University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Roman L. Hruska U.S. Meat Animal Research Center | U.S. Department of Agriculture: Agricultural Research Service, Lincoln, Nebraska

1-1-2021

Comparison of performance of F1 Romanov crossbred ewes with wool and hair breeds during spring lambing under intensive and extensive production systems

Brad A. Freking
USDA ARS Roman L. Hruska U.S. Meat Animal Research Center, brad.freking@usda.gov

Thomas W. Murphy
USDA ARS Roman L. Hruska U.S. Meat Animal Research Center, tom.murphy@usda.gov

Follow this and additional works at: https://digitalcommons.unl.edu/hruskareports

Part of the Beef Science Commons, and the Meat Science Commons

Freking, Brad A. and Murphy, Thomas W., "Comparison of performance of F1 Romanov crossbred ewes with wool and hair breeds during spring lambing under intensive and extensive production systems" (2021). *Roman L. Hruska U.S. Meat Animal Research Center*. 567.
https://digitalcommons.unl.edu/hruskareports/567

This Article is brought to you for free and open access by the U.S. Department of Agriculture: Agricultural Research Service, Lincoln, Nebraska at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Roman L. Hruska U.S. Meat Animal Research Center by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Journal of Animal Science, 2021, Vol. 99, No. 1, 1–10

doi:10.1093/jas/skaa397
Advance Access publication December 13, 2020
Received: 7 October 2020 and **Accepted:** 10 December 2020
Animal Genetics and Genomics

ANIMAL GENETICS AND GENOMICS

Comparison of performance of F1 Romanov crossbred ewes with wool and hair breeds during spring lambing under intensive and extensive production systems

Brad A. Freking[1] and Tom W. Murphy

U.S. Meat Animal Research Center, USDA, ARS, Clay Center, NE 68933-0166

[1]Corresponding author: brad.freking@usda.gov

ORCiD numbers: 0000-0001-5385-5692 (B. A. Freking); 0000-0003-3527-8814 (T. W. Murphy).

Abstract

The objective was to evaluate wool (Dorset and Rambouillet) and hair (Dorper, Katahdin, and White Dorper) breeds for their ability to complement Romanov germplasm in two distinct production systems by estimating direct sire and grandsire effects on lamb growth, survival, and ewe productivity traits. Rams of the five breeds (n = 75) were mated to Romanov ewes (n = 459) over a 3-yr period to produce five types of crossbred lambs (n = 2,739). Sire breed (P > 0.06) did not impact body weight or survival traits of the first-generation crossbred (F1) lambs. The productivity of retained crossbred ewes (n = 830) mated to Suffolk and Texel terminal sires was evaluated at 1, 2, and 3 yr of age in each production system. In the intensive production system, labor and harvested feed were provided for sheep that lambed in March in barns, and ewes were limited to rearing two lambs with additional lambs reared artificially. Ewes in the extensive production system lambed in May on pasture and were responsible for rearing all lambs born with no labor or supplemental feed provided before weaning. A total of 1,962 litters and 4,171 lambs from 2,229 exposures to two terminal sire breeds (Suffolk and Texel) were produced in the experiment. Crossbred ewes in the intensive production system were mated in October, resulting in larger litter sizes than crossbred ewes mated in December for the extensive production system. However, single- and twin-born lamb mortality was similar between the two systems that differed greatly in labor, feed, and facilities. Lambs produced in the intensive system received concentrate feed from an early age and were heavier at 24 wk of age than lambs produced in the extensive system. These outcomes resulted in greater 24-wk litter weight in the intensive than in the extensive system (P < 0.0001). Unexpectedly, the relative performance of crossbred types did not differ importantly between production systems. White Dorper × Romanov crossbred ewes had numerical advantages in productivity in each system; however, differences between ewe types were not significant. In the extensive system, without labor and shelter at lambing or supplemental feed until weaning, 3-yr-old crossbred ewes of all types averaged 1.78 lambs marketed per ewe lambing, and 40% of the ewes that gave birth to triplets weaned their entire litters. These results document that prolific sheep and extensive systems can be successfully combined if appropriate crossbred types are used.

Key words: breeds, production systems, reproduction, sheep

Published by Oxford University Press on behalf of the American Society of Animal Science 2020.
This work is written by (a) US Government employee(s) and is in the public domain in the US.

Abbreviations

ADG_{8-12}	average daily gain from 8 to 12wk
ADG_{12-24}	average daily gain from 12 to 24 wk
BW	body weight
BW_0	body weight at birth
BW_8	body weight at 8 wk
F1	first-generation cross between two breeds
LS_0	litter size per ewe exposed at birth
LS_{12}	litter size per ewe exposed at 12 wk
LS_{24}	litter size per ewe exposed at 24 wk
LW_{12}	total litter weight per ewe exposed at 12 wk
LW_{24}	total litter weight per ewe exposed at 24 wk
$SURV_8$	survival from birth to 8 wk
$SURV_{12}$	survival from birth to 12 wk
USMARC	U.S. Meat Animal Research Center

Introduction

Low reproductive rates, combined with seasonal lamb production and high labor requirements, are significant challenges with maintaining profitable and sustainable commercial sheep enterprises. Loss of the wool incentive program lessened the effective value of wool for regions of the country where environmental conditions are not favorable for fine-wool production. These facts favor a decreased emphasis on wool production and a shift toward efficient lamb production. Improved ewe productivity has been identified as a critical priority to allow sustained competitiveness in the global market for the U.S. lamb production (American Sheep Industry Association, Inc., 2016).

Hair breeds are increasingly viewed as a viable alternative to traditional wool breeds and comprise one of the fastest growing segments in the U.S. sheep industry (NAHMS, 2011). Hair breeds selected to express “easy-care” attributes may perform well under a minimal-input production scenario. In addition to the elimination of shearing costs, potentially favorable attributes of hair sheep include adaptation to harsh environments, parasite tolerance, maternal ability, and lamb vigor (Notter, 1999; Alemseged and Hacker, 2014). The relatively slow growth and small mature size of hair sheep typically have limited their use as pure breeds. Hair breeds of sheep could make contributions to maternal crossbred ewes in terminal sire production systems that would optimize lamb production and ewe maintenance costs.

Past research in intensive systems has documented the exceptional reproductive performance of half- and quarter-blood Romanov crossbred ewes with superior levels of performance for survival, fertility, prolificacy, and length of seasonal fertility (Casas et al., 2004, 2005; Freking and Leymaster, 2004; Notter et al., 2017; Murphy et al., 2019). In this article, we document an experimental evaluation of five types of half-blood Romanov crossbred ewes including both wool and hair breeds under both intensive and extensive production systems, allowing producers to make informed decisions for their specific production system and marketing programs.

Materials and Methods

General experimental design and traits recorded

The U.S. Meat Animal Research Center (USMARC) Institutional Animal Care and Use Committee approved the experiment following recommendations by FASS (1999). The objective was to evaluate wool (Dorset and Rambouillet) and hair (Dorper, Katahdin, and White Dorper) breeds for their ability to complement Romanov germplasm for ewe productivity in two distinct production systems (extensive and intensive). Rams of the five breeds were mated to Romanov ewes during two breeding seasons in each of 3 yr to produce five types of crossbred lambs. Growth and fitness performance traits of all F1 (n = 2,739) lambs were recorded. October and December mating seasons produced females allocated to the intensive and extensive production systems, respectively. Performance of the retained F_1 crossbred ewes mated to terminal sires (Suffolk or Texel) was evaluated at 1, 2, and 3 yr of age in each production system. In the intensive system, labor and harvested feed (silage) were provided for sheep during March lambing indoors, allowing births to be assisted, navels dipped in iodine, and ewes and lambs jugged. Ewes were limited to rearing two lambs with additional lambs reared artificially. Nursery-reared lambs were offered ad libitum milk replacer until 4 to 5 wk of age and then managed with their dam-reared contemporaries thereafter. Lambs were provided access to a total-mixed creep diet (18% crude protein) beginning at about 2 wk of age. Lambs were weighed at 0, 8 (weaning), 12, and 24 wk of age. Ewes in the extensive system lambed on pasture in May and were responsible for rearing all lambs born. In the latter system, no labor (except tagging lambs at birth) or supplemental feed was provided before weaning. Lambs in this system were weighed at 8, 12 (weaning), and 24 wk of age. All lambs were moved to a feedlot after weaning where they were transitioned to being fed ad libitum a total mixed diet (2.96 Mcal of metabolizable energy/kg of dry matter with 14.5% crude protein) during the finishing period.

