Effects of rearing triplet lambs on ewe productivity, lamb survival and performance, and future ewe performance[1,2]

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ABSTRACT: Increasing prolificacy has been proposed to be the most effective way to increase the biological efficiency and profitability of sheep production. However, use of prolific breeds and genes with major effects on ovulation rate can increase prolificacy to levels that may not be desirable or sustainable in extensive rangeland production systems. This study thus evaluated effects of triplet births on ewe productivity and ewe and lamb performance. An initial study used 666 purebred Polypay litters to compare ewes with triplet litters that were required to raise all the lambs (Treatment A) with those whose triplet litters were reduced to 2 lambs (Treatment R). Adult Polypay ewes had an average litter size of 2.35 lambs per litter. The frequency of litters of 3 or more lambs was 43.2%; 56.0% of lambs were born in litters of 3 or more lambs. Ewes that had singles weaned fewer lambs and less body weight (BW) of lambs ($P < 0.001$; 0.94 lambs and 40.4 kg, respectively) than ewes that had twins or triplets. Ewes with triplet litters in Treatment A weaned more lambs ($P < 0.01$) and more BW of lambs ($P < 0.05$) than ewes that had triplets in Treatment R (2.13 lambs and 62.9 kg, respectively, vs. 1.79 lambs and 55.0 kg, respectively), and weaned more lambs than ewes that had twins (1.77 lambs; $P < 0.01$). However, neither group of triplet-bearing ewes weaned more BW of lambs than ewes that had twins (58.9 kg; $P \geq 0.34$). In 2 sets of data involving 442 purebred Polypay litters and 987 litters from Polypay or Romanov–White Dorper × Rambouillet ewes mated to terminal sires, ewes were required to raise all triplet-born lambs. Death losses for triplets in these studies (39.6 and 31.6%, respectively) were higher than those in Treatment A of the initial study (26.2%), resulting in greater numbers of lambs weaned for triplet, compared to twin, litters (1.79 vs. 1.68, respectively; $P = 0.02$) but no greater weight of lambs weaned (54.3 vs. 55.4 kg, respectively; $P = 0.17$). Based on these 3 sets of data, ewes that were required to rear triplet lambs weaned 0.20 more lambs per litter than ewes that had twins but also had 0.75 additional dead lambs per litter, and thus a lamb mortality overhead of 3.75 additional dead lambs for each additional weaned lamb. We conclude that there is an intermediate optimum prolificacy level for extensive rangeland production systems. If optimum prolificacy is exceeded, removal and artificial rearing of surplus lambs are necessary to avoid increased lamb death losses.

Key words: ewe productivity, prolificacy, reproduction, sheep, wool

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INTRODUCTION

The number of lambs weaned is the main factor affecting efficiency of resource use and profitability in sheep production (e.g., Wang and Dickerson, 1991; Borg et al., 2007). However, most studies involving breeding objectives for sheep production systems compared breeds with relatively low prolificacy (e.g., 1.5 to 1.8 lambs born per ewe lambing) with more prolific types. Over the past 30 yr, use of prolific sheep breeds such as the Finnsheep and Romanov (Young and Dickerson, 1985; Thomas, 2010) and the discovery of a number of major genes influencing prolificacy (Davis, 2005) have markedly increased potential ewe prolificacy. High frequencies of triplet and larger litters can be achieved, but, in extensive production systems, may not improve profitability and instead lead to increases in lamb mortality (Borg et al., 2007).

The Polypay breed was developed at the U.S. Sheep Experiment Station (**USSES**) in the 1970's by crossing Rambouillet, Targhee, Dorset, and Finnsheep (Hulet et al., 1984). An average litter size of approximately 2.0 lambs was reported for 1- through 6-yr-old USSES Polypay ewes (Ercanbrack and Knight, 1998). A mean litter size (adjusted to a 4-yr-old ewe basis) of 2.09 lambs was reported by Rao and Notter (2000) for Polypay ewes in U.S. National Sheep Improvement Program (**NSIP**) flocks. Under standard lamb management protocols at USSES, litters of 3 or more lambs were commonly reduced to 2 or fewer lambs. Surplus lambs were fostered to other ewes or sold ("orphaned") for artificial rearing. This protocol improved individual lamb growth and survival but potentially limited the productivity of Polypay ewes. The objective of the current study was therefore to assess effects of rearing triplet lambs on ewe productivity and ewe and lamb performance under extensive rangeland conditions.

MATERIALS AND METHODS

The USSES Institutional Animal Care and Use Committee (**IACUC**) approved all husbandry practices and experimental procedures used in this study (IACUC numbers 0709 and 0905).

Experimental Designs, Animals, and Management

Experiment 1. The objective of Exp. 1 was to compare effects of 2 triplet-management treatments on ewe productivity and ewe and lamb performance in purebred matings of USSES Polypay ewes and rams. Before the start of lambing in 2007 and 2008, treatments were randomly assigned within ewe age and sire to 666 2- through 8-yr-old ewes. Ewes were designated to have triplet litters reduced to 2 lambs (Treatment R, the traditional USSES management protocol) or to raise their triplet lambs (Treatment A). Of the ewes that were assigned to treatments, 625 (93.8%) lambed. Ten ewes had 1 or more lambs that were judged to be premature and 62 ewes had lambs sired by Suffolk clean-up rams. These litters were removed from the data. Excess lambs were normally removed by 3 d of age, but occasionally removed later, as foster ewes became available or problems with the dam emerged. Single and twin lambs and triplet lambs in Treatment A were orphaned or fostered only if the dam or lamb had serious functional or health problems. Fostering of lambs was infrequent and involved recipient ewes from outside the experiment. Litters of 4 or more lambs were not included in the study.

Ewes were bred in feedlot pens for 21 d beginning in mid-October. Ewes were moved to shrub-dominated winter range at the end of this primary mating period and exposed to groups of Suffolk clean-up rams. Ewes were returned to the feedlot in mid- to late January and lambed in outdoor feedlot pens in March and April. Within 15 min after birth, ewes and their lambs were moved indoors and confined in single-ewe bonding pens. Lambs were tagged and weighed within 24 h after birth. Approximately 50% of male Polypay lambs were left intact for evaluation as potential breeding rams. After 48 h indoors, ewes and their lambs were returned to the outdoor feedlot pens for approximately 1 mo. While in feedlots (i.e., during breeding and early lactation), ewes were fed daily a total mixed ration formulated to meet or slightly exceed predicted nutrient requirements for the stage of production and environmental conditions. Ewes and lambs grazed sagebrush steppe from late April through early July and subalpine forest from early July until weaning in early August at a mean lamb age of approximately 120 d. Ewes and lambs were randomly assigned at lambing to 1 of 2 groups ("weaning bands") for summer grazing and herded on generally comparable, but separate, grazing areas.

Experiment 2. Experiment 2 was originally designed to compare ewe productivity and lamb performance of Rambouillet, Polypay, and Romanov–White Dorper × Rambouillet (**RW-RA**) ewes (Notter et al., 2017) and evaluate progeny of industry Polypay rams at USSES. Lambing management was the same as that for Treatment A of Exp. 1. All potentially viable lambs remained with the dam, and forced orphaning (Treatment R) was not used. In the context of the current study, Exp. 2 was used to validate differences in ewe and lamb performance among litter size classes under conditions of Treatment A. Only records of Polypay and RW-RA ewes were used for this study.

Generation 1 of Exp. 2 involved single-sire matings of USSES Polypay ewes to 1 USSES and 19 industry Polypay rams and USSES Rambouillet ewes to 21 Romanov × White Dorper rams from the USDA, ARS, U.S. Meat Animal Research Center, Clay Center, NE. Generation 1 ewes lambed in 2009, 2010, and 2011. Lambing records were available for the current study for 442 lambings by USSES Polypay ewes (Notter et al., 2017). Eighteen litters contained 1 or more lambs that were judged to be premature and were excluded from the data. In Generation 2, Polypay and RW-RA ewes were managed as contemporaries throughout their lives, mated to Columbia, Suffolk, Columbia × Suffolk or Suffolk × Columbia rams, allowed to lamb for the first time at 1 yr of age, and retained for up to 4 lambings. Frequencies of triplet births by yearling ewes were low, and records from these ewes were excluded from the current study. Lambing records were available for 987 2- through 4-yr-old ewes mated to terminal sires. Fifteen litters contained 1 or more lambs that were considered premature, and these litters were excluded from the data.

