed × treatment by date) were significant in some but not all seasonal replicates. Examples of how average BCS scores varied across lactations are provided in Figure 1 (fall 1996) and Figure 2 (spring 1997) for Holsteins and Jerseys in CONFINE and PASTURE groups. There were no breed × treatment interactions.

**DISCUSSION**

This multiple-year study provides insight into health and reproduction issues that can affect the relative economic performance of dairy production systems. Our data agree in general with reports of Goldberg et al. (1992) and Bela et al. (1995) in that pastured cows had improved udder health as measured by fewer clinical cases of mastitis, although we did not observe significant differences in SCC scores associated with treatment. In a 4-yr pasture demonstration, Smith and Hogan (1994) reported low incidences of mastitis and attributed that observation to the probability that pastured cows are exposed to fewer environmental pathogens compared with confinement-housed cows.

Table 3. Least squares means of BCS for treatment and breed groups within season and year.a,b,c,d

<table>
<thead>
<tr>
<th>Group</th>
<th>Spring 95</th>
<th>Fall 95</th>
<th>Spring 96</th>
<th>Fall 96</th>
<th>Spring 97</th>
<th>Fall 97</th>
<th>Spring 98</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFINE1 Holsteins</td>
<td>2.9</td>
<td>2.6</td>
<td>2.6</td>
<td>2.9</td>
<td>2.9</td>
<td>2.6</td>
<td>2.4</td>
</tr>
<tr>
<td>PASTURE2 Holsteins</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.4</td>
<td>2.5</td>
<td>2.6</td>
<td>2.3</td>
</tr>
<tr>
<td>CONFINE1 Jerseys</td>
<td>2.9</td>
<td>2.9</td>
<td>3.0</td>
<td>3.1</td>
<td>3.0</td>
<td>3.0</td>
<td>2.8</td>
</tr>
<tr>
<td>PASTURE2 Jerseys</td>
<td>2.4</td>
<td>2.7</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
<td>3.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

*a*All standard errors ranged from 0.07 to 0.14 and were rounded to 0.1.

*b*Significant treatment effect (*P* < 0.05) for all seasons except fall 97.

*c*Significant breed effect (*P* < 0.05) for all seasons except spring 95; no breed-by-treatment interactions.

*d*Significant interactions involving time included treatment × date (*P* < 0.05) for each seasonal group. Other interactions (breed × date, breed × treatment × date) were significant in some seasonal groups but not others: see Figures 1 and 2.

*e*Treatment group of cows fed a TMR.

*f*Treatment group of cows with pasture as the primary forage source.
When BCS for each breed and treatment are examined (Table 3), it can be seen that during some seasons, the difference between the PASTURE and CONFINE Jerseys is not as great as the difference between the PASTURE and CONFINE Holsteins, suggesting that energy intake relative to output was higher for Jerseys than Holsteins in the PASTURE system. In a separate experiment, we determined that pastured Jerseys could consume as much supplemental concentrate as pastured Holsteins at three different feeding levels (6.8, 4.5, and 2.3 kg/cow per feeding) during measured feeding times of 2.5 to 15 min (White, 2000; White et al., 2000). During the 4-yr trial, pasture-fed cattle of both breeds were fed together, and the Jersey and Holstein cows likely consumed similar amounts of supplements. In this trial, total lactation milk production averages were higher for Holsteins than for Jerseys (7451 vs. 5757 ± 171 kg) and higher for CONFINE than PASTURE (6981 vs. 6228 ± 171 kg), with no breed × treatment interactions (White et al., 2002). Therefore, the Jerseys would have consumed more energy than the Holsteins relative to body size and milk production. This could help explain the relative differences in BCS between breeds within the pasture groups.