Production of generation 1 F1 lambs

Romanov ewes (n = 459 unique ewes) were exposed to 75 unique rams of five breeds over 3 yr of production. Rambouillet (n = 21), Dorset (n = 18), Katahdin (n = 18), Dorper (n = 9), or White Dorper (n = 9) rams were used in single-sire mating pens for six 35-d breeding seasons (two per year) over the fall of 2000, 2001, and 2002. Individual rams were purchased for this experiment from industry sources following the input from each breed association. Ewes were evenly allocated to either October or December breeding for early (March) or late (May) spring lambing groups. A total of 411 Romanov ewes lambed from 2001 to 2003 of which 101, 134, and 176 recorded one, two, and three lambing events in this experiment, respectively. Romanov ewes were 1 to 11 yr of age at lambing, though 71% were 3 yr or less. Service sire breeds were randomly assigned to ewes each fall. However, 95% of ewes that lambed two or more times in the experiment remained in the same spring lambing group in subsequent years.

Individual rams were utilized for a single breeding year, but all rams sired progeny in both lambing groups (early and late) the subsequent spring to provide genetic cross classification with the two production systems evaluated. Eighteen Rambouillet (3 were replaced during breeding), 18 Dorset, and 18 Katahdin rams sired F1 progeny throughout the course of the experiment. There were fewer Dorper (n = 9) and White Dorper (n = 9) rams used because these groups were considered one breed with a single breed registry. However, monitoring of data collection from the current experiment, as well as a review of historical literature of the different breeds that contributed to the formation of the two populations (Milne, 2000), justified distinct classification of the resulting F1 progeny. Throughout the article, we will refer to the Black-headed color variant as Dorper and the white variant as White Dorper.

There were a total of 2,739 F1 lambs born to Romanov ewes. Purebred Romanov ewes were required to rear their entire litter unless lamb nutritional status was observed to be failing, in which case affected lambs were transferred to the nursery for artificial rearing (n = 855). Most of the lambs that required artificial rearing entered the nursery within 24 h of birth. An attempt was made to preferentially leave ewe lambs with their dam to experience a maternal environment. Nursery-reared lambs were offered ad libitum milk replacer until 4 to 5 wk of age and then at weaning time of their dam-reared contemporaries were remixed with them. All lambs were offered a total-mixed creep diet (18% crude protein) beginning at about 2 wk of age, and all ram lambs were castrated at about 2 wk of age. Dam- and nursery-reared lambs were removed from ewe pens at about 8 wk of age and transitioned to a total mixed ration (2.96 Mcal of metabolizable energy/kg of dry matter with 14.5% crude protein; ad libitum) in a drylot. Crossbred lamb body weight (**BW**) was recorded at birth, weaning (59 ± 5.6 d), and postweaning (156 ± 20.5 d).

Production of generation 2 terminal progeny

A total of 908 F1 ewe lambs were present at 20 wk of age, and 830 (91%) were subsequently exposed as breeding replacements. The majority of culled ewe lambs was based on low postweaning weights. Replacement F1 ewe lambs were assigned to drylot or pasture spring lambing treatments based upon their birth month (i.e., their dam's breeding month). Therefore, F1 ewes born in March were assigned to the drylot lambing treatment, and those born in May were assigned to the pasture lambing treatment. This was done to ensure that all F1 ewes were exposed to rams for the first time at about 7 mo of age (206 ± 7.2 d). Ewes were exposed to either a Suffolk or a Texel multiple-sire breeding group for a 35-d season and remained in their spring lambing treatment and service sire breed group for up to three parities. Terminal-sired progeny for this portion of the experiment were produced during the 2002 to 2006 lambing years. A single multi-sire breeding group per breed of sire was used for each 35-d breeding season, and the number of rams within a group ranged from 3 to 11 depending on the number of ewes to be mated. Ewe to ram ratios ranged from 12 to 23 ewes per ram. A total of 65 Suffolk and 66 Texel sires were used in breeding during this experiment, producing 4,171 lambs.

Statistical analysis

Generation 1 F1 lamb BW and survival

Generation 1 was defined as F1 lambs born to Romanov ewes that had been bred to five ram breeds (i.e., Dorset, Rambouillet, Katahdin, Dorper, or White Dorper). Due to the prolific nature of Romanov ewes, there were few (n = 54) single-born F1 lambs. Additionally, while litters of five (n = 45) and six lambs (n = 6) were recorded, they were not cross classified across dam ages, production year, lambing month, and sire breed. Therefore, the F1 lamb birth type was expressed as litters of ≤2, 3, or ≥4 lambs. F1 lamb BW at birth (**BW_0**; n = 2,739) was used to linearly adjust weaning BW to 56 d (body weight at 8 wk [**BW_8**]; n = 1,340), and both were analyzed using the MIXED procedure of SAS (v. 9.4; SAS Institute Inc., Cary, NC) with fixed effects of sire breed, birth month (March or May), birth year (2001, 2002, or 2003), age of dam (1, 2, 3, or 4+), sex, birth type class, and rearing environment (dam or nursery; BW_8 only) and the random effects of sire (nested within sire breed and birth year) and dam. Lamb survival from birth to 8 wk (**$SURV_8$**; n = 1,884) was analyzed with a similar model as weaning BW_8 but as a binary variable in the GLIMMIX procedure, and least-squares means were back-transformed to the original scale. Records from nursery-reared lambs were included in the analysis of BW_0 but not BW_8 or $SURV_8$.

Generation 2 terminal lamb BW and survival

Generation 2 was defined as terminally sired lambs born to F1 ewes bred to Suffolk or Texel rams. A total of 1,985 and 2,186 lambs were born in the intensive-barn and extensive-pasture systems, respectively. Traits included BW_0 (intensive only) and BW_8, average daily gain from 8 to 12 wk (**$ADG_{8–12}$**) and from 12 to 24 wk (**$ADG_{12–24}$**), and survival from birth to 12 wk (**$SURV_{12}$**). Data were analyzed within the production system with fixed effects of sire breed, grandsire breed, birth year (2002 to 2006), age of dam (1, 2, or 3 yr), sex, birth type class (1, 2, or 3+), and all cross-classified two-way interactions and the random effect of dam (nested within sire and grandsire breed). BW at 8 wk was adjusted for age using linear interpolation between BW_0 and the observed weaning weight for intensive system lambs and using a linear covariate (in days) for extensive system lambs. Lamb BW and ADG traits were analyzed in the MIXED procedure, and survival was analyzed as a binary variable in the GLIMMIX procedure. Postnatal performance of nursery-reared lambs born in the intensive system was not considered in the analyses. In total, there were 1,985, 1,373, 1,338, 1,294, and 1,613 records for BW_0, BW_8, $ADG_{8–12}$, $ADG_{12–24}$, and $SURV_{12}$, respectively, for lambs born in the intensive-barn system. Lambs born in the extensive-pasture system had a total of 1,750, 1,691, 1,635, and 2,186 records for BW_8, $ADG_{8–12}$, $ADG_{12–24}$, and $SURV_{12}$, respectively.