Management during mating and gestation in Exp. 2 was the same as that in Exp. 1. In Generation 1, approximately 50% of male Polypay lambs were left intact for evaluation as potential breeding rams. Crossbred male lambs in Generation 2 were all castrated within 24 h after birth. As in Exp. 1, ewes and lambs were randomly assigned at lambing to 1 of 2 weaning bands for spring and summer grazing. Ewes and lambs grazed sagebrush steppe from late April through early July. In 2009 and 2010, ewes and lambs then grazed in subalpine forests from early July until weaning in early August at a mean lamb age of approximately 120 d. However, in 2011 through 2015, ewes and lambs were not moved to subalpine grazing, and lambs were weaned in early July at a mean age of approximately 105 d.

Statistical Methods

Data were analyzed separately for Exp. 1 and 2 and for Generations 1 and 2 of Exp. 2. Litter size distributions and proportions of lambs born in litters of 3 or more lambs were summarized for each dam age class. For Exp. 1 and Generation 1 of Exp. 2, ewes were categorized as 2, 3, 4, 5, 6, or 7 and 8 yr old at lambing. Only 2- through 4-yr-old ewes were present in Generation 2 of Exp. 2. Least-squares means for litter size for Polypay ewes in Exp. 1 and Generation 1 of Exp. 2 were derived using a model that included effects of lambing year, ewe age class, and, for Exp. 1, triplet management. Preliminary analyses confirmed, as expected, that ewes in Exp. 1 that were assigned to different triplet-management treatments but subsequently produced singles or twins did not differ in numbers or BW of weaned lambs ($P \geq 0.72$). Effects of triplet management in Exp. 1 were therefore modeled by nesting effects of triplet management within litter size. Ewes that produced, and lambs born as, singles or twins were assigned to a single management class, and the effect of triplet management nested within litter size therefore specifically compared treatments A and R in triplet litters (Treatments **3A** and **3R**, respectively). For ewes in Generation 2 of Exp. 2, an effect of ewe breed was added to the model and the effect of lambing year was replaced with effects of ewe birth year (2009, 2010, and 2011), ewe age at lambing (2, 3, or 4 yr), and their interaction. The latter 3 effects jointly accounted for effects of lambing year, and allowed emphasis to be placed on ewe age effects, which were cross-classified with ewe birth years, rather than effects of lambing year, which were not cross-classified with effects of ewe birth years. Litter size was analyzed as a negative binomial variable (Stroup, 2013) using the GLIMMIX procedure of SAS (SAS Inst., Cary, NC).

Measures of ewe productivity included numbers of lambs per litter at 3 d (i.e., after leaving the bonding pens and removal of most orphaned or fostered lambs), 14 d, 30 d (when ewes were moved to spring grazing), and weaning, numbers of lambs per litter that were orphaned or fostered, and total BW of weaned lambs. Lamb weaning BW were adjusted for lamb sex (to a 50% ewe, 50% wether basis) using multiplicative adjustment factors developed for Polypay lambs in NSIP (Bradford, 2003). Models for ewe productivity traits included fixed effects used in the analysis of litter size and a fixed effect of litter size and were fit using the GLIMMIX Procedure of SAS. Analyses of lamb numbers assumed a negative binomial distribution, and the analysis of cumulative BW of weaned lambs assumed a normal distribution. Heterogeneity of residual variances among litter sizes and, for Exp. 1, triplet management treatments was tested by comparing models with or without heterogeneous variances using the Akaike Information Criterion (**AIC**; Burnham and Anderson, 2004).

Measures of individual lamb performance included BW at birth and weaning and probabilities that a lamb was present at 3, 14, or 30 d and at weaning, was orphaned or fostered, or died (as opposed to being orphaned or fostered) before weaning. Probabilities that a lamb was weaned, orphaned or fostered, or died were mutually exclusive and exhaustive, and accounted for all lambs born (alive and stillborn). Models of individual lamb performance were fitted using the GLIMMIX Procedure of SAS and included variables in models for ewe productivity plus a fixed effect of lamb sex and a random litter effect. If ram and wether lambs were both present in the data, weaning BW of ram lambs were adjusted to a wether-lamb basis before analysis. Preliminary analyses did not detect differences in survival for ram and wether lambs and these groups were assumed to not differ. The model for lamb weaning BW also included a continuous linear effect of lamb age at weaning. Individual lamb weaning BW were therefore adjusted for dam age class, lamb sex, and weaning age, but not for litter size or number of lambs suckled. Lamb survival traits were analyzed as binomial (0, 1) variables. Birth and weaning BW were assumed to be normally distributed.

Lamb weaning BW distributions were compared for each litter size and triplet-management treatment. Unadjusted weaning BW were initially corrected for effects of year, weaning band, litter size, and year × weaning band interaction. An effect of triplet management was also included in the model for Exp. 1, and an effect of dam breed type was included in the model for Generation 2 of Exp. 2. Heterogeneity of residual variance was then tested among litter size classes and, for Exp. 1, triplet-management treatments using the AIC to compare likelihoods from models with and without heterogeneous variances. Weaning BW was expressed as a deviation from its corresponding predicted value, and residual skewness, kurtosis, and departures from normality were tested within and across litter size classes and, for Exp. 1, triplet-management treatments using the Univariate Procedure of SAS. Skewness and kurtosis were tested using procedures described by Cramer (1997). Departures from normality were tested using the Shapiro-Wilks test (D’Agostino and Stephens, 1986).

Ewe lambs from Exp. 1 and Generation 1 of Exp. 2 were retained as replacements. Effects of litter size and triplet management on probability of retention and, for retained ewe lambs, fleece weight (in February at approximately 10 mo of age), probability of lambing, and litter size were analyzed using models that included effects of year, litter size, and, for Exp. 1, triplet management. Supplemental models were used to determine if a continuous linear effect of weaning BW could account for observed effects of litter size.

Effects of litter size on BW of lactating ewes in April and future ewe performance were evaluated using models that included effects used for analysis of ewe productivity. Seven- and 8-yr-old ewes in Exp. 1 and Generation 1 of Exp. 2 and 4-yr-old ewes in Generation 2 of Exp. 2 were not retained and were excluded from these analyses. Measures of future ewe performance included BW in September after weaning of the lambs, fleece weight in February following weaning, the probability a ewe was present at the start of the next mating season, the probability that these ewes would lamb, and the subsequent litter size. Probabilities that a ewe would be present at the next breeding and, if present, would lamb were fitted as binomial variables and subsequent litter size was fitted as a negative binomial variable; these variables were analyzed using the GLIMMIX Procedure of SAS. All other variables were assumed to be normally distributed and analyzed using the GLM Procedure of SAS.

For all analyses, initial models included all 2-way interactions among independent variables, but final models excluded interactions that did not at least approach significance ($P > 0.10$). Least-squares means and SE for variables assumed to have binomial or negative binomial distributions were back-transformed to the original scale for presentation (SAS Institute Inc., 2017). The Tukey-Kramer procedure (Dunnett, 1980) was used for mean separation.

