Comparison of Weigh-Suckle-Weigh and Machine Milking for Measuring Ewe Milk Production

M. E. Benson, M. J. Henry, and R. A. Cardellino

ABSTRACT: Thirteen crossbred ewes were used to compare weigh-suckle-weigh (WSW) and machine milking (MM) methods for determining milk production of ewes that were rearing single or twin lambs. At parturition, ewes were 13 mo of age and produced six single lambs and seven pairs of twin lambs. Milk production estimates were initiated on d 6 of lactation and a 3-d rotation of the two techniques was implemented. On d 6, milk production was measured using WSW; on d 7, MM was used. No measurement was made on d 8. The 3-d rotation was repeated 20 times throughout a 63-d lactation, resulting in 20 point estimates of milk production for each method of measurement for each ewe. The WSW procedure consisted of a 3-h period in which lambs were withheld from suckling their dams. This was followed by a suckling period, a second 3-h withholding period, and a second suckling period. Differences in pre- and postsuckling lamb weights of the second suckling period were defined as milk consumption and, indirectly, 3-h milk production. The MM procedure included an administration of 10 IU of oxytocin (i.v.), followed by evacuation of the udder with a machine using commercially available sheep milking equipment, and the milk was discarded. Lambs were withheld from suckling the ewes for a 3-h period, followed by a repetition of the oxytocin and machine milking procedures. Milk from the second milking was weighed. Milk production estimates determined using the WSW and MM techniques were similar (P = .42). Average 3-h milk production was 340 and 351 g for WSW and MM, respectively. Machine milking provides a reliable tool in evaluating the milk-producing ability of ewes that are rearing single or twin lambs.

Key Words: Ewes, Lactation, Milk Production, Suckling

Introduction

The quantity of milk produced by ewes is the most important factor in determining lambs' growth rate (Torres-Hernandez and Hohenboken, 1979). Several methods of estimating ewe milk production have been reported and include weigh-suckle-weigh (also referred to as test-weighing), hand milking, machine milking, and indirect assessments using body water dilution techniques (Barnicoat et al., 1949, 1956; Doney et al., 1979; Mellor et al., 1993).

The weigh-suckle-weigh technique is one of the most frequently cited methods for measuring milk production. Limitations of this method include an inability to accurately measure small amounts of milk consumed by young lambs, changes in lamb appetite at specific times of measurements, inability to simultaneously sample for milk composition, and errors associated with urine and fecal losses between weighings. These limitations indicate a need to identify an alternative means for accurately measuring milk production. With the ability to reliably and consistently measure ewe milk production, further refinement in the requirements of lactating ewes and growth requirements of milk-fed lambs can be made. The objective of this experiment was to examine machine milking (MM) as a viable alternative to the weigh-suckle-weigh (WSW) method for determining milk production of ewes rearing single or twin lambs.

Materials and Methods

Thirteen Suffolk-sired, crossbred ewe lambs were bred to lamb at an average age of 13 mo. The ewes gave birth to and reared seven pairs of twin lambs and
were individually penned (1.5 × 1.5 m) for 2 to 4 d before the trial began. During this pretrial period, lamb health and vigor were monitored, tails were docked, and lambs were vaccinated against enterotoxemia and given a selenium supplement. The male lambs were castrated, and all dams were started on a lactation diet. At the start of the experimental period, ewes were randomly allotted to sampling times. The male lambs were vaccinated against enterotoxemia and feed. Ewes had ad libitum access to a complete mixed lactation diet that consisted of 56% corn, 8% soybean meal, 31% ground alfalfa hay, 4.5% molasses, and .5% salt. The diet was formulated to meet or exceed NRC (1985) requirements for lactating ewes, contained 14% CP (DM basis), and was estimated to contain 2.7 Mcal/kg of ME. Pens and feeders were arranged so that the lambs had no access to the ewes’ feed.