Generation 1 F1 ewe productivity

Ewe productivity traits included litter size per ewe exposed at birth, 12, and 24 wk (**LS_0**, **LS_{12}**, and **LS_{24}**, respectively) and total litter weight per ewe exposed at 12 and 24 wk (**LW_{12}** and **LW_{24}**, respectively; n = 2,229 each). Ewes in the intensive system were credited with the performance of their nursery-reared lambs in the calculation of litter size and weight records. Ewe traits were analyzed as repeated measures in the MIXED procedure with the fixed effects of sire breed, service sire breed, birth year (2001, 2002, or 2003), age, and production system, all two-way interactions, and the sire breed × age × production system three-way interaction. Additionally, a random effect of sire (nested within sire breed and ewe birth year) was fit and a compound symmetric covariance structure with heterogenous variance across age was assumed for the ewe (nested within sire, service sire breed, and production system) effect. When the main effect of sire breed was significant ($P \le 0.05$), a customized orthogonal contrast was generated using the LSMESTIMATE statement to compare productivity between ewes sired by wool (Dorset and Rambouillet) or hair breeds (Katahdin, Dorper, and White Dorper).

Results

Generation 1 F1 lamb BW and survival

Least-squares means for the main effects in the analyses of F1 lamb BW and survival are displayed in Table 1. The main effect of year and related two-way interactions were included in all models but are not discussed beyond significance, since year effects cannot be predicted to recur in the future.

The sire breed × birth type, birth month × birth year, and sex × birth type interaction effects were significant in the analysis of F1 lamb BW_0 ($P \le 0.02$). Within birth type, no significant differences among sire breeds were detected ($P \ge 0.06$). Within twin litters, male and female lambs had similar BW_0 ($P > 0.99$) but males were heavier than females in all other litter size classes ($P \leq 0.03$). As main effects, birth month and year did not influence lamb BW_0 ($P \geq 0.26$). Sire breed tended to affect lamb BW_0 ($P = 0.07$) with lambs sired by Rambouillet and Dorper tending to be the heaviest. Lamb BW_0 increased with dam age class from 1 to 3 yr of age ($P < 0.001$) but was not different between lambs born to 3- and 4-yr-old dams ($P > 0.99$). As expected, F1 lamb BW_0 decreased with increased birth type, and males were heavier than females ($P < 0.001$).

The birth month × birth year and birth year × birth type interaction effects were significant in the analysis of F1 lamb BW_8 ($P \leq 0.04$). As a main effect, birth month influenced BW_8 ($P < 0.002$) with heavier May-born lambs. Similar to BW_0, BW_8 increased with the age of dam from 1- to 3-yr old ($P < 0.01$), but differences were not detected between lambs born to 3- and 4-yr-old dams ($P = 0.40$). Lamb BW_8 decreased with increased birth type ($P < 0.001$) but males were not significantly heavier than females ($P = 0.74$). Additionally, differences among sire breeds were not detected for BW_8 ($P = 0.19$). The birth month × birth year interaction effect was significant in the analysis of $SURV_8$ ($P < 0.001$). Generation 1 lamb $SURV_8$ decreased with increased litter size at birth and was greater for females than males ($P \leq 0.02$), but no other main effects were significant ($P \geq 0.19$).

Table 1. Least-squares means (±SE) for model main effects on generation 1 F1 lamb BW_0 and BW_8 and $SURV_8$

		Trait		
Effect	Level	BW_0, kg	BW_8, kg	$SURV_8$, %
Sire breed[1]	Dorset	3.07 ± 0.04	11.7 ± 0.21	0.73 ± 0.03
	Rambouillet	3.11 ± 0.04	11.5 ± 0.21	0.76 ± 0.03
	Katahdin	3.05 ± 0.04	11.2 ± 0.21	0.77 ± 0.02
	Dorper	3.10 ± 0.05	11.8 ± 0.29	0.79 ± 0.03
	White Dorper	2.93 ± 0.05	11.9 ± 0.28	0.78 ± 0.03
Dam age, yr	1	2.71 ± 0.05[c]	9.91 ± 0.33[c]	0.78 ± 0.04
	2	3.01 ± 0.03[b]	11.4 ± 0.20[b]	0.80 ± 0.02
	3	3.24 ± 0.03[a]	12.8 ± 0.19[a]	0.76 ± 0.02
	4+	3.25 ± 0.04[a]	12.4 ± 0.21[a]	0.73 ± 0.03
Birth type, *n*	≤2	3.53 ± 0.04[a]	12.5 ± 0.19[a]	0.85 ± 0.02[c]
	3	3.01 ± 0.03[b]	11.5 ± 0.17[b]	0.75 ± 0.02[b]
	≥4	2.62 ± 0.03[c]	10.8 ± 0.19[c]	0.69 ± 0.02[a]
Sex	Male	3.09 ± 0.03[a]	11.6 ± 0.16	0.73 ± 0.02[b]
	Female	3.01 ± 0.03[b]	11.6 ± 0.14	0.80 ± 0.02[a]
Birth month	March	3.06 ± 0.04	11.2 ± 0.20[b]	0.75 ± 0.03
	May	3.04 ± 0.03	12.0 ± 0.15[a]	0.79 ± 0.02

[1]F1 lambs were all born to Romanov ewes and sired by one of five breeds of ram.
[a–c]Means within a trait and effect with no common superscript are different ($P \leq 0.02$).

Generation 2 terminal-sired lambs

The summary of the scale of the second-generation component to measure ewe productivity is presented in Table 2. All 72 sires from the 5 ram breeds produced crossbred ewe lambs evaluated in both production systems.

Terminal-sired lamb BW and ADG, intensive production system

Least-squares means for the main effects in the analyses of lamb BW and ADG from the intensive production system are displayed in Table 3. Birth year × birth type and age of dam × birth type interaction effects were significant in the analysis of BW_0 ($P \leq 0.03$). The age of dam × birth type interaction was due to a relatively smaller difference in BW_0 between twin and triplet lambs born to 1-yr-old dams compared with other dam ages. Still, BW_0 significantly decreased with increased birth type within each dam age ($P \leq 0.01$). As main effects, BW_0 decreased with increased birth type ($P < 0.001$) and was least for lambs born to 1-yr-old dams ($P < 0.001$) than those born to 2- or 3-yr-old dams, which were not different ($P = 0.13$). Additionally, male lambs had heavier BW_0 than females ($P < 0.001$). Sire breed did not affect BW_0 ($P = 0.61$); however, grandsire breed did ($P < 0.001$). Rambouillet-sired F1 dams produced terminal-cross lambs that were heavier ($P \leq 0.02$) for BW_0 than all other grandsire breeds except White Dorper-sired F1 dams ($P = 0.52$). White Dorper, Dorper, and Dorset grandsire breeds were similar ($P > 0.30$) to each other for BW_0. The Katahdin grandsire breed was lower ($P < 0.01$) for BW_0 than Rambouillet and White Dorper, but similar ($P > 0.38$) to Dorper and Dorset.

The birth year × birth type and age of dam × birth type interaction effects were also significant in the analysis of lamb BW_8 ($P \leq 0.03$) in the intensive production system. Within lambs reared by 1-yr-old dams, singles were heaviest (18.2 ± 0.67 kg; $P < 0.01$), while twins and triplets had similar BW_8 (11.0 ± 0.28 vs. 12.4 ± 0.99 kg; $P = 0.36$). However, within lambs born to 2- and 3-yr-old dams, BW_8 decreased with increased lamb birth type ($P \leq 0.02$). As main effects, lambs reared by 2- and 3-yr-old dams had similar BW_8 ($P = 0.40$), and both were heavier than lambs reared by 1-yr-old dams ($P < 0.001$), and twin- and triplet-born

Table 2. Numbers of crossbred ewes exposed, and the total number of lambs produced from evaluation of five types of half-Romanov ewes mated to terminal sires in intensive and extensive production systems measured through 3 yr of age

Production system	Sire breed	No. of sires	No. of F1 ewes	No. of ewe exposures	No. of litters produced	No. of lambs born
Intensive	Dorset	18	100	267	220	502
	Rambouillet	18	90	235	214	444
	Katahdin	18	112	296	251	576
	Dorper	9	40	108	91	203
	White Dorper	9	49	138	126	260
Extensive	Dorset	18	110	300	269	555
	Rambouillet	18	109	296	260	503
	Katahdin	18	105	278	249	560
	Dorper	9	47	126	114	236
	White Dorper	9	68	185	168	332
Total		72[1]	830	2,229	1,962	4,171

[1]The same sires produced the samples of F1 ewes for both production systems.