RESULTS

Experiment 1

The average litter size for USSES Polypay ewes in Exp. 1 was 2.26 lambs per ewe lambing, and 203 ewes (36.7%) had litters of 3 ($n = 183$), 4 ($n = 19$), or 5 ($n = 1$) lambs. Over half of the lambs born to 3- through 6-yr-old ewes were born in litters of 3 or more (Table 1). Least-squares means for litter size increased ($P = 0.03$) from 2.16 ± 0.05 lambs in 2-yr-old ewes to 2.35 ± 0.05 lambs in 3- through 6-yr-old ewes (with no differences in litter size among these age classes; $P \geq 0.99$), before decreasing ($P = 0.09$) to 2.05 ± 0.12 lambs in older ewes. Litter size distributions in 3- through 8-yr-old ewes

Table 1. Effect of ewe age on the distribution of litter sizes

		Percentage of litters of size:					
Ewe age, years	No. of ewes	1	2	3	4	% of lambs born in litters of 3 or more lambs	Least-squares mean and SE for litter size[2]
--*Experiment 1*—[1,2]							
2	195	13.3	58.0	26.7	2.0	40.6	2.16 ± 0.05
3	166	15.1	44.0	36.1	4.8	55.4	2.32 ± 0.06
4	71	8.5	50.7	39.4	1.4	53.0	2.37 ± 0.09
5	42	16.7	33.3	42.9	7.1	65.3	2.39 ± 0.12
6	45	17.8	42.2	31.1	6.7	56.2	2.32 ± 0.11
7 and 8	34	26.5	41.2	32.3	0.0	47.1	2.05 ± 0.12
--*Experiment 2, Generation 1*—[3,4]							
2	62	9.7	64.5	25.8	0.0	35.8	2.14 ± 0.09
3	126	13.5	53.2	31.0	2.4	46.1	2.23 ± 0.06
4	113	10.6	45.1	38.9	4.4	57.9	2.39 ± 0.07
5	71	5.6	43.7	42.3	8.5	63.3	2.55 ± 0.09
6	34	2.9	52.9	41.2	2.9	55.4	2.45 ± 0.12
7 and 8	18	11.1	27.8	55.6	5.6	73.9	2.54 ± 0.17
--*Experiment 2, Generation 2, Polypay ewes*—[5]							
2	171	29.2	62.0	8.8	0.0	14.7	1.79 ± 0.04
3	153	15.0	68.0	15.0	2.0	26.0	2.03 ± 0.05
4	121	11.6	57.0	28.9	2.5	43.5	2.22 ± 0.05
--*Experiment 2, Generation 2, Romanov-White Dorper × Rambouillet ewes*—[5]							
2	196	19.4	77.0	3.6	0.0	5.9	1.84 ± 0.04
3	174	10.9	72.4	16.7	0.0	24.3	2.06 ± 0.04
4	157	7.0	56.1	35.0	1.9	48.6	2.31 ± 0.05

[1] One 6-yr-old ewe produced a litter of 5 lambs.

[2] Quadratic effect of ewe age on mean litter size ($P = 0.004$).

[3] One 4-yr-old ewe produced a litter of 5 lambs.

[4] Linear effect of ewe age on mean litter size ($P = 0.006$).

[5] For Exp. 2, Generation 2, linear effect of ewe age ($P < 0.001$), ewe breeds differ ($P = 0.04$), and no effect of ewe breed × ewe age interaction ($P = 0.94$).

were over-dispersed relative to that observed for 2-yr-old ewes (Table 1). Proportions of both single and triplet litters were higher for 3-, 5-, 6-, and 7- and 8-yr-old ewes than for 2-yr-old ewes.

Two-way interactions among effects of lambing year, ewe age class, triplet management, and litter size were not significant ($P \geq 0.08$) for measures of ewe productivity and were removed from the final model. Ewes that had twins or triplets weaned more lambs and more BW of lambs than ewes that had singles ($P < 0.001$; Table 2). Ewes in Treatment 3A weaned more ($P < 0.01$) lambs (2.13 ± 0.08) than ewes in Treatment 3R (1.79 ± 0.07) and more ($P < 0.01$) lambs than ewes that had twins (1.77 ± 0.04). Ewes in Treatment 3A likewise weaned more ($P < 0.05$) BW of lambs (62.9 ± 2.2 kg) than ewes in Treatment 3R (55.0 ± 2.2 kg), but neither triplet-management group weaned more BW of lambs than ewes that had twins (58.9 ± 1.2 kg; $P \geq 0.20$). After accounting for stillborn lambs and those that died shortly after birth (i.e., before orphaning), ewes in Treatment 3R had 0.76 ± 0.10 lambs per litter orphaned or fostered, vs. only 0.02 ± 0.01 lambs per litter for ewes in Treatment 3A. No singles and only 2.2% of twins were orphaned or fostered. However, compared to lambs in Treatment 3R, an additional 0.40 lambs per litter in Treatment 3A died before weaning. For litters in treatment 3R that included both orphaned and suckled lambs (i.e., excluding litters that were reduced by stillbirths or early lamb mortality), and after adjusting for fixed effects of year, dam age, and lamb sex and a random litter effect, orphaned lambs weighed an average of 0.56 ± 0.15 kg less at birth that lambs that remained with the dam ($P < 0.001$), indicating orphaning of the smallest lamb in the litter. This difference was somewhat larger than the mean difference in birth weight of 0.41 ± 0.11 kg between triplet lambs that died at, or within 24 h of, birth and those that were alive at 1 d of age. Residual variances for measures of ewe productivity increased as litter size increased. Residual SD for single, twin, and triplet litters, respectively, were 0.28, 0.37, and 0.51 lambs for number of lambs weaned and 12.5, 16.2, and 20.4 kg for cumulative BW of weaned lambs.

Weaning rates were 93.4 ± 2.7% for singles and 88.6 ± 1.5% for twins (Table 3). As expected

Table 2. Least-squares means and SE for average numbers of lambs present at various times between birth and weaning, numbers of lambs orphaned or fostered, and weights of lambs weaned per ewe lambing by litter size and triplet-management treatment for ewes that produced single, twin, or triplet litters

Litter size and triplet management	No. of litters	No. present at: 3 d	14 d	30 d	Weaning	No. orphaned or fostered	Weight weaned, kg
--Experiment 1--							
1	81	0.98 ± 0.02^{a}	0.96 ± 0.03^{a}	0.95 ± 0.03^{a}	0.94 ± 0.03^{a}	0.00	40.4 ± 1.5^{a}
2	269	1.89 ± 0.03^{b}	1.86 ± 0.03^{b}	1.81 ± 0.03^{b}	1.77 ± 0.04^{b}	0.05 ± 0.01^{b}	58.9 ± 1.2^{bc}
3R[1]	94	2.08 ± 0.07^{c}	1.96 ± 0.07^{b}	1.91 ± 0.07^{b}	1.79 ± 0.07^{b}	0.76 ± 0.10^{c}	55.0 ± 2.2^{b}
3A[1]	89	2.72 ± 0.08^{d}	2.48 ± 0.08^{c}	2.25 ± 0.08^{c}	2.13 ± 0.08^{c}	0.02 ± 0.01^{b}	62.9 ± 2.2^{c}
--Experiment 2, Generation 1--							
1	42	0.95 ± 0.06^{a}	0.98 ± 0.07^{a}	0.91 ± 0.07^{a}	0.89 ± 0.08^{a}	0.00	36.1 ± 3.2^{a}
2	212	1.83 ± 0.04^{b}	1.74 ± 0.05^{b}	1.65 ± 0.05^{b}	1.55 ± 0.05^{b}	0.03 ± 0.01^{a}	51.4 ± 1.6^{b}
3	153	2.57 ± 0.06^{c}	2.21 ± 0.06^{c}	1.94 ± 0.06^{c}	1.65 ± 0.06^{b}	0.10 ± 0.03^{b}	50.8 ± 1.7^{b}
--Experiment 2, Generation 2--							
1	155	0.97 ± 0.02^{a}	0.98 ± 0.03^{a}	0.96 ± 0.03^{a}	0.96 ± 0.03^{a}	0.00	41.2 ± 1.3^{a}
2	644	1.92 ± 0.02^{b}	1.91 ± 0.02^{b}	1.88 ± 0.02^{b}	1.81 ± 0.02^{b}	0.01 ± 0.01^{a}	59.3 ± 0.7^{b}
3	164	2.60 ± 0.04^{c}	2.38 ± 0.04^{c}	2.20 ± 0.04^{c}	1.93 ± 0.04^{c}	0.06 ± 0.03^{b}	57.7 ± 1.3^{b}

[1] Ewes with triplet lambs were either required to rear all their lambs (A) or had their litters reduced to 2 lambs (R).

[abc] Means within a row with different superscripts differ ($P < 0.05$) based on the Tukey-Kramer mean-separation procedure.

