J. Dairy Sci. 84:1660–1668

Effect of Weaning System on Commercial Milk Production and Lamb Growth of East Friesian Dairy Sheep

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ABSTRACT

East Friesian crossbred ewes (n = 99) and their lambs (n = 232) were used to study the effects of three weaning systems on milk production and lamb growth. Prior to parturition, a ewe and her lambs were assigned to one of the following three treatments for the first 28 ± 3 d of lactation: 1) ewes weaned from their lambs at 24 h postpartum, ewes machine milked twice daily, and their lambs raised artificially (DY1); or 2) beginning 24 h postpartum, ewes separated from their lambs for 15 h during the evening, ewes machine milked once daily in the morning, and their lambs allowed to suckle for 9 h during the day (MIX); or 3) ewes not machine milked and exclusively suckled by their lambs (DY30). After the treatment period, lambs were weaned from MIX and DY30 ewes, and all three groups were machine milked twice daily. Daily commercial milk yield and milk composition were recorded weekly or twice monthly, and lambs were weighed at weaning or at 28 d and at approximately 120 d of age. Average lactation length (suckling + milking period) was 183 ± 5 d and was similar among weaning systems. Differences among weaning systems for milk yield, milk fat and protein percentages, and somatic cell count were highly significant prior to and around weaning, and became nonsignificant by 6 wk in lactation. Total commercial milk production was greatest for DY1 and MIX ewes (261 ± 10 and 236 ± 10 kg/ewe, respectively) and least for DY30 ewes (172 ± 10 kg/ewe). Daily gain of lambs to 30 d and weight at 30 d were similar regardless of weaning system; however, by 120 d, DY30 lambs tended to be heaviest, MIX lambs intermediate, and DY1 lambs lightest (47.3 ± 1.6, 45.9 ± 1.8, and 43.7 ± 1.2 kg, respectively). Overall financial returns for milk and lamb sales were greatest for the MIX system because of the increase in marketable milk during the first 30 d of lactation compared with the DY30 system and because of acceptable 120-d lamb weights without the expenses of artificial rearing compared with the DY1 system. A mixed system of suckling and milking during early lactation appears to be a valuable management tool for dairy sheep production.
(**Key words:** dairy sheep, weaning, East Friesian)

Abbreviation key: DY1 = d-1 weaning system, **DY30** = d-30 weaning system, **MIX** = mixed suckling and milking weaning system.

INTRODUCTION

Approximately 25% of the total milk yield of a dairy ewe is produced during the first 30 d of lactation (Folman et al., 1966; Ricordeau and Denamur, 1962), a time when lambs in US dairy sheep operations are typically allowed to suckle their dams. Dairy ewes are now capable of producing amounts of milk that exceed the requirements for normal lamb growth (Bocquier et al., 1999). Therefore, for a dairy sheep enterprise, waiting until after 30 d to begin machine milking significantly reduces economic returns because less marketable milk is produced (Gargouri et al., 1993) yet this potentially benefits lamb growth (Peters and Heaney, 1974). In an effort to maximize commercial milk yield and lamb growth, a variety of mixed management systems that allow for both suckling and machine milking have been described (Folman et al., 1966; Gargouri et al., 1993; Papachristoforou, 1990). Mixed management systems, although not necessarily common in dairy cattle, are used extensively throughout the world for dairy ewes and goats. The American sheep dairy industry is young, and, as a consequence, effective weaning and rearing strategies specific to American crossbred dairy sheep have not yet been determined. It is hypothesized that a mixed management weaning system is superior in terms of overall financial returns from milk and lamb sales compared with traditional d-30 and immediate postpartum weaning of dairy ewes. Therefore, the objectives of this study were to compare commercial milk yield, milk composition and quality, and lamb growth traits of three weaning systems for East Friesian cross-

Received October 16, 2000.
Accepted March 12, 2001.
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bred dairy sheep and to estimate their relative impact on economic returns.

MATERIALS AND METHODS

The experiment was conducted at the University of Wisconsin-Madison during the 1998 lactation at the Spooner Agricultural Research Station in northwest Wisconsin. During 1993, the station initiated research with the East Friesian breed of sheep to develop a flock of dairy-type crossbred ewes to compare with domestic crossbreds (Dorset-sired) for milk and lamb production (Thomas et al., 2000). From this flock, 99 second- or third-parity East Friesian-crossbred ewes giving birth to two or more Texel- or East Friesian-sired lambs (n = 232) were blocked on their previous lactation's milk production, and before parturition, randomly assigned to one of three treatments for the first 28 ± 3 d of lactation. Treatments were the following: 1) ewes weaned from their lambs at 24 h postpartum, ewes machine milked twice daily, and their lambs raised artificially (**DY1**, n = 31 ewes and their 72 lambs); or 2) beginning 24 h postpartum, ewes separated from their lambs for 15 h during the evening, ewes machine milked once daily the following morning, and their lambs allowed to suckle for 9 h during the day (**MIX**, n = 35 ewes and their 82 lambs); or 3) ewes not machine milked and exclusively suckled by their lambs (**DY30**, n = 33 ewes and their 78 lambs). After the treatment period, MIX and DY30 ewes were weaned, and all three groups were machine milked twice daily.