Measurements of milk production were initiated on d 6 ± 1 of lactation. Milk production was measured at 3-d intervals using two techniques: weigh-suckle-weigh (WSW) and machine milking (MM). On d 6 of lactation, milk production was measured using the WSW method, on d 7, MM was used to measure milk production, and on d 8, no milk production estimate was made. This 3-d rotation was repeated 20 times throughout a 63-d lactation, resulting in 20 point estimates of milk production for each method of measurement for each ewe. Experimental procedures for both techniques were initiated at 0800, and ewes were randomly allotted to sampling times.

Weigh-Suckle-Weigh

Milk production determined using the WSW technique followed the procedure of Doney et al. (1979) using a modified suckling sequence. In the present experiment, a 6-h test period included two suckling sessions. At the start of the test period, lambs were separated from their dams and held at the rear of the pens using wire mesh panels for a 3-h period. This arrangement allowed sight and smell contact between the ewe and lamb(s) but suckling was not possible. Following the 3-h separation, lambs were returned to the ewe and allowed to suckle and empty the udder. When lambs stopped suckling, they were returned to the holding area within the pen and separated from their dams for an additional 3-h period. Following this second separation, lambs were weighed prior to suckling the ewe, allowed to suckle, and weighed again immediately following suckling. The difference between pre- and postsuckling weights was defined as milk consumption and indirectly as 3-h milk production. No attempt was made to collect feces or urine if they were excreted during the suckling period.

Machine Milking

The MM technique used commercially available sheep milking equipment (Westfalia Sheep Milking System, Westfalia Systemat, Elk Grove, IL). An operating vacuum of 40.6 kPa was used. The pulsator was operated at 120 cycles/min with a 50:50 milk:rest ratio. Milk production measurements were made as follows. The ewe was injected via jugular venipuncture with 10 IU of oxytocin, and the udder was immediately evacuated using the milking machine. Milk collected during this initial milking was discarded. The ewe was returned to the pen, and the lamb(s) was(were) separated from the ewe to prevent suckling for a 3-h period using the same pen arrangement as described for the WSW technique. Following the separation period, the udder was evacuated using the same procedure and the milk was collected, weighed, and discarded.

Statistical Analysis

The experimental design consisted of a split-split-plot with repeated measurements on animals (Gill, 1988). The linear model used to describe an observation for response variable MP (grams per 3-h milk production) was as follows:

\[
MP_{ijkl} = \mu + R_i + E_{ij} + M_k + (RM)_{ik} + (EM)_{ijk} + D_l + (RD)_{il} + (ED)_{ijl} + (MD)_{kl} + (RMD)_{ikl} + (EMD)_{ijkl}
\]

where \(\mu\) is the general mean, \(R_i\) is the effect of type of rearing (single or twin lamb), \(E_{ij}\) is the random effect of ewe within rearing type, \(M_k\) is the effect of the method of milking (WSW or MM), \(D_l\) is the effect of the day of lactation (6, 9, 12, . . ., 60, 63), and all terms in parentheses are interactions of the effects symbolized. The four error terms were \(E1 = E_{ij}, E2 = (EM)_{ijk}, E3 = (ED)_{ijl},\) and \(E4 = (EMD)_{ijkl}\). Subscript ranges are \(i = 1, 2; j = 1, 2, . . . , 6\) (singles) or 7 (twins); \(k = 1, 2;\) and \(l = 1, 2, . . . , 20\). Data were analyzed using the GLM procedures of SAS (1990). To further evaluate milk production throughout a 63-d lactation, total lactation was divided into segments of early (d 6 to 21), middle (d 24 to 42), and late (d 45 to 63), and the data were analyzed using the same model as for total lactation. Correlations of 3-h milk production with lamb gain were calculated. To determine the consequence of estimating milk production at less frequent intervals, the following measurement schedules were simulated: 1) 6-d intervals (6, 12, 18, 24, 30, 36, 42, 48, 54, and 60 d of lactation); 2) 9-d intervals (6, 15, 24, 33, 42, 51, and 60); 3) d 15, 33, and 54 of lactation; and 4) d 6, 36, and 63 of lactation. Correlations were then calculated between milk production measurements obtained at 3-d intervals and milk production measurements obtained at less frequent intervals.