Table 3. Numbers of lambs born and weaned and least-squares means and SE for effects of litter size and triplet management on performance of Polypay lambs in Exp. 1

Item	Litter size and triplet management[1]: 1	2	3R	3A
No. of lambs born	81	538	282	267
No. of lambs weaned[2]	75	469	169	188
Birth weight, kg	5.51 ± 0.08^{a}	4.62 ± 0.04^{b}	3.77 ± 0.06^{c}	3.89 ± 0.06^{c}
Present at 3 d, %	97.8 ± 1.6^{a}	94.5 ± 1.1^{a}	69.5 ± 3.5^{b}	91.1 ± 1.8^{a}
Present at 14 d, %	95.6 ± 2.2^{a}	93.0 ± 1.2^{a}	65.4 ± 3.4^{b}	83.7 ± 2.4^{c}
Present at 30 d, %	95.5 ± 2.2^{a}	90.9 ± 1.4^{a}	63.0 ± 3.3^{b}	75.8 ± 2.8^{c}
Weaned, %[3]	93.4 ± 2.7^{a}	88.6 ± 1.5^{a}	59.5 ± 3.3^{b}	72.0 ± 2.9^{c}
Orphaned and fostered, %[3]	0.0	2.4 ± 0.7^{a}	25.5 ± 3.1^{b}	0.8 ± 0.5^{a}
Dead lambs, %[3]	6.2 ± 2.5^{ab}	8.6 ± 1.3^{a}	15.3 ± 2.4^{b}	26.2 ± 3.0^{c}
Adjusted weaning wt, kg	42.1 ± 0.6^{a}	34.2 ± 0.3^{b}	31.6 ± 0.5^{c}	30.3 ± 0.4^{c}

[1] Ewes with triplet lambs were either required to rear all their lambs (A) or had their litters reduced to 2 lambs (R).

[2] One twin lamb and 2 lambs from Treatment 3A were managed in the "hospital" band due to health problems or injury of the lambs or their dams and were excluded from the analysis of adjusted weaning weights.

[3] These 3 categories are mutually exclusive and exhaustive and jointly account for all lambs born.

[abc] Means within a row with different superscripts differ ($P < 0.05$) based on the Tukey–Kramer mean-separation procedure.

from the experimental design, ewes in Treatment 3A weaned a higher percentage ($P = 0.02$) of triplets (72.0 ± 2.9%) than ewes in Treatment 3R (59.5 ± 3.3%). Percentages of lambs that died before weaning were 26.2 ± 3.0% for triplets in Treatment 3A, 15.3 ± 2.4% for triplets in Treatment 3R, 8.6 ± 1.3% for twins, and 6.2 ± 2.5% for singles. Weaning BW declined as litter size increased ($P < 0.001$) and were somewhat greater for Treatment 3R lambs than for Treatment 3A lambs ($P = 0.08$). Results in Table 3 were consistent across years and ewe ages ($P \geq 0.15$ for 2-way interactions involving year, ewe age, triplet management, and litter size).

Weaning BW SD were similar for lambs from different litter sizes and triplet-management treatments (Table 4); fitting heterogeneous residual variances among these groups did not improve goodness of fit. However, after scaling for differences in mean BW, CV increased with increases in litter size, from 12.4% for singles to an average of 17.7% for triplets. Triplets in Treatment 3A had only slightly greater CV than triplets in Treatment 3R (18.2 vs. 17.1%). Weaning BW distributions were skewed left for singles ($P < 0.001$) and both groups of triplets ($P < 0.01$), indicating the presence of a few lambs with notably low weaning BW in these groups, but the weaning BW distribution for twins did not depart from normality ($P = 0.07$).

When lambs were combined across litter size classes and stratified by triplet management using treatment assignments applied prior to lambing to simulate effects of triplet management on variability for the entire lamb crop, SD and CV did not differ between triplet-management treatments (Table 4). Positive kurtosis ($P < 0.05$) was present for both triplet-management treatments, as expected from combining lambs from different litter size classes. Right skewness ($P < 0.05$) and departures from normality ($P = 0.004$) were present for Treatment R, presumably because there were no triplet-reared lambs on the left side of the weaning BW distribution. Departures from normality were not present ($P \geq 0.26$) for weaning BW for Treatment A.

Proportions of ewe lambs retained for breeding (Table 5) differed between years. In 2007, 82% of available ewe lambs were retained. Only ewe lambs that were considered to be too small to potentially conceive or had faults in breed type or body structure were excluded. By contrast, 41% of available ewe lambs were retained in 2008, with greater selection emphasis on the cumulative ewe productivity of the dam (Ercanbrack and Knight, 1998). Thus, 84% of

Table 4. Effects of litter size on the distribution of weaning weights[1]

Litter size and triplet management[2]	No.	Mean, kg	SD, kg	CV, %	Skewness	Kurtosis	Significance of departure from normality (*P* =)[3]
Experiment 1							
1	75	43.3	5.35	12.4	-1.03***	1.87**	0.002
2	468	33.6	4.99	14.9	-0.01	-0.19	0.07
3A	186	30.3	5.49	18.2	-0.50**	0.72*	0.04
3R	169	31.1	5.33	17.1	-0.59**	0.45	0.004
All – A	461	33.0	6.20	18.8	-0.01	0.48*	0.26
All – R	437	33.5	6.14	18.3	0.23*	0.48*	0.004
Experiment 2, Generation 1							
1	36	39.5	5.91	15.0	-1.23**	1.17	0.002
2	338	31.7	5.56	17.6	-0.22†	0.44†	0.29
3	257	29.2	5.04	17.3	-0.23	0.44	0.14
All	631	31.9	6.08	19.1	0.07	0.28	0.06
Experiment 2, Generation 2							
1	139	41.9	4.94	11.8	-0.21	-0.07	0.58
2	1148	32.7	4.66	14.3	-0.14†	0.77***	< 0.001
3	323	28.8	5.76	20.2	-0.10	0.86**	0.09
All	1610	32.6	5.81	17.9	0.12*	0.68***	< 0.001

$^{\dagger}P < 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

[1] Estimates of distributional parameters are based on actual weights of weaned lambs. If both ram and wether lambs were present, lamb weights were adjusted to a wether-lamb basis, and weights in Exp. 2, Generation 2 were adjusted for effects of dam breed. Weights were not adjusted for effects of ewe age, lamb age at weaning, or lamb sex (wether vs. ewe). Classes designated “All” included lambs from all litter size classes with no adjustment for effects of litter size on weaning BW and reflect the distribution of actual lamb weights for the entire lamb crop at weaning.

[2] Ewes with triplet lambs in Exp. 1 were either required to rear all their lambs (A) or had their litters reduced to 2 lambs (R).

[3] Based on the Shapiro–Wilk test of normality in the Univariate Procedure of SAS.

Table 5. Least-squares means and SE for effects of litter size and triplet management on performance of Polypay replacement ewe lambs in Exp. 1

	Litter size and triplet management[1]			
Item	1	2	3R	3A
Percentage retained, 2007[2]	83.5 ± 10.7^{ab}	88.8 ± 3.3^{a}	66.9 ± 6.9^{b}	81.0 ± 6.7^{ab}
Percentage retained, 2008[2]	5.3 ± 5.2^{a}	36.6 ± 4.6^{ab}	57.6 ± 9.2^{b}	46.7 ± 6.9^{b}
Fleece weight, kg[3]	2.67 ± 0.15^{a}	2.07 ± 0.04^{b}	1.95 ± 0.06^{bc}	1.86 ± 0.06^{c}
Percentage that lambed	91.1 ± 8.5	76.6 ± 3.8	71.1 ± 5.9	64.4 ± 6.7
Litter size	1.72 ± 0.46	1.48 ± 0.12	1.41 ± 0.19	1.33 ± 0.20

[1] Ewes with triplet lambs were either required to rear all their lambs (A) or had their litters reduced to 2 lambs (R).

[2] Percentage of weaned ewe lambs retained as replacements. The total percentages retained were 82.1% in 2007 and 41.1% in 2008.

[3] In February, at approximately 10 mo of age.