Table 3. Least-squares means (±SE) for the main effects of sire breed, grandsire breed, age of dam, birth type, and sex on generation 2 lamb BW and ADG measured in the intensive production system

		Trait[1]			
Effect	Level	BW_0, kg	BW_8, kg	$ADG_{8–12}$, kg/d	$ADG_{12–24}$, kg/d
Sire breed	Suffolk	4.35 ± 0.05	16.1 ± 0.25[a]	0.328 ± 0.007[a]	0.286 ± 0.002[a]
	Texel	4.33 ± 0.05	15.5 ± 0.24[b]	0.306 ± 0.006[b]	0.256 ± 0.002[b]
Grandsire breed	Dorset	4.28 ± 0.06[b,c]	16.0 ± 0.28[a,b]	0.309 ± 0.008[b]	0.268 ± 0.003[b]
	Rambouillet	4.55 ± 0.06[a]	15.9 ± 0.29[b,c]	0.323 ± 0.008[a,b]	0.266 ± 0.003[b]
	Katahdin	4.17 ± 0.06[c]	15.2 ± 0.27[c]	0.309 ± 0.007[b]	0.268 ± 0.003[b]
	Dorper	4.29 ± 0.08[b,c]	15.6 ± 0.39[b,c]	0.303 ± 0.010[b]	0.269 ± 0.005[b]
	White Dorper	4.43 ± 0.07[a,b]	16.4 ± 0.35[a,b]	0.342 ± 0.009[a]	0.285 ± 0.004[a]
Dam age, yr	1	4.03 ± 0.08[b]	13.9 ± 0.42[b]	0.290 ± 0.012[b]	0.273 ± 0.003
	2	4.41 ± 0.07[a]	16.5 ± 0.33[a]	0.324 ± 0.008[a]	0.270 ± 0.003
	3	4.59 ± 0.07[a]	17.0 ± 0.36[a]	0.337 ± 0.010[a]	0.270 ± 0.003
Birth type, *n*	1	5.29 ± 0.11[a]	20.2 ± 0.51[a]	0.353 ± 0.012[a]	0.270 ± 0.004
	2	4.25 ± 0.03[b]	14.0 ± 0.16[b]	0.310 ± 0.004[b]	0.274 ± 0.002
	3+	3.50 ± 0.06[c]	13.2 ± 0.37[b]	0.288 ± 0.011[b]	0.269 ± 0.003
Sex	Male	4.44 ± 0.05[a]	16.0 ± 0.24[a]	0.328 ± 0.007[a]	0.281 ± 0.002[a]
	Female	4.24 ± 0.05[b]	15.6 ± 0.24[b]	0.306 ± 0.006[b]	0.262 ± 0.002[b]

[1]Lambs were weaned at approximately 8 wk of age. Lambs in the intensive system were exposed to creep feed, reared in a drylot, and weaned from their dams at 8 wk of age and then entered the drylot for finishing through 24 wk of age.
[a–c]Means within a column and effect with no common superscript are different ($P \le 0.05$).

lambs were similar ($P = 0.10$) but both lighter than single-born lambs ($P < 0.001$). Eight weeks BW was greater for males than females and greater for Suffolk- than Texel-sired lambs ($P \le 0.01$). Lambs born to 50% Dorset and 50% White Dorper dams both had heavier BW_8 than lambs born to 50% Katahdin dams ($P \le 0.04$), but no other grandsire breed differences were observed ($P \ge 0.10$).

The age of dam × birth type interaction effect was also significant in the analysis of intensive production system lamb $ADG_{8–12}$ ($P < 0.001$). Within 1-yr-old dams, twin- and triplet-born lamb $ADG_{8–12}$ was similar (0.270 ± 0.007 and 0.241 ± 0.032 kg/d, respectively; $P = 0.64$) but both were slower growing than single lambs (0.357 ± 0.009 kg/d; $P < 0.001$). Conversely, within lambs reared by 2- and 3-yr-old dams, there were no significant differences in $ADG_{8–12}$ between birth types ($P \ge 0.05$). As a main effect, single-born lambs were faster growing ($P < 0.01$) than twins and triplets, which were similar to each other ($P = 0.14$). Lambs born to 1-yr old dams had lower $ADG_{8–12}$ ($P \le 0.03$) than lambs born to 2- or 3-yr-old dams which were not different ($P = 0.55$). Males had greater $ADG_{8–12}$ than females ($P < 0.001$), and Suffolk-sired lambs were faster growing than Texel-sired lambs ($P < 0.001$). Lambs reared by 50% White Dorper dams had greater $ADG_{8–12}$ than those reared by 50% Dorset, 50% Katahdin, or 50% Dorper dams ($P \le 0.01$), but no other grandsire breeds were different ($P \ge 0.25$).

No two-way interaction effects were significant in the analysis of intensive production system lamb $ADG_{12–24}$ ($P \ge 0.17$). Dam age and birth type did not impact $ADG_{12–24}$ ($P \ge 0.19$) but males were still faster growing than females ($P < 0.001$). Additionally, Suffolk-sired lambs maintained a growth advantage through 24 wk over Texel-sired lambs ($P < 0.001$). Lambs born to 50% White Dorper ewes had greater $ADG_{12–24}$ than lambs born to any other F1 dam ($P \le 0.05$).

Terminal-sired lamb BW and ADG, extensive production system

Least-squares means for the main effects in the analysis of extensive production system lamb BW and ADG are displayed in Table 4. The grandsire breed × birth year, grandsire breed × age of dam, birth year × sex, and age of dam × birth type interaction effects were significant in the analysis of BW_8 ($P \le 0.02$). Within 1-yr old dams, lambs reared by 50% White Dorper ewes were heavier than those reared by 50% Katahdin ewes (19.0 ± 0.55 vs. 16.7 ± 0.41 kg; $P < 0.01$). Within 2-yr-old dams, lambs reared by 50% White Dorper and 50% Rambouillet ewes (19.7 ± 0.45 and 19.8 ± 0.36 kg, respectively) were heavier than those reared by 50% Katahdin (18.2 ± 0.37 kg; $P \le 0.04$) and 50% Dorper (17.5 ± 0.61 kg; $P \le 0.02$). Within 3-yr-old dams, lambs reared by 50% White Dorper (22.3 ± 0.48 kg) and 50% Dorset ewes (21.2 ± 0.45 kg) were heavier than those reared by 50% Katahdin ewes (19.3 ± 0.51; $P \le 0.02$) and those reared by 50% White Dorper were heavier than those reared by 50% Rambouillet (20.7 ± 0.43; $P = 0.04$). Lamb BW_8 was different among all birth type classes within those reared by 2- and 3-yr-old dams ($P < 0.001$), but twins and triplets reared by 1-yr-old dams did not differ in BW_8 (16.6 ± 0.24 and 15.6 ± 0.65 kg, respectively; $P = 0.24$) though both were lighter than singles (21.3 ± 0.30 kg; $P < 0.001$). As main effects, BW_8 was greater for Suffolk- than Texel-sired lambs, increased with greater age of dam, decreased with increased birth type, and was greater for males than females ($P < 0.01$). Grandsire breed influenced BW_8 with lambs reared by 50% White Dorper dams being heavier than all other grandsire breeds ($P \le 0.04$) except Rambouillet ($P = 0.06$). Lambs reared by 50% Rambouillet or 50 % Dorset dams were similar to each other ($P > 0.99$) and greater than those reared by 50% Katahdin dams ($P < 0.001$). No other maternal grandsire breed contrasts were significant in the analysis of lamb BW_8 in the extensive system ($P \ge 0.46$).