Results and Discussion

Similar results were found when milk production was determined using either the WSW or MM technique.
As shown in the analysis of variance (Table 1), type of rearing (R) did not affect milk production over the 63-d lactation (P = .157). When the WSW and MM methods were compared, milk production estimates were similar (P = .424) with no interaction found between type of rearing and method of estimation. Day (D) was a significant factor (P = .0001) affecting milk production. Lactation in sheep peaks around d 21 to 24 and declines thereafter (Cardellino and Benson, 1994). A type of rearing × D interaction was also significant (P = .028) and indicates that the shape of the lactation curves of ewes rearing singles differs from that of ewes rearing twins. No other significant effects or interactions were found in the analysis.

Three-hour milk production of ewes rearing single and twin lambs as measured by both WSW and MM methods is shown in Figure 1. During the first 21 d of lactation, milk production measurements obtained with the WSW method were more erratic for ewes rearing single lambs than for ewes rearing twin lambs. This may be explained by the inability of a young lamb to consume all of the milk produced by a ewe during a 3-h period in one suckling bout. Newborn lambs suckle as often as every 30 min following parturition, and the frequency is reduced to approximately once every hour during the 1st wk (Hinch, 1989). Hinch (1989) further reported that suckling frequency continues to decline to once every 3 h by 9 wk of age. Because the MM technique measures milk synthesized by the mammary gland during a 3-h period, the ability and desire of the lamb to suckle at a given time is removed, and a lactation curve with less variation results. The variation in these lactation curves during the first 21 d of lactation demonstrates the necessity for multiple measurements of milk production when assessing lactational performance.

Milk production measurements were consistently, although not significantly (P = .16), higher with the MM technique than with the WSW method through d 21 of lactation. This response correlates with results of Doney et al. (1979), who reported that use of an oxytocin method gave higher yield estimates in the 1st wk than did a WSW method. It was further reported that this yield difference between methodologies was greatly reduced with ewes rearing twin lambs compared to those rearing a single lamb. Doney et al. (1979) concluded that oxytocin was useful in ensuring

Figure 1. Milk production determined with machine milking (MM) and weigh-suckle-weigh (WSW) techniques for ewes rearing (A) single (MM-1, WSW-1) or (B) twin (MM-2, WSW-2) lambs.
MEASURING MILK PRODUCTION OF EWES

Table 2. Analysis of variance of ewe milk production (g/3 h) in partial lactation periods measured with machine milking (MM) and weigh-suckle-weigh (WSW) techniques

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Stage of lactation</th>
<th>df</th>
<th>MS</th>
<th>P</th>
<th>df</th>
<th>MS</th>
<th>P</th>
<th>df</th>
<th>MS</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Early (6 to 21 d)</td>
<td>1</td>
<td>211,948</td>
<td>.075</td>
<td>1</td>
<td>115,350</td>
<td>.155</td>
<td>1</td>
<td>24,097</td>
<td>.507</td>
</tr>
<tr>
<td>E (E1)</td>
<td>Middle (24 to 42 d)</td>
<td>11</td>
<td>54,854</td>
<td>11</td>
<td>49,350</td>
<td>11</td>
<td>31,350</td>
<td>11</td>
<td>30,900</td>
<td>11</td>
</tr>
<tr>
<td>M</td>
<td>Late (45 to 63 d)</td>
<td>1</td>
<td>30,870</td>
<td>.163</td>
<td>1</td>
<td>28</td>
<td>.967</td>
<td>1</td>
<td>3,004</td>
<td>.472</td>
</tr>
<tr>
<td>RM</td>
<td></td>
<td>1</td>
<td>79</td>
<td>.941</td>
<td>1</td>
<td>487</td>
<td>.065</td>
<td>1</td>
<td>1,300</td>
<td>.496</td>
</tr>
<tr>
<td>EM (E2)</td>
<td></td>
<td>11</td>
<td>13,770</td>
<td></td>
<td>11</td>
<td>16,139</td>
<td></td>
<td>11</td>
<td>3,400</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>5</td>
<td>42,701</td>
<td>.001</td>
<td>6</td>
<td>13,122</td>
<td>.042</td>
<td>6</td>
<td>47,587</td>
<td>.000</td>
</tr>
<tr>
<td>RD</td>
<td></td>
<td>5</td>
<td>6,512</td>
<td>.595</td>
<td>6</td>
<td>20,788</td>
<td>.003</td>
<td>6</td>
<td>5,231</td>
<td>.472</td>
</tr>
<tr>
<td>ED (E3)</td>
<td></td>
<td>55</td>
<td>8,772</td>
<td></td>
<td>66</td>
<td>5,630</td>
<td></td>
<td>66</td>
<td>5,561</td>
<td></td>
</tr>
<tr>
<td>MD</td>
<td></td>
<td>5</td>
<td>7,554</td>
<td>.546</td>
<td>6</td>
<td>919</td>
<td>.988</td>
<td>6</td>
<td>3,163</td>
<td>.723</td>
</tr>
<tr>
<td>RMD</td>
<td></td>
<td>5</td>
<td>1,865</td>
<td>.961</td>
<td>6</td>
<td>3,912</td>
<td>.697</td>
<td>6</td>
<td>4,653</td>
<td>.504</td>
</tr>
<tr>
<td>EMD (E4)</td>
<td></td>
<td>55</td>
<td>9,290</td>
<td></td>
<td>66</td>
<td>6,101</td>
<td></td>
<td>66</td>
<td>5,196</td>
<td></td>
</tr>
</tbody>
</table>