[abc] Means within a row with different superscripts differ ($P < 0.05$) based on the Tukey–Kramer mean-separation procedure.

single, 89% of twin, and 74% of triplet ewe lambs were retained in 2007, whereas 5% of single, 37% of twin, and 52% of triplet ewe lambs were retained in 2008. Proportions of retained triplets did not differ ($P \geq 0.15$) between triplet-management treatments in either year and the proportion of retained ewe lambs that lambed at 1 yr of age did not differ between years ($P = 0.25$). The percentage of retained ewe lambs that lambed at 1 yr of age declined as the size of the litter in which they were born increased but these differences were not significant ($P = 0.13$). The size of the litter produced at 1 yr of age by the retained ewe lambs averaged 1.52 lambs and was not affected ($P = 0.12$) by the litter size in which the replacement ewe lamb was born. At shearing in February, before the first lambing opportunity, fleece weights of replacement ewe lambs declined as the size of the litter in which they were born increased ($P < 0.001$) and were 29% less for triplets than for singles (Table 5). After adjusting for weaning BW, percentage lambing, litter size, and fleece weight were not affected ($P \geq 0.43$) by the size or triplet management of the litter in which the replacement ewe lamb was born.

Litter size affected ewe BW (Table 6). Ewes that produced singles were 6.1 kg heavier than ewes that produced twins or triplets in early lactation ($P < 0.001$), but this difference declined to 2.4 kg ($P = 0.02$) after weaning. Fleece weights in February (after weaning but before the next lambing) declined with increasing litter size ($P = 0.01$). Ewes that had triplets produced 8.5% less wool than ewes that had singles. Litter size did not affect the probability that a ewe would be present at the next mating or her subsequent likelihood of lambing ($P \geq 0.40$; Table 6). Ewes that produced twins and triplets had larger litters (2.34 ± 0.10) in the following year than ewes that produced singles (2.18 ± 0.21), but the difference was not significant

Table 6. Effect of litter size on ewe BW in spring (during lactation) and autumn (after weaning), fleece weights in February (following weaning), and reproductive performance at the next lambing opportunity

	Litter size		
Item	1	2	3
--*Experiment 1*—[1]			
No. of ewes	81	269	183
No. of ewes weighed in spring, fall	81, 80	268, 254	178, 174
Spring ewe weight, kg	73.3 ± 0.9[a]	68.0 ± 0.5[b]	66.5 ± 0.6[b]
Autumn ewe weight, kg	81.1 ± 0.9[a]	78.5 ± 0.6[b]	79.0 ± 0.6[ab]
Fleece weight, kg	3.15 ± 0.08[a]	3.03 ± 0.04[a]	2.88 ± 0.05[b]
Percentage of ewes that were re-bred[2]	79.7 ± 5.1	80.2 ± 2.9	74.5 ± 3.6
Percentage of bred ewes that lambed	93.6 ± 3.8	97.2 ± 1.3	99.9 ± 1.3
Litter size	2.18 ± 0.21	2.33 ± 0.13	2.35 ± 0.15
--*Experiment 2, Generation 1*--			
No. of ewes	42	212	153
No. of ewes weighed in spring, fall	41, 40	208, 203	149, 143
Spring ewe weight, kg	70.7 ± 1.2[a]	63.6 ± 0.6[b]	61.9 ± 0.7[b]
Autumn ewe weight, kg	80.8 ± 1.2[a]	75.6 ± 0.6[b]	76.9 ± 0.7[b]
Fleece weight, kg	3.38 ± 0.11[a]	3.03 ± 0.05[b]	2.90 ± 0.05[b]
Percentage of ewes that were re-bred[2]	59.9 ± 8.1	70.7 ± 3.4	74.0 ± 3.8
Percentage of bred ewes that lambed	93.1 ± 5.0	91.0 ± 2.7	96.2 ± 1.8
Litter size	2.00 ± 0.49	2.24 ± 0.15	2.57 ± 0.18
----*Experiment 2, Generation 2*--			
No. of ewes	155	644	164
No. of ewes weighed in spring, fall	154, 151	638, 625	161, 155
Spring ewe weight, kg	67.8 ± 0.7[a]	62.2 ± 0.3[b]	62.4 ± 0.7[b]
Autumn ewe weight, kg	73.8 ± 0.6[a]	70.7 ± 0.3[b]	71.6 ± 0.6[b]
Fleece weight, kg	2.98 ± 0.05[a]	2.80 ± 0.03[b]	2.84 ± 0.07[ab]
Percentage of ewes that were re-bred[2]	91.3 ± 2.4	84.5 ± 1.7	86.6 ± 4.0
Percentage of bred ewes that lambed	96.4 ± 1.7	97.8 ± 0.7	100.0
Litter size	2.08 ± 0.14	2.12 ± 0.07	2.40 ± 0.20

[1] No effect of triplet management on subsequent performance of triplet-bearing ewes in Exp. 1 ($P = 0.17$ for percent ewes bred and $P \geq 0.60$ for all other traits).

[2] Percentage of ewes that were present at the start of breeding in the next year.

[ab] Means within a row with different superscripts differ ($P < 0.05$) based on the Tukey–Kramer mean-separation procedure.

($P = 0.75$). For ewes that produced triplets, those in Treatment R were somewhat more likely than ewes in Treatment A to be present at the next mating (79.1 ± 4.6% vs. 69.4 ± 5.4%; $P = 0.17$), but triplet management did not affect any other measure of future ewe performance ($P \geq 0.60$; data not shown).

Experiment 2, Generation 1

For USSES Polypay ewes mated to industry Polypay rams in Generation 1 of Exp. 2, 36.1% had 3, 3.8% had 4, and 0.2% (1 ewe) had 5 lambs (Table 1). Average litter sizes were 2.14 ± 0.09 lambs for 2-yr-old ewes, 2.41 ± 0.04 lambs for 3- through 6-yr-old ewes, and 2.54 ± 0.17 lambs for 7- and 8-yr-old ewes. Litter size distributions were again over-dispersed in adult ewes compared to 2-yr-old ewes; 3-, 4-, and 7- and 8-yr old ewes had higher frequencies of both single and triplet litters than 2-yr-old ewes.

The incidence of orphaned and fostered lambs was 0.00, 0.03, and 0.10 lambs per litter for singles, twins, and triplets, respectively (Table 2). Ewes that had twins and triplets weaned slightly less than twice as many lambs as ewes that had singles (1.55 ± 0.05 and 1.65 ± 0.06, respectively, vs. 0.87 ± 0.08 lambs; $P < 0.001$; Table 2). Ewes that had singles weaned 29.4% less BW of lamb ($P < 0.001$) than ewes that had twins and triplets, which did not differ ($P = 0.96$; Table 2).

On an individual basis (Table 7), 90.3 ± 4.7% of singles, 80.4 ± 2.2% of twins, and 55.3 ± 2.6% of triplets were weaned ($P < 0.001$), and 9.3 ± 4.4% of singles, 16.7 ± 2.0% of twins, and 39.6 ± 2.6% of triplets died ($P < 0.001$). After adjusting for effects of lamb sex, dam age, and weaning age, individual lamb weaning BW declined ($P < 0.001$) as litter size increased, from 40.1 ± 0.9 kg for singles to 29.4 ± 0.4 kg for triplets. The SD of lamb weaning BW tended to decline, but corresponding CV tended to increase, as litter size increased (Table 4). However, models that assumed heterogeneity of residual variances among litter sizes did not improve goodness of fit. As in Exp. 1, weaning BW of singles were skewed left ($P < 0.01$) and deviated from normality ($P = 0.002$), but weaning BW for twins and triplets did not deviate from normality ($P \geq 0.14$). Notable departures from normality for

Table 7. Numbers of lambs born and weaned and least-squares means and SE for effects of litter size on lamb performance in Exp. 2