The grandsire breed × birth year and sire breed × sex interaction effects were significant in the analysis of extensive production system lamb $ADG_{8–12}$ ($P \le 0.03$). Lamb $ADG_{8–12}$ was similar between male and female Suffolk-sired lambs ($P = 0.99$) but greater for males within Texel-sired lambs ($P < 0.01$). As main effects, lamb $ADG_{8–12}$ did not differ between sire breeds ($P = 0.55$) but was greater for males than females and decreased within increased birth type ($P \le 0.04$). Lambs reared by 1-yr-old dams had lower $ADG_{8–12}$ ($P < 0.001$) than those reared by 2- or 3-yr-old dams which were not different from each other ($P = 0.69$). Lambs reared by 50% Rambouillet and Katahdin ewes had greater

Table 4. Least-squares means (±SE) for the main effects of sire breed, grandsire breed, age of dam, birth type, and sex on BW and ADG measured in the extensive production system

		Trait[1]		
Effect	Level	BW_8, kg	ADG_{8-12}, kg/d	ADG_{12-24}, kg/d
Sire breed	Suffolk	19.5 ± 0.20[a]	0.099 ± 0.003	0.268 ± 0.002[a]
	Texel	18.9 ± 0.20[b]	0.097 ± 0.003	0.230 ± 0.002[b]
Grandsire breed	Dorset	19.4 ± 0.25[b]	0.095 ± 0.004[a,b]	0.254 ± 0.003[a,b]
	Rambouillet	19.4 ± 0.25[a,b]	0.108 ± 0.004[a]	0.260 ± 0.003[a]
	Katahdin	18.1 ± 0.27[c]	0.109 ± 0.005[a]	0.230 ± 0.003[c]
	Dorper	18.6 ± 0.47[b,c]	0.079 ± 0.009[b]	0.238 ± 0.006[b,c]
	White Dorper	20.4 ± 0.29[a]	0.099 ± 0.005[a,b]	0.264 ± 0.003[a]
Dam age, yr	1	17.8 ± 0.28[c]	0.084 ± 0.004[a]	0.247 ± 0.003
	2	18.9 ± 0.24[b]	0.104 ± 0.004[b]	0.250 ± 0.003
	3	20.8 ± 0.32[a]	0.107 ± 0.004[b]	0.249 ± 0.003
Birth type, *n*	1	22.9 ± 0.34[a]	0.117 ± 0.005[a]	0.259 ± 0.004[a]
	2	18.4 ± 0.15[b]	0.093 ± 0.003[b]	0.250 ± 0.002[b]
	3+	16.2 ± 0.23[c]	0.084 ± 0.004[c]	0.238 ± 0.003[c]
Sex	Male	19.6 ± 0.20[a]	0.103 ± 0.003[a]	0.258 ± 0.002[a]
	Female	18.7 ± 0.19[b]	0.095 ± 0.003[b]	0.240 ± 0.002[b]

[1]Lambs in the extensive system were on pasture with their dams until 12 wk of age and entered the drylot for finishing through 24 wk of age.
[a–c]Means within a column and effect with no common superscript are different ($P \le 0.05$).

ADG_{8-12} than those reared by Dorper ($P = 0.02$), but not other maternal grandsire breed differences were observed ($P \ge 0.13$).

The grandsire breed × birth year and sire breed × birth year interaction effects were significant in the analysis of extensive production system ADG_{12-24} ($P < 0.01$). Age of dam did not affect ADG_{12-24} ($P = 0.71$), but males were faster growing than females and growth decreased with birth type ($P \le 0.05$). Suffolk-sired lambs had greater ADG_{12-24} than Texel-sired lambs ($P < 0.001$). Lambs reared by 50% Rambouillet, 50% White Dorper, and 50% Dorset ewes had greater ADG_{12-24} than lambs reared by 50% Katahdin ($P < 0.001$). Additionally, lambs reared by 50% Rambouillet and 50% White Dorper ewes had greater ADG_{12-24} than lambs reared by 50% Dorper ewes ($P < 0.01$).

Terminal-sired lamb survival, intensive and extensive production systems

Least-squares means for the main effects in the analysis of survival for both intensive and extensive production system born lambs are displayed in Table 5. As main effects, lamb $SURV_{12}$ in the intensive system was greatest for those born to 2-yr-old dams ($P \le 0.02$) but not different between lambs born to 1- and 3-yr-old dams ($P = 0.45$). Additionally, $SURV_{12}$ was greater for Texel than Suffolk-sired lambs ($P = 0.03$) and decreased with increased birth type ($P < 0.001$), but no other main effects were significant in the analysis of lamb survival in the intensive system ($P \ge 0.06$). For lambs born in the extensive system, $SURV_{12}$ was lower for lambs from 1-yr-old dams ($P < 0.001$) than those from 2- or 3-yr-old dams, which were not different ($P = 0.83$). Similar to the intensive system, $SURV_{12}$ in the extensive system was greater for Texel- than Suffolk-sired lambs ($P = 0.04$) and decreased with an increased birth type ($P \le 0.01$), but no other main effects were significant ($P \ge 0.09$).

Table 5. Least-squares means (±SE) for the main effects of sire breed, grandsire breed, age of dam, birth type, and sex on generation 2 lamb $SURV_{12}$ in intensive and extensive production systems

		Production system[1]	
Effect	Level	Intensive	Extensive
Sire breed	Suffolk	0.86 ± 0.02[b]	0.79 ± 0.02[b]
	Texel	0.90 ± 0.02[a]	0.83 ± 0.02[a]
Grandsire breed	Dorset	0.89 ± 0.02	0.80 ± 0.02
	Rambouillet	0.88 ± 0.02	0.79 ± 0.02
	Katahdin	0.90 ± 0.02	0.80 ± 0.02
	Dorper	0.82 ± 0.04	0.80 ± 0.03
	White Dorper	0.92 ± 0.02	0.87 ± 0.02
Dam age, yr	1	0.85 ± 0.03[b]	0.72 ± 0.03[b]
	2	0.92 ± 0.02[a]	0.85 ± 0.02[a]
	3	0.88 ± 0.02[b]	0.85 ± 0.02[a]
Birth type, *n*	1	0.96 ± 0.01[a]	0.90 ± 0.02[a]
	2	0.86 ± 0.02[b]	0.84 ± 0.01[b]
	3+	0.77 ± 0.03[c]	0.64 ± 0.02[c]
Sex	Male	0.87 ± 0.02	0.82 ± 0.02
	Female	0.90 ± 0.02	0.81 ± 0.02

[1]Lambs were weaned at 8 and 12 wk of age in the intensive and extensive production systems, respectively.
[a–c]Means within a column and effect with no common superscript are different ($P \le 0.04$).

Generation 1, F1 Ewe Productivity

The significance of main and interaction effects for each ewe productivity trait is displayed in Table 6. The ewe age × production system interaction effect was significant in the analysis of all ewe productivity traits ($P \le 0.01$) and associated least-squares means are displayed in Table 7. Within 2-yr-old ewes, all litter size traits were greater for those in the intensive than extensive system ($P < 0.01$). However, the production system did not affect the litter size of 1- and 3-yr-old ewes ($P \ge 0.07$). Conversely, litter weight was greater for intensive than extensively managed ewes within all ages ($P \le 0.02$). The sire breed × age interaction effect was only significant for LW_{24} ($P < 0.01$), and there were no differences between sire breeds within 1-yr-old ewes ($P \ge 0.47$). Within 2-yr olds, 50% White Dorper ewes had greater LW_{24} than 50% Katahdin ewes (82.2 ± 3.73 and 68.4 ± 2.81 kg, respectively; $P = 0.02$), and, within 3-yr-olds, 50% White Dorper had greater LW_{24} than 50% Dorper and 50% Rambouillet (92.4 ± 4.53, 69.8 ± 5.35, and 71.6 ± 3.56 kg, respectively; $P \le 0.01$).

Least-squares means for the main effects on ewe productivity traits are displayed in Table 8. Litter size near birth was different between all ewe ages ($P < 0.01$); however, for all other litter size and weight traits, performance was not different between 2- and 3-yr-old ewes ($P \geq 0.08$) though both were greater than 1-yr-old ewes ($P < 0.001$). Due to the greater survival for Texel- than Suffolk-sired lambs, ewe LS_{12} and LS_{24} were greater for those bred to Texel than Suffolk ($P \leq 0.03$). However, due to the greater BW and ADG for Suffolk- than Texel-sired lambs, ewe litter weight was not different between service sire breeds ($P \geq 0.20$). All litter size and weight traits, except for LS_0 ($P = 0.27$), were greater for ewes in the intensive than extensive system ($P < 0.001$). Sire breed only significantly impacted LW_{24} and 50% White Dorper ewes accounted for more weight of lamb marketed than 50% Rambouillet and 50% Katahdin ewes ($P \leq 0.03$) and tended to be higher performing than 50% Dorset ($P = 0.07$) and 50% Dorper ($P = 0.06$). The orthogonal contrast of hair- vs. wool-sired ewes was, therefore, only tested for LW_{24} but was not significantly different from zero ($P = 0.20$).