aR = type of rearing, E = ewe, M = method of measurement, and D = day of lactation.
bMS = mean square.

The complete milk letdown and had no effect on overall level of production.

To further evaluate milk production, the lactation was divided into three periods: early (d 6 to 21), middle (d 24 to 42), and late (d 45 to 63). The analyses of variance of these partial lactations are shown in Table 2. There was a difference (P =.075) in milk production as affected by rearing type during early lactation. Although day of lactation affected milk production during all three partial lactations, a rearing type × day of lactation interaction (RD) was identified during midlactation (P = .003). This response corresponds to differences in occurrences of lactation peaks between ewes that reared single lambs and those that reared twins. Consistent with the measurements of milk production over the total 63-d lactation, no other interactions were found, and WSW and MM measurements were similar throughout the three partial lactation periods.

Average 3-h production during early lactation was 316 g for ewes rearing a single lamb and 390 g for ewes rearing twins (Table 3). This equates to a 23% increase in milk production of ewes rearing twins over ewes rearing single lambs. The magnitude of this difference decreased in later stages of lactation. Gardner and Hogue (1964) also reported a difference in milk production between ewes with single or twin lambs during the 1st wk of lactation, but production was similar by wk 10.

It is generally accepted and supported in the literature that ewes rearing multiple lambs produce more milk than those rearing singles (Torres-Hernández and Hohenboken, 1979; Snowder and Glimp, 1991; Ramsey et al., 1998). The NRC (1985) reports that ewes rearing twin lambs produce 20 to 40% more milk than those rearing singles. The similar milk production levels seen between ewes with single lambs and ewes rearing twins in this study may be explained by a difference in age. In the present study, ewes lambed at 13 mo of age and were in their first lactation; ewes in the above-mentioned studies ranged in age from 2 to 7 yr and were likely in later parities.

Least squares means of 3-h milk production comparing WSW and MM are shown in Table 4. The average 3-h production for ewes as measured by MM was 351 g and for WSW was 340 g. Daily milk production was calculated to be 2.808 kg for the MM and 2.720 kg for the WSW method. Reports of daily

Table 3. Least squares means of milk production (g/3 h) of ewes rearing single or twin lambs

<table>
<thead>
<tr>
<th>Rearing</th>
<th>Stage of lactation</th>
<th>Overall (6 to 63 d)</th>
<th>Early (6 to 21 d)</th>
<th>Middle (24 to 42 d)</th>
<th>Late (45 to 63 d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td></td>
<td>321 ± 23.2</td>
<td>316 ± 27.6</td>
<td>345 ± 24.2</td>
<td>302 ± 24.7</td>
</tr>
<tr>
<td>Twin</td>
<td></td>
<td>369 ± 21.5</td>
<td>399 ± 25.6</td>
<td>396 ± 22.4</td>
<td>326 ± 22.9</td>
</tr>
</tbody>
</table>

aLeast squares means ± SE.
bWithin a column, means with unlike superscripts differ (P = .075).