	Litter size		
Item	1	2	3
--*Experiment 2, Generation 1*--			
No. of lambs born	42	424	459
No. of lambs weaned	38	340	266
Birth weight, kg	5.47 ± 0.11^{a}	4.58 ± 0.05^{b}	3.84 ± 0.05^{c}
Present at 3 d, %	96.0 ± 3.0	93.8 ± 1.4	88.8 ± 2.0
Present at 14 d, %	95.3 ± 3.3^{a}	90.0 ± 1.7^{a}	77.9 ± 2.5^{b}
Present at 30 d, %	92.7 ± 4.1^{a}	85.7 ± 1.9^{a}	67.0 ± 2.6^{b}
Weaned, %[1]	90.3 ± 4.7^{a}	80.4 ± 2.2^{a}	55.3 ± 2.6^{b}
Orphaned and fostered, %[1]	0.0	1.9 ± 0.7	3.3 ± 1.0
Died, %[1]	9.3 ± 4.4^{a}	16.7 ± 2.0^{b}	39.6 ± 2.6^{c}
Adjusted weaning wt, kg[2]	40.1 ± 0.9^{a}	32.0 ± 0.4^{b}	29.4 ± 0.4^{c}
--*Experiment 2, Generation 2*--			
No. of lambs born	154	1289	492
No. of lambs weaned	142	1154	492
Birth weight, kg	5.91 ± 0.07^{a}	4.99 ± 0.03^{b}	4.08 ± 0.05^{c}
Lambs present at 3 d, %	97.5 ± 1.3^{a}	96.7 ± 0.5^{a}	88.9 ± 1.9^{b}
Lambs present at 14 d, %	96.1 ± 1.6^{a}	95.3 ± 0.6^{a}	81.3^{b} ± 2.0
Lambs present at 30 d, %	94.4 ± 1.8^{a}	94.2 ± 0.7^{a}	75.9 ± 2.5^{b}
Lambs weaned, %[1]	93.6 ± 1.9^{a}	90.8 ± 0.9^{a}	65.5 ± 2.6^{b}
Orphaned and fostered, %[1]	0.0	0.7 ± 0.2	1.5 ± 0.8
Dead lambs, %[1]	6.1 ± 1.8^{a}	8.4 ± 0.8^{a}	31.6 ± 2.5^{b}
Adjusted weaning wt, kg[2]	42.2 ± 0.4^{a}	32.9 ± 0.2^{b}	28.9 ± 0.3^{c}

[1] These 3 categories are mutually exclusive and exhaustive and jointly account for all lambs born.

[2] Adjusted for effects of ewe birth year, ewe age, lamb sex, and lamb age at weaning.

[abc] Means within a row with different superscripts differ ($P < 0.05$) based on the Tukey–Kramer mean-separation procedure.

weaning BW were not present for the entire lamb crop ($P = 0.06$; Table 4).

The percentage of ewe lambs retained for breeding was 71.8%. Only ewe lambs that were considered to be too small to conceive or had major structural faults were not kept. Retention rates (Table 8) were 76, 73, and 67% for singles, twins, and triplets, respectively ($P = 0.45$). The percentage of retained ewe lambs that lambed at 1 yr of age tended to decline as the size of the litter in which they were born increased ($P = 0.06$), from 91 ± 9% for singles to 78 ± 4% for twins and 64 ± 6% for triplets. Litter sizes at 1 yr of age for replacement ewe lambs born as singles, twins, and triplets were 1.64 ± 0.35, 1.36 ± 0.12, and 1.29 ± 0.17 lambs, respectively ($P = 0.64$). Fleece weights of replacement ewe lambs declined as the size of the litter in which they were born increased ($P < 0.001$). Ewe lambs born as triplets produced 22.5% less wool than those born as singles (Table 8). This difference was reduced to 10.6% ($P = 0.12$) when fleece weights were adjusted for effects of weaning BW.

Ewe BW in spring during lactation and autumn after weaning were greater ($P < 0.001$) for ewes that had singles than for ewes that had twins or triplets (Table 6), but the difference in BW was reduced by 56% between spring and autumn. Fleece weights in February after weaning declined linearly with increases in litter size ($P < 0.001$) and were 14.2% less for ewes that had triplets than for ewes that had singles. Litter size did not affect the probability that a ewe would be present at the next mating or her subsequent likelihood of lambing (both $P = 0.24$; Table 6). Subsequent litter sizes for ewes that had single, twins, and triplets were 2.00 ± 0.49, 2.24 ± 0.15, and 2.57 ± 0.18, respectively ($P = 0.29$).

Experiment 2, Generation 2

The incidence of triplet births in Generation 2 of Exp. 1 increased exponentially from 6.0% in 2-yr-old ewes to 15.9% in 3-yr-old ewes and 32.4% in 4-yr-old ewes (Table 1). Quadruplet births were rare, with frequencies of 0.1% in 3-yr-old ewes and 2.2% in 4-yr-old ewes. The average litter size (Table 1) was 1.82 ± 0.03 lambs in 2-yr-old ewes, 2.05 ± 0.03 lambs in 3-yr-old ewes, and 2.27 ± 0.04 lambs in 4-yr-old ewes ($P < 0.001$) and was similar ($P = 0.15$) for Polypay (2.01 ± 0.03 lambs) and RW-RA ewes (2.07 ± 0.03 lambs). However, Polypay ewes had higher frequencies of singles than RW-RA ewes (Table 1). Over-dispersion of litter size distributions for 3- and 4-yr-old ewes, compared to 2-yr-old ewes, was not obvious for either ewe breed (Table 1); frequencies of single litters declined and triplet litters increased as ewes became older. No single lambs, 0.01 lambs per twin litter, and 0.06 lambs per triplet litter were orphaned or fostered ($P = 0.03$; Table 2). Ewes that had singles, twins, and triplets weaned 0.96 ± 0.03, 1.81 ± 0.02, and 1.93 ± 0.04 lambs per ewe lambing ($P < 0.001$; Table 2). Ewes that had singles weaned less BW of lamb (41.2 ± 1.3 kg) than ewes that had twins (59.3 ± 0.7) or triplets (57.7 ± 1.3) ($P < 0.001$), which did not differ ($P = 0.27$).

For individual lambs (Table 7), 93.6 ± 1.9% of singles, 90.8 ± 0.9% of twins, and 65.5 ± 2.6% of triplets were weaned ($P < 0.001$). Death losses were similar for singles (6.1 ± 1.8%) and twins (8.4 ± 0.8%) but higher for triplets (31.6 ± 2.5%). Individual lamb weaning BW declined ($P < 0.001$) as litter size increased, from 42.2 ± 0.4 kg for singles to 28.9 ± 0.3 kg for triplets. Goodness of fit was improved by allowing residual variances for weaning BW to vary with litter size. Residual SD were similar for twins (4.94 kg) and singles (4.66 kg) but larger (5.76 kg) for triplets (Table 4). The residual CV for weaning BW therefore increased with increasing litter size and was much larger for triplets. Weaning BW were skewed left for all litter size classes, indicating the presence of a few relatively low BW lambs, but skewness approached significance only for twins ($P < 0.10$). Positive kurtosis was

Table 8. Least-squares means and SE for effects of litter size on performance of Polypay replacement ewe lambs in Exp. 2, Generation 1

	Litter size		
Item	1	2	3
Percentage retained[1]	76.3 ± 10.7	73.3 ± 4.1	66.5 ± 5.0
Fleece weight, kg[2]	2.62 ± 0.10[a]	2.14 ± 0.03[b]	2.03 ± 0.05[b]
Percentage that lambed	90.8 ± 8.8	77.8 ± 3.9	63.7 ± 6.0
Litter size	1.64 ± 0.35	1.36 ± 0.12	1.29 ± 0.17

[1] Percentage of weaned ewe lambs retained as replacements.

[2] In February, at approximately 10 mo of age.

[ab] Means within a row with different superscripts differ ($P < 0.05$) based on the Tukey-Kramer mean-separation procedure.

present for both twins and triplets ($P < 0.01$). When lambs were combined across litter size classes, right skewness ($P < 0.05$) and positive kurtosis ($P < 0.001$) were observed for weaning BW.

Ewe BW in spring during lactation and autumn after weaning were greater ($P < 0.001$) for ewes that produced singles than for ewes that produced twins or triplets (Table 6), but the difference was reduced by approximately 50% between spring and autumn. Fleece weights in February after weaning were 5.4% less ($P < 0.01$) for ewes that had twins and triplets than ewes that had singles. Ewes that had singles were not more likely to return for another mating ($P = 0.13$) or more likely to lamb ($P = 0.67$) than ewes that had twins and triplets (Table 6). Ewes that had triplets had numerically larger litters in the next year (2.40 ± 0.20 lambs) than ewes that had singles (2.08 ± 0.14 lambs) and twins (2.12 ± 0.07 lambs) ($P = 0.34$). After adjusting for litter size, mean BW were 2.2 less in spring and 2.9 kg less in autumn and fleece weights were 0.29 kg less for RW-RA ewes, compared to Polypay ewes (all $P < 0.001$). The percentage of ewes present at the next mating was 6.4% higher ($P = 0.007$) for RW-RA ewes than for Polypay ewes.