For approximately the first 3 mo of lactation, all ewes were housed indoors in a drylot and received legume-grass hay and a concentrate ration of whole corn and soybean meal. Because of another concurrent experiment, at approximately 75 d in lactation, half of the ewes were allocated to graze a kura clover (*Trifolium ambiguum* M. Bieb. cv. Endura) and orchard grass (*Dactylis glomerata* L. cv. Orion) pasture between the morning and evening milkings and continued to receive concentrate. The other half were housed exclusively in the drylot with a hay and concentrate ration.

After receiving colostrum from their dams, all DY1 lambs were raised artificially on milk replacer dispensed from a custom-made lamb-bar and weaned at 25 ± 0.6 d of age. The MIX lambs were allowed to suckle their dams during the daytime hours of 0800 to 1700, after which they were separated for the evening in a nearby pen. The MIX lambs were weaned at 27 ± 0.9 d of age. DY30 lambs were allowed unrestricted access to their dams and were weaned at 32 ± 0.9 d of age. All lambs had ad libitum access to a 19% CP concentrate ration beginning at 8 d of age. At weaning, lambs were grouped in one drylot, and 3 to 4 wk after weaning were switched to a 13% CP ration in a self-feeding system. Male lambs were not castrated.

Machine milking took place at 0600 and 1700 in a 2 × 12 high-line Casse system pit milking parlor. The milking machine (Alfa Laval Agri Inc., Kansas City, MO) was set to provide 180 pulsations per minute in a 50:50 ratio with a vacuum level of 37 kPa. Immediately following milking, both teats were dipped in a chlorhexidine-based teat dip. Individual ewe milk was sampled and production was recorded weekly for the first 3 mo of lactation and, thereafter, twice monthly. Milk composition analyses for percentage of fat, percentage of protein, and Fossomatic SCC were performed by a State of Wisconsin certified laboratory. No attempt was made to sample or measure suckled milk. Ewes were dried-off when their total milk production from the a.m. and p.m. milkings on a test day fell below 200 ml, in accordance with the international regulations for milk recording in sheep (ICAR, 1992). Total commercial milk production and total fat and protein yield were estimated according to Thomas et al. (2000). The overall lactation percentage of milk fat and protein were calculated by dividing total fat and protein yield by total milk yield. Somatic cell count was transformed to logarithms of base 10. Lambs were weighed at birth, at weaning or at 28 d, and at approximately 120 d of age, and, from these measurements, age-adjusted 30- and 120-d weights, and average daily weight gains were calculated.

For economic analysis, the following prices and expenses were used. The prices received for commercial milk and for live lamb marketed at 120 d of age were $1.32 and $1.87/kg, respectively. Additional labor and supply expenses were incurred for the DY1 and MIX systems relative to the DY30 system. These expenses included the labor to milk the DY1 ewes twice daily and the MIX ewes once daily ($0.27/ewe per milking) during the first 30 d of lactation ($16.20 and $8.10 per ewe, respectively); the extra labor (15 min/d for two people at $8.00/h per person) to separate the MIX lambs and ewes once every evening for 30 d ($3.43/ewe); the milk replacer (8.4 kg/lamb at $2.51/kg), labor (1.2 h/lamb at $8.00/h), and supplies ($.34/lamb) to raise the DY1 lambs artificially ($31.03 per lamb).

Least squares means analysis of variance for ewe and lamb traits were conducted with the mixed models procedure of SAS (1999). The following fixed effects were included in the models for lamb production and milk lactation traits of an individual ewe: block (1997 milk production: high, medium, or low), weaning system (DY1, MIX, or DY30), parity (two or three), ewe breed (≤25% or >25% East Friesian), and midlactation forage (pasture or drylot). The models for lamb growth traits contained the following fixed effects: weaning sys-

Table 1. Least squares means ± SEM for ewe lactation traits by weaning system treatment.