Discussion

Within annual production systems of fall breeding and spring lambing, genetic changes for traits with the most impact on biological efficiency are changes in survival, fertility, and prolificacy (Wang and Dickerson, 1991a, 1991b, 1991c). Romanov sheep have documented superior levels of performance for survival, fertility, prolificacy, and length of seasonal fertility (Casas et al., 2004, 2005; Freking and Leymaster, 2004). Efficiency and profitability of commercial sheep production would be positively impacted by increased reproductive rates with the current national average of 1.07 lambs per ewe (USDA NASS, 2019) having hardly increased in over 40 yr (0.94 lambs per ewe; USDA ESCS, 1979), and genetic improvement due to direct selection within populations is slow (Burfening et al., 1993). Compared with other competing meat animal species, variation in and among sheep breeds available to U.S. producers for prolificacy, including multiple major genes associated with fecundity (Heaton et al., 2017), is quite large and can be exploited through planned crossbreeding systems to meet specific production system and marketing objectives.

The U.S sheep industry could realize greater profitability if it could utilize land and forage resources under more extensive conditions than would be typically thought of for prolific breeds or crosses without additional labor as a constraint. As an example, purebred Romanov ewe reproduction levels would often exceed optimum levels of litter size for most of the management and labor production systems (Fahmy, 1996). However, the reproductive advantages appear to be genetically controlled in a quantitative manner and not subject to large reciprocal effects (Freking and Bennett, 2019) allowing reproductive rates to be manipulated and more easily managed to target specific levels of prolificacy by altering the % Romanov contribution in a crossbred ewe. Breeds that would best complement the increased prolificacy potential in Romanov crossbred ewes would ideally provide increased milk production, improved maternal behavior to improve lamb survival, and fitness traits by adapting to the environment. Few studies have evaluated breeds that would best complement prolific genetics such as the Romanov to produce a desirable crossbred ewe in more extensive production system environments (Walker et al., 1993; Notter et al., 2017).

Traditional expectations are that these kinds of highly prolific ewes do not fit with lower labor, more extensive production systems. Prior industry efforts to increase ewe productivity on pasture have been limited by most of the production systems being unable to effectively manage triplet and greater birth types (Juengel et al., 2018; Notter et al., 2018). This indicates a balance of prolificacy and fitness to a production system needs to be considered. Efforts to examine these relationships must be conducted with large-scale experiments to allow for the evaluation of lamb survival and litter birth weight variation (Kenyon et al., 2019). At moderate levels of prolificacy, selection efforts to improve the innate genetic ability to rear twins and triplets are often masked because too many ewes give birth to single lambs. Efforts to initiate genetic improvement

Table 6. Significance of main and interaction effects tested in the models for ewe productivity traits

	Trait[1]				
Effect[2,3]	LS_0	LS_{12}	LS_{24}	LW_{12}	LW_{24}
S					*
SS		*	*		
Y			**		***
A	***	***	***	***	***
PS		**	**	***	***
S × A		*			**
Y × A		**		**	
A × PS	**	*	**	***	***

[1]LS_i, litter size per ewe exposed at birth (0), 12, and 24 wk; LW_i, total litter weight per ewe exposed at 12 and 24 wk.
[2]S, sire breed; SS, service sire breed; Y, birth year; A, age, PS, production system.
[3]All two-way interactions and the S × A × PS three-way interaction were tested but are only displayed if they were significant for at least one ewe productivity trait.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 7. Least-squares means (±SE) for the interaction of ewe age × production system on litter size and weight of 50% Romanov ewes

		Trait[1]				
Age, yr	Production system	LS_0, *n*	LS_{12}, *n*	LS_{24}, *n*	LW_{12}, kg	LW_{24}, kg
1	Intensive	1.33 ± 0.04	1.06 ± 0.04	1.01 ± 0.04	22.5 ± 0.76[a]	43.7 ± 1.47[a]
	Extensive	1.39 ± 0.04	0.97 ± 0.04	0.93 ± 0.03	19.9 ± 0.71[b]	36.2 ± 1.38[b]
2	Intensive	2.16 ± 0.05[a]	1.88 ± 0.05[a]	1.82 ± 0.05[a]	43.1 ± 1.03[a]	83.9 ± 2.15[a]
	Extensive	1.98 ± 0.05[b]	1.61 ± 0.05[b]	1.53 ± 0.05[b]	33.6 ± 0.97[b]	65.0 ± 2.02[b]
3	Intensive	2.25 ± 0.06	1.84 ± 0.06	1.77 ± 0.06	43.5 ± 1.30[a]	82.8 ± 2.63[a]
	Extensive	2.21 ± 0.06	1.76 ± 0.06	1.72 ± 0.05	37.5 ± 1.21[b]	74.4 ± 2.45[b]

[1]LS_i, litter size per ewe exposed at parturition (0), 12, and 24 wk; LW_i, total litter weight per ewe exposed at 8 and 24 wk.
[a,b]Means within a trait and age with no common superscript are different ($P \leq 0.02$).

Table 8. Least-squares means (± SE) for the main effects of sire breed, service sire breed, age, and production system on litter size and weight of 50% Romanov ewes

Effect	Level	Trait[1]				
		LS_0, *n*	LS_{12}, *n*	LS_{24}, *n*	LW_{12}, kg	LW_{24}, kg
Sire breed	Dorset	1.86 ± 0.06	1.49 ± 0.04	1.42 ± 0.04	32.2 ± 0.92	63.7 ± 1.91[a,b]
	Rambouillet	1.81 ± 0.06	1.45 ± 0.05	1.42 ± 0.04	32.7 ± 0.94	61.9 ± 1.97[b]
	Katahdin	2.02 ± 0.06	1.57 ± 0.04	1.51 ± 0.04	32.5 ± 0.91	62.8 ± 1.91[b]
	Dorper	1.93 ± 0.09	1.54 ± 0.07	1.47 ± 0.07	33.7 ± 1.40	61.3 ± 3.00[a,b]
	White Dorper	1.82 ± 0.08	1.55 ± 0.06	1.50 ± 0.06	35.6 ± 1.23	72.0 ± 2.55[a]
	wool vs. hair[2]	—	—	—	—	−2.57 ± 1.99[ns]
Service sire breed	Suffolk	1.86 ± 0.04	1.47 ± 0.03[b]	1.42 ± 0.03[b]	32.8 ± 0.68	64.7 ± 1.33
	Texel	1.92 ± 0.04	1.57 ± 0.03[a]	1.51 ± 0.03[a]	33.9 ± 0.68	64.0 ± 1.33
Age, yr	1	1.36 ± 0.03[c]	1.01 ± 0.03[b]	0.97 ± 0.03[b]	21.2 ± 0.54[b]	40.0 ± 1.04[b]
	2	2.07 ± 0.04[b]	1.74 ± 0.03[a]	1.68 ± 0.03[a]	38.4 ± 0.72[a]	74.4 ± 1.52[a]
	3	2.23 ± 0.05[a]	1.80 ± 0.04[a]	1.75 ± 0.04[a]	40.5 ± 0.90[a]	78.6 ± 1.85[a]
Production system	Intensive	1.92 ± 0.04	1.59 ± 0.03[a]	1.53 ± 0.03[a]	36.4 ± 0.74[a]	70.1 ± 1.46[a]
	Extensive	1.86 ± 0.04	1.44 ± 0.03[b]	1.39 ± 0.03[b]	30.3 ± 0.69[b]	58.6 ± 1.37[b]

[1]LS_i, litter size per ewe exposed at parturition (0), 12, and 24 wk; LW_i, total litter weight per ewe exposed at 8 and 24 wk.
[2]Orthogonal contrast comparing least-squares means of wool (Dorset and Rambouillet) and hair (Katahdin, Dorper, and White Dorper) sire breeds was tested when the main effect of sire breed was significant.
[a–c]Means within a trait and effect with no common superscript are different ($P \leq 0.03$).
[ns]Orthogonal contrast of wool vs. hair sire breed is not significantly different from zero ($P = 0.20$).