Summary of Results

The average litter size for adult (3- through 6-yr-old) USSES Polypay ewes raising purebred Polypay lambs in Exp. 1 and Generation 1 of Exp. 2 was 2.38 ± 0.05 lambs born per ewe lambing, the mean frequency of triplet or larger litters was 43.0%, and 56.6% of lambs were born in litters of 3 or more lambs. Two-year-old USSES ewes were less prolific than adult ewes. Their mean litter size was 2.15 ± 0.05 lambs, 27.3% of the ewes had litters of 3 or more lambs, and 38.2% of the lambs were born in litters of 3 or more lambs. Prolificacy of 7- and 8-yr-old ewes was not consistent across the 2 studies. Mean litter sizes for these ewes were 2.05 ± 0.12 lambs in Exp. 1 and 2.54 ± 0.17 lambs in Generation 1 of Exp. 2. Ewes at USSES normally were culled after 6 yr of age, but a few sound and apparently productive older ewes were retained, depending on available numbers and project needs. Differences in prolificacy for older ewes likely reflected their small numbers and culling history as well as age effects per se.

Polypay and RW-RA ewes in Generation 2 of Exp. 2 appeared to be less prolific than USSES Polypay ewes. For 2- through 4-yr-old ewes in Generation 2 of Exp. 2, the mean litter size was 2.04 ± 0.02 lambs, 19.1% of the ewes had litters of 3 or more lambs, and 27.2% of lambs were born in litters of 3 or more. By comparison, 2- through 4-yr-old USSES Polypay ewes in Exp. 1 and Generation 1 of Exp. 2 had an average litter size of 2.27 ± 0.03 lambs, 35.6% of litters contained 3 or more lambs, and 48.1% of lambs were born in litters of 3 or more lambs. However, USSES Polypay ewes and Polypay ewes sired by industry rams were not directly compared. The USSES Polypay ewes lambed in 2007 through 2011 whereas 2- through 4-yr-old Polypay ewes sired by industry rams lambed in 2011 through 2015.

Across experiments, death losses for triplets (excluding Treatment 3R of Exp. 1) ranged from 26 to 40%. Death losses ranged from 8.4 to 16.7% for twins and 6.2 to 9.3% for singles. Weaning BW for individual twin-born lambs were 3.5 ± 0.3 kg (11.9%) greater than those for lambs born as triplets. Triplets had somewhat higher CV for weaning BW than singles and twins, but, across the entire lamb crop, reducing triplet litters to at most 2 lambs in Exp. 1 did not improve the uniformity of individual lamb weaning BW. Departures from normality in distributions of weaning BW for the entire lamb crop were modest, with occasional right skewness associated with a few heavy single lambs but no evidence of less-desirable left skewness denoting the presence of a few lambs with notably low weaning BW.

Comparisons among single, twin, and triplet litters were the focus of this study. However, approximately 5% of the 3- to 6-yr-old USSES Polypay ewes in Exp. 1 and Generation 1 of Exp. 2, but less than 3% of the 3- and 4-yr-old Polypay ewes sired by industry rams in Generation 2 of Exp. 2, produced litters of 4 or more lambs. Litters of size 4 are thus not infrequent in USSES Polypay ewes, and litters of 5 lambs occasionally occur.

Single-born Polypay ewe lambs retained as replacement ewes in Exp. 1 and Generation 1 of Exp. 2 had higher average lambing frequencies (91.0 ± 6.1%) and larger litters (1.68 ± 0.29 lambs) than ewe lambs born as twins (77.2 ± 2.7% and 1.42 ± 0.08 lambs, respectively) or triplets (64.1 ± 4.5% and 1.31 ± 0.13 lambs, respectively). The linear effect of litter size was significant for lambing frequency ($P = 0.01$) but not litter size ($P = 0.25$). Yearling fleece weights in retained ewe lambs also decreased as litter size increased from 1 (2.65 ± 0.09 kg) to 2 (2.11 ± 0.03) to 3 (1.95 ± 0.04) lambs; linear and quadratic trends (both $P < 0.001$) were present. Linear adjustment of ewe lamb performance for lamb weaning BW consistently accounted for observed effects of litter size.

Ewes that produced twin and triplet lambs weighed 9.2% less in spring ($P < 0.001$) and 4.1% less in autumn ($P < 0.10$) than ewes that produced singles. Least-squares means for fleece weights were 3.17 ± 0.05, 2.95 ± 0.02, and 2.87 ± 0.03 kg for ewes that had produced 1, 2, or 3 lambs, respectively, with both linear ($P < 0.001$) and quadratic ($P < 0.05$) effects of litter size on fleece weight. Fleeces from ewes that produced twins or triplets weighed 8.2% less than fleeces from ewes that had singles, and fleeces from ewes that produced triplets weighed 2.7% less than those from ewes that produced twins.

The litter size did not affect the likelihood that a ewe would be present at the next mating. Mean rates of return ranged from 77.0 to 78.5%. Subsequent pregnancy rates for ewes that had produced triplets were consistently higher than those observed for ewes that produced twins or single (98.7 ± 0.7, 95.3 ± 1.0, and 94.4 ± 2.1%, respectively), with a linear association ($P = 0.05$) between litter size and subsequent pregnancy rate. Litter size was somewhat repeatable between adjacent years and tended to increase linearly with changes in previous litter size ($P < 0.09$), with means of 2.09 ± 0.18, 2.23 ± 0.07, and 2.44 ± 0.10 for ewes that produced 1, 2, or 3 lambs, respectively. The repeatability estimate for litter size in adjacent years was 0.18.

DISCUSSION

Ewe Productivity and Lamb Performance

Litter size distributions for USSES Polypay ewes were over-dispersed, with higher-than-expected frequencies of single births in adult, compared to 2-yr-old, ewes, indicating that increased ovulation rates in adult ewes did not result in proportionately larger litters at birth. This result presumably reflected joint effects of failures of fertilization and (or) implantation for a proportion of the ova that were produced and subsequent embryonic and fetal death losses in litters of 2 or more lambs. Negative carry-over effects on ovulation rates between adjacent years did not appear to be a source of over-dispersion. Ewes with triplet litters had higher average pregnancy rates and larger litters in the next year compared to ewes that produced singles or twins. Meyer (1985) and West et al. (1991) estimated that ewes with twin ovulations produced approximately 0.7 more lambs at birth that ewes with single ovulations. Ewes that produced 3 ova had approximately 0.6 more lambs at birth than ewes with 2 ovulations. Dixon et al. (2007) demonstrated that embryonic and fetal death losses occurred throughout gestation and estimated that approximately 21% of embryos or fetuses were lost from d 25 of gestation to term.

Over-dispersion of litter sizes in Generation 2 of Exp. 2 was less than that observed for purebred matings involving USSES Polypay ewes. Increases of 8 to 13% in frequencies of triplet and quadruplet lambs between 2- and 3-yr-old ewes were accompanied by nearly compensatory declines of 9 to 14% in frequencies of single births. However, an approximate further doubling of frequencies of triplet and quadruplet births between 3 and 4 yr of age was accompanied by declines of only 3 to 4% in incidence of single births. Possible explanations for reduced over-dispersion of litter sizes in Generation 2 of Exp. 2 included a lower mean litter size, heterosis for prenatal lamb survival in crossbred lambs and crossbred RW-RA ewes, and removal of a portion of accumulated inbreeding (Zhang et al., 2013) in USSES Polypay ewes by outcrossing with industry rams.