cComplete milk letdown and had no effect on overall level of production.

dTo further evaluate milk production, the lactation was divided into three periods: early (d 6 to 21), middle (d 24 to 42), and late (d 45 to 63). The analyses of variance of these partial lactations are shown in Table 2. There was a difference (P =.075) in milk production as affected by rearing type during early lactation. Although day of lactation affected milk production during all three partial lactations, a rearing type × day of lactation interaction (RD) was identified during midlactation (P = .003). This response corresponds to differences in occurrences of lactation peaks between ewes that reared single lambs and those that reared twins. Consistent with the measurements of milk production over the total 63-d lactation, no other interactions were found, and WSW and MM measurements were similar throughout the three partial lactation periods.

Average 3-h production during early lactation was 316 g for ewes rearing a single lamb and 390 g for ewes rearing twins (Table 3). This equates to a 23% increase in milk production of ewes rearing twins over ewes rearing single lambs. The magnitude of this difference decreased in later stages of lactation. Gardner and Hogue (1964) also reported a difference in milk production between ewes with single or twin lambs during the 1st wk of lactation, but production was similar by wk 10.

It is generally accepted and supported in the literature that ewes rearing multiple lambs produce more milk than those rearing singles (Torres-Hernández and Hohenboken, 1979; Snowder and Glimp, 1991; Ramsey et al., 1998). The NRC (1985) reports that ewes rearing twin lambs produce 20 to 40% more milk than those rearing singles. The similar milk production levels seen between ewes with single lambs and ewes rearing twins in this study may be explained by a difference in age. In the present study, ewes lambed at 13 mo of age and were in their first lactation; ewes in the above-mentioned studies ranged in age from 2 to 7 yr and were likely in later parities.

Least squares means of 3-h milk production comparing WSW and MM are shown in Table 4. The average 3-h production for ewes as measured by MM was 351 g and for WSW was 340 g. Daily milk production was calculated to be 2.808 kg for the MM and 2.720 kg for the WSW method. Reports of daily

Table 4. Least squares means of milk production (g/3 h) measured with machine milking (MM) or weigh-suckle-weigh (WSW) techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Stage of lactation</th>
<th>Overall (6 to 63 d)</th>
<th>Early (6 to 21 d)</th>
<th>Middle (24 to 42 d)</th>
<th>Late (45 to 63 d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM</td>
<td></td>
<td>351 ± 17.7</td>
<td>367 ± 21.8</td>
<td>370 ± 19.7</td>
<td>318 ± 18.4</td>
</tr>
<tr>
<td>WSW</td>
<td></td>
<td>340 ± 16.4</td>
<td>339 ± 20.2</td>
<td>371 ± 18.3</td>
<td>310 ± 17.0</td>
</tr>
</tbody>
</table>

aLeast squares means ± SE.
milk production in the literature include .097 to 1.660 kg/d (Snowder and Glimp, 1991), 1.128 kg/d (Torres-Hernandez and Hohenboken, 1979), and 1.380 kg/d (Langlands, 1973) when ewes and lambs were managed under pasture and range conditions. Milk production estimates for ewes fed forage-based diets supplemented with concentrates include 1.61 to 2.33 kg/d (Gardner and Hogue, 1964), 2.13 to 3.03 kg/d (Appeddu et al., 1995), and 2.716 to 3.470 kg/d (Loerch et al., 1985). Various methods and milking frequencies were used to arrive at these estimates. The range in reported milk production levels is not unexpected given the diverse management strategies and differences in genetic composition of the ewes evaluated in these studies.

In the present study, peak milk production occurred at 21 d for ewes rearing singles and 28 d for ewes rearing twins. This time frame is consistent with reported milk production peaks occurring around the 3rd wk of lactation (Gardner and Hogue, 1966; Torres-Hernandez and Hohenboken, 1979; Cardellino and Benson, 1994; Appeddu et al., 1995).