Trait	Weaning system treatment[1] DY1 (n = 31)	MIX (n = 35)	DY30 (n = 33)
Lactation length, d	183.4 ± 5.4	179.2 ± 5.1	182.9 ± 5.5
Machine milking period, d	182.4 ± 5.4[a]	178.2 ± 5.1[a]	152.3 ± 5.5[b]
Commercial milk yield, kg	260.1 ± 9.7[a]	235.8 ± 9.1[b]	171.7 ± 9.9[c]
Average milk yield, kg/d	1.42 ± 0.04[a]	1.32 ± 0.04[b]	1.11 ± 0.04[c]
Peak milk yield, kg/d	2.81 ± 0.11[ab]	2.93 ± 0.11[a]	2.56 ± 0.11[b]
Milk fat, %	5.06 ± 0.11[a]	4.53 ± 0.11[b]	4.81 ± 0.12[ab]
30-d milk fat, %	4.82 ± 0.20[a]	2.80 ± 0.20[b]	—
Milk fat, kg	13.2 ± 0.6[a]	10.9 ± 0.5[b]	8.4 ± 0.6[c]
Milk protein, %	5.27 ± 0.07	5.14 ± 0.06	5.21 ± 0.07
Milk protein, kg	13.7 ± 0.5[a]	12.1 ± 0.5[b]	9.0 ± 0.5[c]

[a,b,c]Within a trait, means with different superscripts differ ($P < 0.05$).

[1]DY1 = Ewes weaned from their lambs at 24 h postpartum; MIX = ewes suckled and machine milked for the first month of lactation; DY30 = ewes exclusively suckled during the first month of lactation. DY1 ewes were machine milked twice daily for the entire lactation. MIX and DY30 ewes were machine milked twice daily following weaning at approximately 30 d of lactation.

tem (DY1, MIX, or DY30), sex (male or female), breed of sire (Texel or East Friesian), breed of dam (≤25% or >25% East Friesian), and age of dam (2 or 3 yr). Residual error for all models was a random effect. Birth weight was included in the models as a continuous covariable for all lamb growth traits except birth weight. Lamb mortality data were analyzed by chi-square analysis using Fisher's exact test.

RESULTS

Milk Yield

All ewes, regardless of weaning system treatment, lactated for a similar number of days; however, the DY30 system had the shortest ($P = 0.0003$) machine milking period because machine milking did not start until 30 d postpartum for this treatment (Table 1). Ewes managed with the DY1 and MIX systems produced 51 and 37%, respectively, more ($P = 0.007$) total commercial milk and had higher ($P = 0.03$) average daily milk yields than ewes in the DY30 system (Table 1). Treatment differences for test-day commercial milk yield were only significant during the first 4 wk of lactation (Figure 1A). This is the period before weaning of MIX ewes (once-daily milked), and when MIX ewes produced about 60% of the commercial milk of DY1 ewes (twice-daily milked). Peak milk yield of MIX ewes was greater ($P = 0.04$) than that of DY30 ewes, with DY1 ewes being intermediate (Table 1).

The proportion of East Friesian breeding was not a significant source of variation for any lactation trait. Third-parity ewes produced more milk ($P = 0.08$) than second-parity ewes (233 vs. 212 kg, respectively), and ewes grazing a kura-clover pasture during mid to late lactation produced 28 kg more milk ($P = 0.02$) and lactated for 14 more days ($P = 0.04$) than ewes kept only in drylot.

Milk Composition and Quality

Percentage of milk fat over the machine milking period was higher ($P = 0.003$) for DY1 ewes than for MIX ewes and intermediate for DY30 ewes, yet milk fat yield was superior ($P = 0.003$) for DY1 ewes, intermediate for MIX ewes, and inferior for DY30 ewes (Table 1). Before weaning, ewes that were partially suckled and milked once daily had an average 30-d milk fat percentage that was two percentage units lower ($P < 0.0001$) than ewes that were exclusively machine milked (Table 1 and Figure 1B). Milk fat suppression ($P < 0.0001$) was also observed for DY30 ewes at the 5-wk test day; however, there were no differences among treatments in milk fat content for the remainder of lactation (Figure 1B). Parity, proportion of East Friesian breeding, and pasture grazing were not significant sources of variation for milk fat percentage.

No significant differences between treatments were observed for percentage of milk protein over the machine-milking period (Table 1); however, DY30 ewes were significantly inferior at the 5-wk test day (Figure 1C). Milk protein yield was higher ($P = 0.03$) for DY1 ewes, intermediate for MIX ewes, and lower for DY30 ewes. Parity, proportion of East Friesian breeding, and pasture grazing were not significant sources of variation for milk protein percentage or yield.