Romanov sheep were first imported into the United States in 1986 and appear to be superior to Finnsheep for a number of ewe performance traits (Thomas, 2010). However, Polypay and RW-RA ewes in Generation 2 of Exp. 2 did not differ in mean prolificacy and appeared to be less prolific than USSES Polypay ewes. Polypay ewes in Generation 2 of Exp. 2 were sired by industry Polypay rams. The Polypay breed was developed at USSES (Hulet et al., 1984), but recent genetic connections between USSES and industry Polypay flocks were limited. Selection at USSES was primarily for weight of lamb weaned per ewe joined (Ercanbrack and Knight, 1998). Industry Polypay flocks conceptually had similar breeding goals but may have had less rigorous data recording and selection, at least before 2008, when a Polypay ewe productivity index was introduced by NSIP. That index was analogous to the Katahdin ewe productivity index described by Vanimisetti et al. (2007); 81% of additive genetic variation in that index was associated with additive genetic differences in numbers of lambs weaned. The current study suggested that selection of USSES Polypay ewes for ewe productivity may have increased litter size relative to industry Polypays. Litter size means for USSES Polypay ewes were larger than those reported for adult ¼-Finnsheep ewes lambing in April (Notter and Copenhaver, 1980) and adult Polypay ewes lambing in March through May in NSIP Polypay flocks (Notter, 2000). The litter size for adult

USSES Polypay ewes was also larger than the average litter size of ¼-Finnsheep ewes reported by Thomas (2010), although the latter value likely included some yearling ewes. By contrast, Taylor et al. (2009) reported an average litter size of 2.3 to 2.4 lambs per litter for adult USSES Polypay ewes lambing in 1989 through 1991.

When USSES Polypay ewes in Exp. 1 raised all (Treatment A) or at most 2 (Treatment R) triplet-born lambs, ewes in Treatment A weaned more lambs and more total weight of lambs than ewes in Treatment R and more lambs than ewes that had twins. However, in Exp. 2, where forced orphaning was not employed (i.e., all triplet-bearing ewes were required to rear all viable offspring), survival rates for triplet lambs were lower than those for triplet lambs in Treatment A of Exp. 1. Ewes with triplets in Exp. 2 did not differ from ewes with twins in numbers or weight of weaned lambs. On an individual basis, the probability that a triplet lamb in Exp. 2 would be present at weaning was 55.3% for the purebred Polypay lambs in Generation 1 and 65.5% for the crossbred lambs in Generation 2, both lower than the weaning rate of 72.0 ± 2.9% for USSES Polypay triplets in Treatment 3A of Exp. 1. Treatments in Exp. 1 were assigned to ewes at random, within ewe age class and sire, and lambing dates and management practices were the same for the 2 experiments. Birth weights of triplet lambs born to ewes in Treatment 3A were slightly, but not significantly, greater (by 0.12 ± 0.08 kg) than those of lambs born to ewes in Treatment 3R. Differences in birth weights between twin and triplet lambs were similar in Exp. 1 (0.79 ± 0.05 kg) and Generation 1 of Exp. 2 (0.74 ± 0.07 kg) but larger for the crossbred lambs in Generation 2 of Exp. 2 (0.91 ± 0.06 kg).

Lamb death losses were substantial if prolific ewes raised all of their triplet lambs. Across experiments, death losses for triplets (excluding Treatment 3R of Exp. 1) ranged from 26 to 40%. Borg et al. (2007) reviewed the performance of prolific ewes in rangeland production systems and predicted that death losses for triplet lambs in this situation would approach 50% of lambs born and were unlikely to be less than 33%. Based on observed average death and weaning rates of 11.2 and 86.6%, respectively, for twin lambs and 32.5 and 64.3%, respectively, for triplet lambs, 100 triplet litters would wean 20 more lambs than 100 twin litters, but also produce 75 additional dead lambs. Each additional lamb weaned from the triplet litters would therefore come with an "overhead" of 3.75 dead lambs, a figure that would concern many sheep producers. By contrast, 100 twin litters were predicted to wean 81 more lambs but have only 15 more dead lambs than 100 single litters (with average death and weaning rates of 7.2 and 92.4%, respectively), giving a lamb mortality overhead of 0.19 additional dead lambs for each additional weaned lamb, or 1 additional dead lamb for each 6.7 additional twin litters.

Maintenance of high levels of genetic merit for prolificacy requires retention of replacement ewe lambs from large litters. However, triplet ewe lambs had smaller weaning BW than singles and twins, and negative phenotypic associations between ewe lamb BW and reproductive performance may cause genetically superior animals to perform at lower levels than genetically inferior, but larger, contemporaries. Linear adjustment of these variables for lamb weaning BW accounted for observed effects of litter size, confirming that reduced performance of ewe lambs born in larger litters was mainly a phenotypic effect associated with lower BW. Adjustment of postweaning feeding levels to remove or reduce BW differences would potentially reduce observed effects of litter size on ewe lamb performance. In adult ewes, litter size did not affect the likelihood that a ewe would be present at the next mating opportunity. The estimated repeatability of litter size of 0.18 between adjacent lambing was the same as the average estimate of 0.18 across all lambings reported by Safari et al. (2005).

Implications

Results of this study were contingent on environmental conditions and management at USSES, and provided a baseline for evaluation of alternative management practices. Ewe and lamb management at USSES was similar to that used by commercial, range-type sheep producers in the region. Under these conditions, our results strongly indicated that the goal of increasing prolificacy in commercial sheep flocks in the Upper Mountain West and similar regions should be to minimize frequencies of single births while avoiding, to the extent possible, associated increases in triplet and larger litters. Unfortunately, over-dispersion of litter size distributions in adult ewes resulted in larger-than-expected frequencies of single litters, especially in purebred Polypay matings, and complicated achievement of this goal. In agreement with the results of Borg et al. (2007), under extensive rangeland conditions, there appeared to be little value in increasing the average litter size in adult ewes beyond an average of approximately 2.2 lambs per litter. Results of this study suggest a need to develop nonlinear economic weightings for litter size in breeding objectives for purebred flocks and to develop procedures that will allow commercial ram buyers to identify sires that will optimize litter size distributions in their flocks.

Lamb death losses for ewes that nursed 3 lambs under extensive grazing conditions demonstrated a need to consider orphaning and (or) artificial rearing of surplus lambs. One thousand breeding ewes with a lambing frequency of 90%, a ewe-age distribution equal to that used by Borg et al. (2007), prolificacy equal to that observed for USSES Polypay ewes, and 90% survival of triplet lambs to 3 d of age would produce approximately 233 surplus lambs from triplet litters. Orphan lambs in the current study were sold shortly after birth, and subsequent survival and performance data were not available. However, local markets for orphan are common near large-scale, range-type sheep operations in the Upper Mountain West, suggesting that purchase and rearing of orphan lambs is a viable enterprise. Hand ("bottle") feeding of orphan lambs or use of "milk bars" (Umberger, 2009) has, in recent years, been supplanted by increasingly automated equipment (e.g., LAC-TEK Milk Feeding System, Biotic Industries, Inc., Bell Buckle, TN) to periodically mix and dispense fresh milk replacer to orphan lambs. In a study involving artificial rearing of lambs from prolific ewes in an intensive management system (Heaney et al., 1982), survival rates for artificially reared lambs averaged 85%, well above our survival rates for triplet lambs nursing their dams under extensive grazing conditions. One hundred ewes with triplet litters reduced to at most 2 lambs at birth and survival rates of 85% for orphan lambs would produce 70 more weaned lambs and 35 more dead lambs than 100 ewes with twin litters, resulting in a lamb mortality overhead of 0.5 dead lambs for each additional weaned lamb, or 1 additional dead lamb for every 2 additional triplet litters.

Potential to artificially rear surplus lambs from large litters depends, in large part, on the ability of producers to integrate artificial rearing into existing farm and ranch management without prohibitive additional investments in facilities or labor. In intensive and semi-intensive production systems, growing lambs are often creep fed prior to weaning, weaned at 60 to 90 d of age, and marketed at 120 to 180 d of age. Incorporating groups of artificially reared lambs into these management systems is generally feasible, at least in terms of potential availability of facilities and labor. By contrast, in extensive grazing conditions, ewes and lambs often go to rangeland pastures by 30 to 60 d after the start of lambing. Lambs are often not weaned until 120 to 180 d of age and commonly marketed immediately after weaning. Artificially rearing of surplus lambs therefore often requires additional facilities and labor, but, if the density of commercial sheep flocks is high, sale of lambs at birth to specialist orphan-lamb growers may be a viable option. However, in purbred flocks, artificial rearing of a high proportion of the lambs born in triplet and larger litters restricts opportunities to evaluate genetic differences in rearing capacity (primarily milk production and mothering ability) among individual ewes and their sires. Results of the current study will thus assist producers to determine optimal prolificacy levels and ewe and lamb management under extensive rangeland conditions.

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