The rations for both PASTURE and CONFINE groups were developed using the same ration program (Smith et al., 1994), but the PASTURE cows usually did not maintain as much body condition as the CONFINE cows. Lower BCS on pasture were also reported with a short-term comparison trial between confinement-fed and pasture-fed cows (Kolver and Muller, 1998). In our experiment, PASTURE cows usually had an average BCS at or below 3.0 throughout the lactation. Several other grazing trials have reported average BCS at or below 3.0. (Fales et al., 1995; Holden et al., 1994; Hengerholt et al., 1997; Jones-Endsley et al., 1997; McDougall et al., 1995). This difference in BCS may be partially explained by the differing energy balances between the two groups of cows. First, there are limitations on the total consumption of fresh forage; a grazing dairy cow fed no supplement can consume only about 80 kg of fresh forage per day (Holden et al., 1994). Also, variations in pasture type, quality, and quantity could have affected body condition. In addition, pasture cows most likely expend more energy than a confinement-fed cow because of walking to and from grazing paddocks and while grazing. Some grazing paddocks were up to 1200 m from the milking area, which could have had an impact on the cow's energy balance. The consistently lower BCS for the PASTURE cows may indicate that the PASTURE cows were in a longer and more severe negative energy balance than the the CONFINE cows. However, cows provided variable amounts of supplements in three feeding strategies still averaged less than 3.0 BCS in a 24-wk feeding trial (Hoffman et al., 1993). Therefore, lower BCS in pasture-fed cows may not indicate a problem unless milk production, reproduction, or health is compromised. Milk production averaged 11% lower among PASTURE cows but, because of lower feed costs, income over feed costs were similar for PASTURE and CONFINE groups (White et al., 2002). PASTURE cows generally did re-
gain body condition as their lactations progressed (Figures 1 and 2). Because cows from both PASTURE and CONFINE were managed together during nonlactating periods, additional gain in body condition occurred for cows remaining in the study from one year to the next.

Despite differences in body condition and BW, reproduction for PASTURE cows was at least as good as for the CONFINE cows. However, we did not observe a trend for improved reproductive performance across years as reported by Zartman and Shoemaker (1994), nor did we observe significantly improved reproduction from PASTURE cows as Bela et al. (1995) had reported.

In the current experiment, across feeding systems, Holsteins had an average overall conception rate of 49.6%, while Jerseys averaged 59.6%, which are higher rates compared with recent data on conception in 10 Southeastern states (Washburn et al., 2002). In that report, both Jerseys and Holsteins in commercial herds showed an increasing trend in services per conception and in days open. An earlier study from NC State University (Fonseca et al., 1983) also reported significant differences in first-service conception rates (72% for Jerseys vs. 49% for Holsteins) and a higher estrus detection rate (73% for Jerseys vs. 43% for Holsteins), but those data were confounded in that the two breeds were managed in separate herds. Also, Jerseys in Florida were reported to have shorter calving intervals than Holsteins (Silva et al., 1992). Breed differences in reproduction were quite significant in the current study while under similar management, and this must be considered if seasonal breeding is to be feasible. Even with use of aids to enhance detection of estrus, 14% of the Holsteins were not detected in estrus and inseminated during the designated 75-d breeding periods. In contrast, almost all of the Jerseys were inseminated at least once during the respective breeding periods. Therefore, Jerseys might be a more appropriate choice for a seasonal calving pattern due to higher rates of insemination, conception, and pregnancy in restricted breeding periods. However, other breed factors of economic importance would need to be considered as well (White et al., 2002). The percentages of cows successfully surviving all reasons for culling to be retained for another lactation were only 41% for CONFINE Holsteins and 51% for PASTURE Holsteins, much lower than for Jerseys (71 and 72%, respectively), suggesting maintaining seasonal calving would be a difficult challenge for producers using Holsteins. Although not significant in the current study, the 10-percentage-point numerical advantage of PASTURE Holsteins over CONFINE Holsteins in survival until the next lactation is of potential economic importance if substantiated by further research and under commercial farming conditions. Further studies are warranted specifically to determine whether a more aggressive strategy of estrous synchronization can increase proportions of pregnant cows within 75-d breeding periods and to examine relative conception rates and productivity of Jersey-Holstein crossbred cows in various management systems.

CONCLUSIONS

This study was a planned comparison of pasture versus confinement systems using two breeds of dairy cows, replicated in two calving seasons and across multiple years. There were no differences in reproduction due to treatment or season but breed differences were significant. Pastured cows consistently had lower clinical mastitis and lower BCS than cows managed in a confinement system. Breed differences were also evident, as Jersey cows had less clinical mastitis, higher BCS, higher insemination rates, higher conception rates, and lower culling rates than Holsteins. Such differences may partially offset differences in milk yield of alternative breeds and dairy systems. Based on the results obtained in this study, maintaining seasonal reproduction appears more feasible with Jerseys than with Holsteins, regardless of production system.

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REFERENCES