Ewes managed under the MIX or DY1 system had similar SCC at the 1-wk test day; however, MIX ewes subsequently maintained significantly lower SCC than did DY1 ewes until weaning (Figure 1D). Following weaning, there were no significant differences in SCC

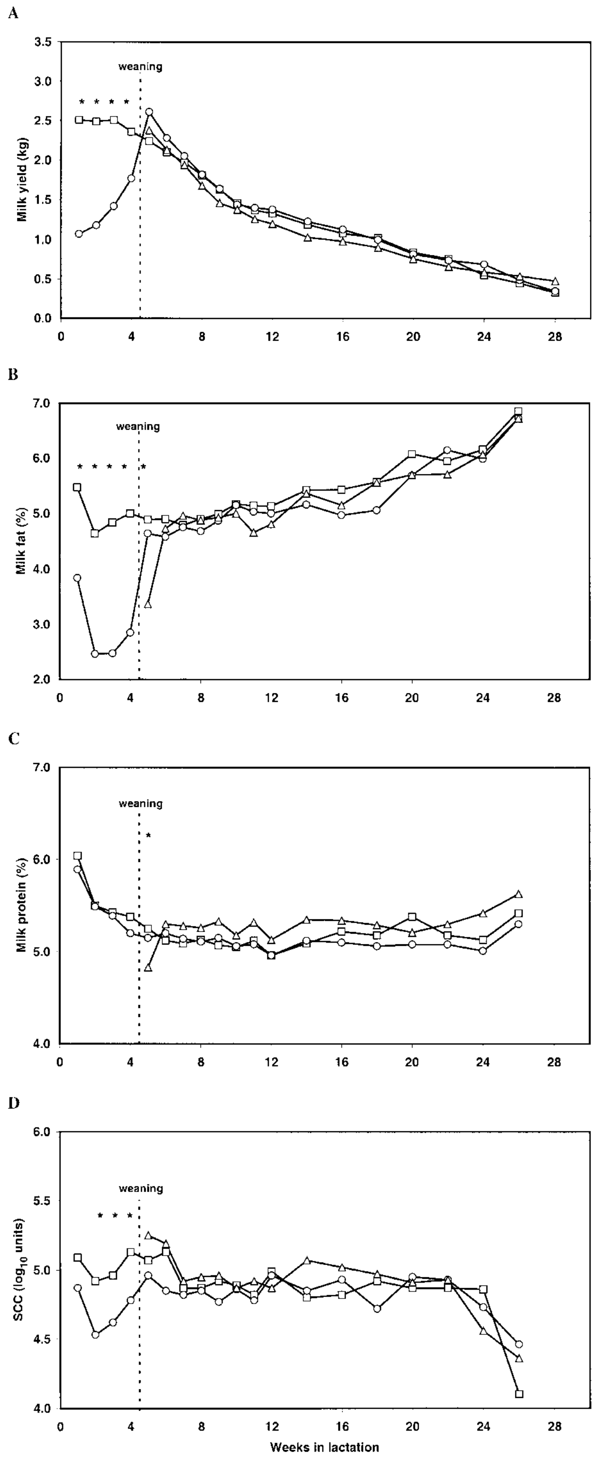

Figure 1. Test-day commercial milk yield, milk fat, milk protein, and somatic cell count (panels A, B, C, and D, respectively) for the three treatment groups: DY1 ewes were weaned of their lambs at 24 h postpartum and machine milked twice daily (□, n = 31), MIX ewes were suckled and machine milked once daily for the first 4 wk of lactation (○, n = 35), and DY30 ewes were exclusively suckled for the first 4 wk of lactation (∆, n = 33). The dotted line indicates weaning of the MIX and DY30 ewes. * Indicates a significant difference among treatments ($P \leq 0.01$).

among treatments. Parity and proportion of East Friesian breeding were not significant sources of variation for SCC. The SCC tended to be higher ($P < 0.10$) when ewes grazed pasture compared with ewes in the drylot (data not shown).

Lamb Growth

The significant differences in birth weight (Table 2) between lamb rearing groups were unexpected; therefore, lamb birth weight was fitted as a continuous covariable in the lamb models used to analyze the remaining lamb growth traits. Growth and weight of lambs up to 30 d were not different among treatment groups. From 30 to 120 d of age, DY30 and MIX lambs had greater ($P = 0.03$) average daily gains than DY1 lambs. There was a tendency ($P < 0.10$) for DY30 lambs to be the heaviest, MIX lambs to have intermediate weight, and DY1 lambs to be the lightest at 120 d. Male lambs were consistently heavier and grew faster than female lambs ($P < 0.05$; data not shown). East Friesian- and Texel-sired lambs had similar average daily gain to 30 d and 30-d weight; however, from 30 to 120 d, East Friesian-sired lambs grew faster and weighed 4.5 kg more at 120 d than Texel-sired lambs ($P = 0.07$, data not shown). Lambs born from dams of ≤25% East Friesian breeding weighed 3.0 kg more at 120 d than lambs born from dams of >25% East Friesian breeding ($P = 0.02$, data not shown).