Correlations of 3-h milk production (estimated with MM and WSW) with lamb gain are presented in Table 5. Lamb gain and milk production were most highly correlated during early lactation, and this correlation declined as lactation progressed. Over the 63-d lactation, correlations between milk production and lamb gain over the same period were .53 and .60 for MM and WSW methods, respectively. Correlations between cow milk production and calf gains or calf weights range widely in the literature (r = .16 to .76); however, they follow the same trend found in this study (Rutledge et al., 1971; Belcher et al., 1980; Beal et al., 1990). Rutledge and coworkers (1971) reported correlations of .49, .38, .36, .38, .37, .29, and .25 for milk production determined at mo 1 through 7 of lactation, respectively, as estimated by calf weaning weight. In the present study, correlations also declined as lactation progressed through early, middle, and late stages. This was expected, because lamb weights and, therefore, maintenance requirements continued to increase while milk production was static or declining. These results, however, identify milk production as a primary factor influencing lamb gain.

To determine how often milk production needs to be measured to obtain a reliable estimate, simulation procedures were conducted in which selected points were dropped from the analysis. Table 6 presents correlations between the measurements made at 3-d intervals and measurements made at less frequent sampling times. When milk production was determined from measurements taken at 6- or 9-d intervals, correlations with 3-d estimates were .97 and .95 for MM and .97 and .86 for WSW, respectively. As frequency of measurements declined to sampling at 15, 33, and 54 d of lactation, correlations declined to .91 and .79 for MM and WSW, respectively. When measuring milk production at the start of the trial, at midlactation, and at the end of the 63-d lactation, correlations were reduced to .85 and .83 for MM and WSW, respectively. There seems to be no benefit, however, to measuring at 3-d intervals compared with 6-d intervals. Caution is advised when using a limited number of production estimates over a 63-d lactation to evaluate lactating ewes.

### Implications

Machine milking can be a valuable, reliable tool in evaluating the milk-producing ability of ewes rearing single or twin lambs. In addition to providing a more

---

**Table 5. Correlations of 3-h milk production estimates from machine milking (MM) or weigh-suckle-weigh (WSW) with lamb gain**

<table>
<thead>
<tr>
<th>Lamb gains</th>
<th>MM</th>
<th>WSW</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>.53 (.06)</td>
<td>.60 (.03)</td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>.66 (.01)</td>
<td>.82 (.001)</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>.45 (.12)</td>
<td>.26 (.38)</td>
<td></td>
</tr>
<tr>
<td>Late</td>
<td>.18 (.56)</td>
<td>.24 (.42)</td>
<td></td>
</tr>
</tbody>
</table>

*aValues in parentheses are P-values.

**Table 6. Correlations of 3-h milk production measured at various intervals with 3-h milk production measured at 3-d intervals**

<table>
<thead>
<tr>
<th>Measurement schedule/frequency</th>
<th>6-d intervals</th>
<th>9-d intervals</th>
<th>Days 15, 33, 54</th>
<th>Days 6, 36, 63</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine milking</td>
<td>.97</td>
<td>.95</td>
<td>.91</td>
<td>.85</td>
<td></td>
</tr>
<tr>
<td>Weigh-suckle-weigh</td>
<td>.97</td>
<td>.86</td>
<td>.79</td>
<td>.83</td>
<td></td>
</tr>
</tbody>
</table>

*aMeasurement schedule: 6-d = 6, 12, 18, 24, 30, 36, 42, 48, 54, and 60 d of lactation; 9-d = 6, 15, 24, 33, 42, 51, and 60 d of lactation.

*bP < .0015.
consistent estimate than traditional weigh-suckle-weigh methods, it also facilitates the collection of a milk sample that can be studied for compositional analysis. Multiple estimates of milk production are recommended for reliable evaluation of lactating ewes. Accurate assessment of milk-producing ability is important when defining the nutritional requirements of lactating ewes. Determination of milk production of ewes is also needed to study the efficiency of nutrient utilization during lactation. Furthermore, machine milking provides useful methodology to further study growth and nutrient utilization of suckling lambs.

**Literature Cited**