Economic Analyses

Ewe prolificacy was similar among treatment groups (Table 3). Lamb mortality rates from birth to 30 d and from birth to 120 d were highest, although nonsignificant, for the DY1 and MIX systems compared with the DY30 system. The DY1 system generated the most ($P = 0.001$) total receipts, yet had the highest ($P = 0.001$) additional labor and supply expenses compared with the other two systems (Table 3). Overall financial returns were 7.4 and 1.1% higher, although nonsignificant, for the MIX and DY1 systems, respectively, relative to the DY30 system.

DISCUSSION

Milk Yield

After the first 6 wk in lactation, no test-day differences were found between treatment groups for any lactation trait (Figure 1A to D); however, large significant differences in total yield of milk, milk fat, and milk protein were observed over the machine milking period (Table 1). These findings demonstrate that decisions about early-lactation management of dairy ewes are

Table 2. Least squares means ± SEM for lamb growth traits by weaning system treatment.

Trait	Weaning system treatment[1] DY1 (n = 72)	MIX (n = 82)	DY30 (n = 78)
Birth weight, kg	5.1 ± 0.2[a]	4.5 ± 0.3[b]	4.8 ± 0.2[ab]
Weaning age, d	24.9 ± 0.6[c]	26.7 ± 0.9[b]	31.8 ± 0.9[a]
ADG[2] birth to 30 d, g/d	350.9 ± 13.2	321.8 ± 20.0	338.1 ± 18.2
30-d weight, kg	15.4 ± 0.4	14.5 ± 0.6	15.0 ± 0.5
ADG 30 to 120 d, g/d	314.4 ± 12.1[b]	348.0 ± 18.5[a]	358.2 ± 16.8[a]
120-d weight, kg	43.7 ± 1.2[f]	45.9 ± 1.8[e]	47.3 ± 1.6[d]

[a,b,c]Within a trait, means with different superscripts differ ($P < 0.05$).

[d,e,f]Within a trait, means with different superscripts differ ($P < 0.10$).

[1]DY1 = Lambs removed from their dams at 24 h postpartum and then reared artificially; MIX = lambs suckled their dams for 9 h/d until weaning; DY30 = lambs exclusively suckled their dams until weaning.

[2]ADG = Average daily gain.

important to overall lactational performance. This study and others (Folman et al., 1966; Gargouri et al., 1993; Louca, 1972) have shown that significantly more marketable milk is produced when ewes are milked twice daily, or at least once daily in addition to suckling during the first 30 d of lactation, compared with ewes that are not milked during this period. Although DY30 ewes gave up enough marketable milk during the first 4 wk of lactation to significantly decrease total machine milk yield, exclusive suckling during early lactation was not detrimental to lactation length (Table 1).

Similar to reports in the cow (Bar-Peled et al., 1995) and in the goat (Peris et al., 1997), MIX ewes had lower commercial milk yields throughout the entire suckling period compared with DY1 ewes (Figure 1A). Although these findings are largely due to differences in milking frequency during early lactation, these also may be explained in part by inhibition of milk ejection during machine milking. Marnet and Negrão (2000) demonstrated that for ewes managed in a MIX system, plasma oxytocin concentrations during suckling were always significantly higher compared with during machine milking during the period of lactation when ewes had some daily contact with their lambs. They concluded that during early lactation, the lack of a proper signal during machine milking, which is normally present when ewes are suckled by their own lambs, inhibits oxytocin release and the milk ejection reflex. The milk

Table 3. Least squares means ± SEM for prolificacy, mortality, and economic traits for an individual ewe and her lambs by weaning management system.

Trait	Weaning management system[1] DY1	MIX	DY30
Lambs born per ewe, no.	2.4 ± 0.1	2.5 ± 0.1	2.3 ± 0.1
MR[2] birth to 30 d, %	5.8	8.2	1.3
MR 30 to 120 d, %	6.2	6.0	5.2
MR birth to 120 d, %	11.6	13.7	6.4
Milk marketed per ewe, kg	260.1 ± 9.7[a]	235.8 ± 9.1[b]	171.7 ± 9.9[c]
Lamb marketed per ewe, kg	92.8 ± 4.5[a]	78.7 ± 4.1[b]	100.5 ± 4.5[a]
Total receipts,[3] %	506.52 ± 18.07[a]	458.23 ± 17.05[b]	415.25 ± 18.53[b]
Added expenses,[4] %	87.16 ± 2.98[a]	14.40 ± 3.04[b]	—
Returns,[5] $	420.86 ± 16.87	446.47 ± 15.91	415.81 ± 17.30

[a,b,c]Within a trait, means with different superscripts differ ($P < 0.05$).

[1]DY1 = Ewes were milked twice per day for the entire lactation and their lambs were reared artificially; MIX = lambs were allowed to suckle their dams for 9 h/d and the ewes were machine milked once daily for the first month of lactation; DY30 = ewes were not machine milked for the first month of lactation and lambs were allowed unlimited access to suckling of their dams. MIX and DY30 ewes were machine milked twice daily following weaning at approximately 30 d.

[2]MR = Mortality rate.

[3]Milk and lamb were marketed at $1.32 and $1.87/kg, respectively.

[4]Additional labor and supply expenses per ewe relative to the DY30 system during the first 30 d of lactation.

[5]Returns = total receipts − added expenses.

ejection reflex also is inhibited, at least in stressed cows, by milking in unfamiliar surroundings, and in primiparous cattle that are not adapted to the milking routine (Bruckmaier et al., 1992, 1993). These phenomena are most likely a result of no oxytocin release at the level of the hypothalamus, as normal milk ejection could be reinitiated following administration of physiologic doses of oxytocin (Bruckmaier et al., 1993). Therefore, in the present experiment, it is likely that milk ejection was inhibited during machine milking of MIX ewes before weaning, which resulted in significant retention of milk in the udder.

Although suckled milk yield was not measured, it is likely that MIX ewes maintained 24-h milk secretion rates superior to those of DY1 ewes. It has been reported that during the transition at weaning from either exclusive or partial suckling to exclusive machine milking, there is a drop in total milk secretion of approximately 30% (Folman et al., 1966; Labussière and Pétrequin, 1969; Ricordeau and Denamur, 1962). This phenomenon is most likely due to less frequent udder evacuation (Bar-Peled et al., 1995; Labussière et al., 1978), a change in the quality of stimulus because of the total absence of the lamb (Marnet and Negrão, 2000), and (or) subsequent accumulation of autocrine regulators of milk secretion such as the feedback inhibitor of lactation identified by Wilde et al. (1987). Therefore, if MIX ewes were in fact producing 30% less total milk at weaning compared with just before weaning, total daily milk yield would have been in the order of 3.7 kg/ewe compared with 2.4 kg/ewe produced by DY1 ewes (Figure 1A). Furthermore, 30-d weight of lambs can be used as an estimation of milk production (Ricordeau and Boccard, 1961). The fact that lambs from MIX ewes grew as fast as lambs from DY1 ewes and had similar 30-d weights (Table 2) suggests that the amount of milk available to lambs in a mixed suckling and milking system is substantial. Although BW and condition changes of ewes were not assessed in the present experiment, MIX ewes were probably synthesizing and secreting milk at their maximum genetic potential because of the increased metabolic demands placed on milk secretion of ewes in a mixed management system (Bocquier et al., 1999). Logically, peak daily milk production, which typically occurs during the first month of lactation (Ricordeau and Denamur, 1962), could also be considered as an indicator of maximum milk production potential. Unfortunately, in the present experiment, true peak milk production for MIX and DY30 ewes is not known because suckled milk was not measured.

After complete weaning, oxytocin concentrations during machine milking gradually increase and become similar by 5 d postweaning to levels recorded in ewes that have been exclusively machine milked from shortly after parturition (Marnet and Negrão, 2000). Normal milk ejection during machine milking can be expected in the majority of dairy ewes (Labussière, 1988). Some authors have proposed the use of mixed management as a way to avoid the large drop in milk yield at the time of weaning (Labussière and Pétrequin, 1969; Marnet and Negrão, 2000), and to increase milk yield later in lactation in ewes (Gargouri et al., 1993) and in cows (Peel et al., 1979); however, in the present experiment, despite small nonsignificant increases in daily milk production for the 3 wk following weaning, MIX ewes were not any more productive than the other two treatment groups for the remainder of lactation (Figure 1A). Because lactation length was similar between treatment groups, differences in average daily milk yield were merely reflections of the differences in total commercial milk yield (Table 1).

Milk Composition and Quality

Normal ewe milk contains high concentrations of milk fat during early lactation (Noble et al., 1970). Additionally, the milk fat globule in ewes is large compared with the cow (Muir et al., 1993), and probably requires active expulsion from the alveoli in order to descend to the cistern. Labussière (1969) measured the distribution of fat in the udder of ewes and found only a small proportion (25%) to be present in the cisternal milk fraction, while the largest proportion (75%) remained in the alveolar milk fraction. Our observation regarding the low commercial milk fat content of MIX ewe milk during the partial suckling period (Table1) and for the DY30 ewes immediately following weaning (Figure 1B) agrees with this distribution and is consistent with failed milk ejection at milking (Labussière, 1969; Marnet and Negrão, 2000). Low commercial milk fat has been demonstrated in other evaluations of mixed management weaning systems, not only in ewes (Fuertes et al., 1998; Gargouri et al., 1993; Papachristoforou, 1990), but also in cows (Bar Peled et al., 1995) and in goats (Eik et al., 1999).

Fat suppression in the present experiment is probably not associated with the "low-fat milk syndrome" seen in high producing periparturient dairy cattle because when rumen-protected bypass fat was fed to MIX and DY1 ewes of this same flock during a subsequent lactation, commercial milk fat yield was unchanged in MIX ewes; however, it increased significantly in DY1 ewes (McKusick et al., 1999). Commercial milk fat of suckled ewes could also be influenced by the lack of transfer of milk fat from the alveoli to the cistern from the time ewes are separated from the lambs every evening to the time the ewes are milked the following morning. During this time, ewes are no longer suckled and hence do not experience periodic milk ejection. As a consequence, accumulation of milk fat within the alveoli could impair fatty acid synthesis (Levy, 1964) and therefore reduce fat yield during the suckling period.

One of the major concerns for the dairy sheep industry for milk marketed during early lactation from ewes managed with the MIX system will be the processing characteristics of low-fat milk and, subsequently, the value placed upon this milk by cheese-processing facilities. There is at least one report that cheese made from the milk of suckled ewes had significant negative alterations in curd yield and sensory characteristics compared with milk later in lactation during exclusive machine milking (Requena et al., 1999). Because of the extremely low commercial milk fat content of MIX ewe milk compared with DY1 ewe milk during the first 30 d of lactation, average fat percentage and total fat yield over the entire milking period were significantly lower for MIX ewes.

There were no differences among treatments in milk protein content in early lactation. Milk protein percentage tended to decrease as milk yield increased (Figure 1C), a common phenomenon due to a dilution effect (Fuertes et al., 1998). Immediately after weaning, milk from DY30 ewes may have been deficient in milk protein as a consequence of failure of milk ejection and subsequent milk solid retention in the udder (Figure 1C). Overall milk protein yield reflected the treatment differences in overall commercial milk yield (Table 1).

Although significant treatment differences for SCC were observed during early lactation, SCC for all three treatments were low (range of 4.0 to 5.4 log units, corresponding to 10,000 to 252,000 cells/ml) compared with reports in the literature for normal ewe milk (Ranucci and Morgante, 1996). Mixed weaning systems of suckling and machine milking in early lactation have been shown to significantly reduce SCC and mastitis incidence in high-producing dairy cows (Krohn, 1999). Our findings concerning MIX ewe SCC agree with those of Krohn (1999); however, if milk ejection was inhibited as hypothesized, only somatic cells present in the cisternal milk fraction would have been analyzed. Nonetheless, MIX ewe milk tended to have the lowest SCC for the 3 wk immediately postweaning, when the milk ejection reflex would have been reestablished (Figure 1D).

SCC of exclusively suckled ewes is reportedly higher than that of ewes exclusively machine milked immediately postpartum (Bergonier et al., 1996; McKusick et al., 2000) quite possibly associated to udder trauma involved in aggressive suckling and the resulting recruitment of leukocytes (Bergonier et al., 1996). Our findings of high SCC of DY30 ewes at weaning are in agreement, but could also be explained by the fact that when udders undergo less frequent evacuation, SCC tend to rise (Plommet, 1974) without necessarily causing concomitant damage to mammary secretory cells (Stelwagen and Lacy-Hulbert, 1996). Somatic cell count greater than 500,000 cells/ml in dairy cows (Everson, 1984) and in ewes (Pellegrini et al., 1997) has a negative impact on the manufacturing of cheese. The highest average SCC for any treatment group occurred during wk 5 for DY30 ewes (5.3 log units, corresponding to 200,000 cells/ml, Figure 1D). Therefore it is unlikely that the SCC differences due to weaning system treatments would significantly alter cheese production.

Lamb Growth

Thirty-day weight and gain to 30 d were similar among lamb treatment groups (Table 2), which agrees with work done on Mediterranean dairy sheep breeds by Lawlor et al. (1974) and Louca (1972). Conversely, there are reports of poor early lamb performance for mixed weaning systems (Hadjipanayiotou and Louca, 1976) or artificial rearing systems (Peters and Heaney, 1974) compared with exclusive suckling controls. Our observations may differ from these latter reports simply because of creep feeding of all lambs and an excellent management system employed at our research station for artificially reared lambs, as evidenced by consistently low mortality rates and high weight gains over several years (Berger and Schlapper, 1993). Furthermore, MIX lambs probably benefitted from the fact that milk solids were retained in the udder of MIX ewes during machine milking, and they were able to take advantage of the rich milk obtained by suckling-induced milk ejection (Folman et al., 1966; Papachristoforou, 1990). Following weaning, growth of DY1 lambs was significantly retarded compared with the other two treatment groups, which tended to reduce final 120-d weight of artificially reared lambs. Other authors report no difference in final lamb weight for lambs reared artificially (Lawlor et al., 1974; Peters and Heaney, 1974) or in a mixed system (Gargouri et al., 1993; Hadjipanayiotou and Louca, 1976; Louca, 1972) compared with normal ewe rearing conditions. Lambs raised in the MIX system appeared to have compensatory weight gain after weaning, which has been previously confirmed in growing animals with prior nutrition limitations (Peters and Heaney, 1974).

Economic Analysis

While several authors have evaluated commercial milk and (or) lamb production for a variety of weaning systems and report differences in quantity of marketable milk and lamb, there are almost no estimations or comparisons in the literature of financial returns for any of the weaning systems. Because DY30 ewes were machine milked for approximately a month less than MIX or DY30 ewes, the amount of marketable milk was significantly diminished with delayed milking (Table 3). Although lamb mortality rates were not significantly different among treatment groups, there were large mean differences that when used in the economic analysis resulted in significantly fewer kilograms of lamb marketed by MIX ewes.

In the present experiment, the DY30 system was considered as a reference because this was the system used most frequently by American dairy sheep operations. While the DY1 system offered about $91.00/ewe more in receipts, the additional labor and supplies associated with artificial rearing, and the lighter 120-d lamb weights, absorbed almost all of the financial advantages of exclusive machine milking relative to the DY30 system. Relatively little additional expense was associated with the suckling and milking system, and, therefore, despite significantly smaller amounts of marketable lamb per ewe, the MIX system resulted in approximately $31.00 more in financial returns relative to the DY30 system. Although this difference is statistically nonsignificant, a comparable increase in financial returns per ewe of this magnitude for a management practice related to other sheep commodities (e.g., lamb or wool) would be rare in the sheep industry.

A final caveat to the economic analysis is that milk purchase price was independent of composition. It is reasonable to assume that in the future, producers will receive lower prices for milk of low fat content, and therefore, because of the milk fat suppression observed during the suckling period for the MIX ewes, overall financial returns for that system may be reduced somewhat. Relative economic returns of the three weaning systems also will differ, with changes in number of lambs marketed per ewe and the values of a unit of milk and lamb. In the future, extrapolation of the results of this study to generate estimated economic returns for the three weaning systems, using several different levels of lamb production and milk and lamb prices, would allow the individual dairy sheep producer to choose the weaning system that had the greatest potential for increased returns under his/her set of production and marketing parameters.

CONCLUSIONS

The present experiment has demonstrated that suckling and machine milking during early lactation provides a valuable management tool for dairy sheep production. The main advantage of the "mixed" management system is that significant quantities of commercial milk can be obtained during early lactation without the expenses associated with artificial rearing of lambs or severe detriment to lamb growth. While milk protein percentage and SCC are not disadvantaged compared with ewes weaned immediately postpartum, low milk fat during the suckling period of mixed-managed ewes is problematic to the manufacture of sheep milk dairy products. Further work is necessary to determine how milk fat yield can be improved in mixed-managed ewes during early lactation.

ACKNOWLEDGMENTS

The authors express their sincere gratitude to the Babcock Institute for International Dairy Research and Development (Madison, WI) who have generously supported the dairy sheep research program at the University of Wisconsin-Madison. The authors wish to thank Richard Schlapper, Mary Langland, Lori Brekenridge, and Larissa Fawcett at the Spooner Agricultural Research Station for their committed efforts in the care and maintenance of the animals, and for their excellent help with data collection during the experiments. This study was funded by the Research Division, College of Agricultural and Life Sciences, University of Wisconsin-Madison and contributes to the regional efforts of NCR-190 "Increased Efficiency of Sheep Production."

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