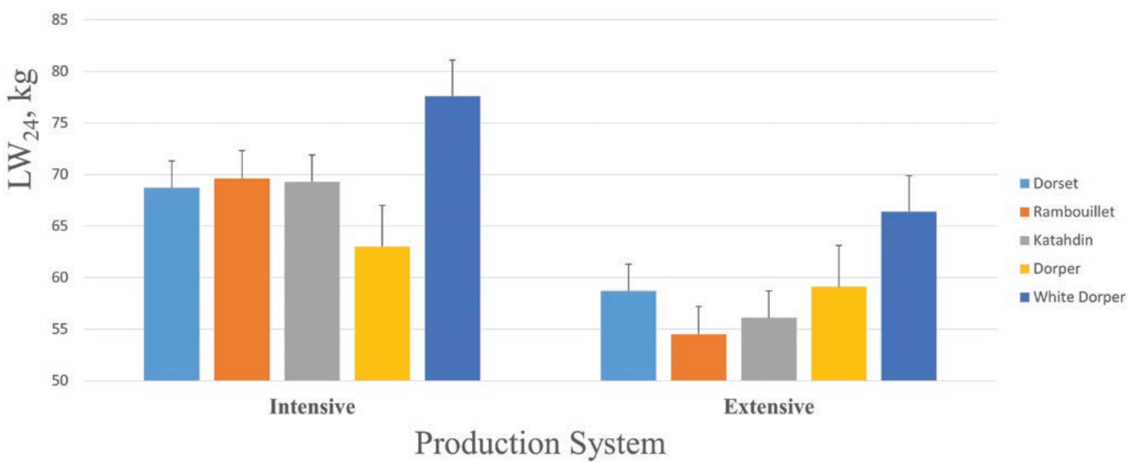

Figure 1. Annual lamb output measured as the least-squares means of LW_{24} for the production system × sire breed interaction effect. This trait would account for differences among crossbred ewe types in percentage of ewes lambing, number born, lamb survival, and lamb growth. The sire breed × production system interaction was not significant ($P = 0.68$), but both main effects were ($P \leq 0.02$).

of the number reared under these conditions are biologically constrained by the number born.

In the current experiment, we addressed this issue by evaluating high levels of prolificacy from five types of Romanov crossbred ewes lambing on pasture without human intervention, to identify crossbred types that were better able to balance prolificacy and maternal ability (behavior and milk production) to improve survival of twin- and triplet-born lambs. We were able to document in these 50% Romanov crossbred ewes across all ages of dam, that survival to 12 wk of age of twin-born lambs averaged 84% compared with 90% survival of single-born lambs under extensive conditions. This survival rate was comparable to the observed 86% and 96%, respectively, for twin- and single-born lambs in the intensive production system. Survival to 12 wk of age of triplet-born lambs averaged 64% for the extensive system compared with 77% for the intensive system. Of the 228 triplet litters produced in the extensive production system, 4.8%, 14.5%, 40.8%, and 39% consisted of 0, 1, 2, or 3 lambs at weaning, respectively.

The suitability of utilizing crossbred Romanov ewes for commercial operations will also be dependent on their ability to produce lambs that meet U.S. markets requirements. From 2014 to 2019, monthly average live weights of federally inspected lambs ranged from 56.8 to 64.9 kg (USDA ERS, 2019). Terminally crossed lambs in the present study were substantially lighter at 24 wk (43.8 ± 7.8 kg) and would likely not capture carcass weight premiums of the traditional market. Nevertheless, such lambs would fit the expanding nontraditional ethnic market as these consumers generally prefer much lighter lambs (Stepanek Shiflett et al., 2010). The Suffolk continues to be the prominent terminal sire in commercial U.S. sheep production and outperformed the Texel in postweaning growth (30 to 38 g/d) in the present study. This agrees with others that have reported greater growth through finishing in Suffolk- compared with Texel-sired lambs (Scales et al., 2000; Leeds et al., 2012; Notter et al., 2012). However, Texel-sired lambs have displayed advantages in certain carcass characteristics (Leymaster and Jenkins, 1993; Kremer et al., 2004). Furthermore, Texel-sired lambs had greater survival in the present study, which offset the growth advantages of Suffolk-sired lambs so that no service sire differences were observed on a litter weight per ewe exposed basis. Therefore, the choice of terminal sire breed could be another management tool for producers to meet the demands of their specific marketing channel.

Performance data collected from the current experiment are somewhat lower than the crossbred Romanov ewe performance reported in Casas et al. (2004). Although both experiments have in common an evaluation of 50% Romanov ewes, individual breed contributions, management systems, and BW end-point differences existed that limit direct comparisons of mean values. In the previous experiment, Casas et al. (2004) reported the number of lambs born per ewe lambing was 2.35 from October breeding and 2.18 from December breeding. Total productivity of dam-reared lambs was nearly 156 kg per ewe over 3 yr of production but was measured at 20 wk of age for lambs produced rather than 24 wk as in the current experiment. Total productivity for 3 yr of lambs marketed in the current experiment averaged 210 kg per ewe in the intensive and 176 kg per ewe in the extensive systems (extrapolated from Table 8).

It was somewhat surprising that no interaction of sire breeds with the production system for total productivity was observed (Table 6). While all of the half-Romanov crossbred ewe types were productive, the White Dorper × Romanov cross had excelled in both systems (Figures 1). The advantage of this particular crossbred type of ewe was numerically greater than any difference observed between wool or other hair crosses that all performed similarly to each other in intensive and extensive systems. The designed experiment originally sampled 18 rams equally representing White Dorper and Dorper genetics (n = 9 rams each) with the intent of having one Dorper breed group to compare with Dorset, Rambouillet, and Katahdin breeds. Subsequently, splitting the two Dorper variants left one half the number of F1 ewes in each of those two breed groups and created larger standard errors in those two samples compared with the other three breed groups, which impacted statistical comparisons for total ewe productivity traits.

The Dorper and White Dorper populations were created in the late 1930s and into the 1940s in South Africa in response to a need to create a relatively easy care sheep with an acceptable meat carcass under demanding conditions of low rainfall areas of the Northern Province (Milne, 2000). The crossing of Dorset Horn with local Persian breeds was one of the initial attempts to determine the proportion of British mutton breeds that could be introduced without losing the hardiness of the indigenous breeds. The first crosses between Persian and Dorset Horn were mostly spotted but there were also white lambs. Additional germplasm from Round-ribbed Afrikaner was also involved, and it appears that a breeder with a particular focus on the white color variant utilized Van Rooy breed genetics to build up the numbers of White Dorper. It is likely that these contributing breed differences are associated with the conclusions from the current experiment that those two populations are different in performance.

Experimental comparison of F1 ewes from five different sire breeds in this experiment provides information to help producers increase levels of prolificacy under various extensive production systems. While any combination of half-Romanov ewe would increase the overall ewe productivity in most of the commercial settings, we did generate evidence of the superiority of White Dorper complementing the Romanov under both intensive and extensive production systems. This combination provided an advantage in the overall heterosis of the crossbred ewe for traits likely important to taking full advantage of these higher levels of prolificacy. The solution to improving lamb survival and increasing ewe productivity while minimizing human intervention lies in using specific genetic resources that are well adapted to extensive, pasture-lambing production systems.

Acknowledgments

The mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer. We acknowledge Kreg A. Leymaster (retired) who provided the primary leadership for conceiving, designing, and conducting this experiment. We also acknowledge Stephanie Schmidt for assistance with manuscript preparation and the U. S. Meat Animal Research Center (USMARC) sheep operations for animal husbandry.

Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

Literature Cited

Alemseged, Y., and R. B. Hacker. 2014. Introduction of Dorper sheep into Australian rangelands: implications for production and natural resource management. *Rangeland J.* **36**:85–90. doi:10.1071/RJ13034

American Sheep Industry Association, Inc. 2016. U.S. Sheep industry research, development, and education priorities. ASI website. Available from http://www.sheepusa.org/Resources_Publications_ResearchEducationPriorities2016. Accessed October 1, 2020

Burfening, P. J., S. D. Kachman, K. J. Hanford, and D. Rossi. 1993. Selection for reproductive rate in Rambouillet sheep: estimated genetic change in reproductive rate. *Small Rum. Res.* **10**:317–330. doi:10.1016/0921-4488(93)90136-6

Casas, E., B. A. Freking, and K. A. Leymaster. 2004. Evaluation of Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep. II. Reproduction of F1 ewes in fall mating seasons. *J. Anim. Sci.* **82**:1280–1289. doi:10.2527/2004.8251280x

Casas, E., B. A. Freking, and K. A. Leymaster. 2005. Evaluation of Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep: V. Reproduction of F1 ewes in spring mating seasons. *J. Anim. Sci.* **83**:2743–2751. doi:10.2527/2005.83122743x

FASS. 1999. *Guide for the care and use of agricultural animals in agricultural research and teaching*. 1st rev. ed. Savoy (IL): Federation of Animal Science Societies.

Freking, B. A., and G. L. Bennett. 2019. Rambouillet and Romanov reciprocal breed effects on survival and growth traits of F1 lambs and on reproductive traits of F1 ewes. *J. Anim. Sci.* **97**:578–586. doi:10.1093/jas/sky474

Freking, B. A., and K. A. Leymaster. 2004. Evaluation of Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep: IV. Survival, growth, and carcass traits of F1 lambs. *J. Anim. Sci.* **82**:3144–3153. doi:10.2527/2004.82113144x

Heaton, M. P., T. P. L. Smith, B. A. Freking, A. M. Workman, G. L. Bennett, J. K. Carnahan, and T. S. Kalbfleisch. 2017. Using sheep genomes from diverse U.S. breeds to identify missense variants in genes affecting fecundity. *F1000Res.* **6**:1303. doi:10.12688/f1000research.12216.1

Juengel, J. L., G. H. Davis, R. Wheeler, K. G. Dodds, and P. D. Johnstone. 2018. Factors affecting differences between birth weight of littermates (BWTD) and the effects of BWTD on lamb performance. *Anim. Reprod. Sci.* **191**:34–43. doi:10.1016/j.anireprosci.2018.02.002

Kenyon, P. R., F. J. Roca Fraga, S. Blumer, and A. N. Thompson. 2019. Triplet lambs and their dams—a review of current knowledge and management systems. *N. Zeal. J. Agric. Res.* **62**:399–437. doi:10.1080/00288233.2019.1616568

Kremer, R., G. Barbato, L. Castro, L. Rista, L. Rosés, V. Herrera, and V. Neirotti. 2004. Effect of sire breed, year, sex, and weight on carcass characteristics of lambs. *Small Rum. Res.* **53**:117–124. doi:10.1016/j.smallrumres.2003.09.002

Leeds, T. D., D. R. Notter, K. A. Leymaster, M. R. Mousel, and G. S. Lewis. 2012. Evaluation of Columbia, USMARC-Composite, Suffolk, and Texel rams as terminal sires in an extensive rangeland production system: I. Ewe productivity and crossbred lamb survival and preweaning growth. *J. Anim. Sci.* **90**:2931–2940. doi:10.2527/jas.2011-4640

Leymaster, K. A., and T. G. Jenkins. 1993. Comparison of Texel- and Suffolk-sired crossbred lambs for survival, growth, and compositional traits. *J. Anim. Sci.* **71**:859–869. doi:10.2527/1993.714859x

Milne, C. 2000. The history of the Dorper sheep. *Small Rumin. Res.* **36**:99–102. doi:10.1016/s0921-4488(99)00154-6

Murphy, T. W., W. C. Stewart, D. R. Notter, M. R. Mousel, G. S. Lewis, and J. B. Taylor. 2019. Evaluation of Rambouillet, Polypay, and Romanov-White Dorper × Rambouillet ewes mated to terminal sires in an extensive rangeland production system: body weight and wool characteristics. *J. Anim. Sci.* **97**:1568–1577. doi:10.1093/jas/skz070

NAHMS. 2011. Sheep 2011 Part IV. Changes in Health and Production Practices in the U.S. Sheep Industry, 1996-2011. Available from www.aphis.usda.gov/animal_health/nahms/sheep/downloads/sheep11/Sheep11_dr_PartIV.pdf.

Notter, D. R. 1999. Potential for hair sheep in the United States. *J. Anim. Sci.* **77**(E-Suppl.):1–8. doi:10.2527/jas2000.77E-Suppl1h

Notter, D. R., T. D. Leeds, M. R. Mousel, J. B. Taylor, D. P. Kirschten, and G. S. Lewis. 2012. Evaluation of Columbia, USMARC-composite, Suffolk, and Texel rams as terminal sires in an extensive rangeland production system: II. Postweaning growth and ultrasonic measures of composition for lambs fed a high-energy feedlot diet. *J. Anim. Sci.* **90**:2941–2952. doi:10.2527/jas.2011-4641

Notter, D. R., M. R. Mousel, T. D. Leeds, G. S. Lewis, and J. B. Taylor. 2018. Effects of rearing triplet lambs on ewe productivity, lamb survival and performance, and future ewe performance. *J. Anim. Sci.* **96**:4944–4958. doi:10.1093/jas/sky364

Notter, D. R., M. R. Mousel, G. S. Lewis, K. A. Leymaster, and J. B. Taylor. 2017. Evaluation of Rambouillet, Polypay, and Romanov-White Dorper × Rambouillet ewes mated to terminal sires in an extensive rangeland production system: lamb production. *J. Anim. Sci.* **95**:3851–3862. doi:10.2527/jas2017.1619

Fahmy, M. H., editor. 1996. *Prolific sheep*. Wallingford (UK): CAB International.

Scales, G. H., A. R. Bray, D. B. Baird, D. O′Connell, and T. L. Knight. 2000. Effect of sire breed on growth, carcass, and wool characteristics of lambs born to Merino ewes in New Zealand. *N. Zeal. J. Agric. Res.* **43**:93–100. doi:10.1080/00288233.2000.9513412

Stepanek Shiflett, J., G. W. Williams, and P. Rodgers. 2010. The nontraditional lamb market: characteristics and marketing strategies. Agribusiness, Food, and Consumer Economics Research Center. Commodity Market Research Report No. CM-02-10. Available from http://afcerc.tamu.edu/publications/Publication-PDFs/CM-02-10%20Nontraditional%20Lamb%20Market%20Study-TCG2_FINAL.pdf. Accessed October 1, 2020

U.S. Department of Agriculture Economic Research Service (USDA ERS). 2019. Livestock & meat domestic data. [accessed September 26, 2019]. Available from https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/livestock-meat-domestic-data/#Livestock%20and%20poultry%20live%20and%20dressed%20weights

U.S. Department of Agriculture Economics, Statistics, & Cooperative Service (USDA ESCS). 1979. Sheep and goats. [accessed August 1, 2019]. Available from https://downloads.usda.library.cornell.edu/usda-esmis/files/000000018/2n49t433j/h989r580z/SheeGoat-01-26-1979.pdf

U.S. Department of Agriculture National Agricultural Statistics Service (USDA NASS). 2019. Sheep and goats. [accessed August 1, 2019]. Available from https://downloads.usda.library.cornell.edu/usda-esmis/files/000000018/np193h05c/4t64gt965/shep0219.pdf

Walker, J. W., H. A. Glimp, S. L. Kronberg, and T. R. Kellom. 1993. When less may mean more: studies on range versus shed lambing in a cold desert shrub ecosystem. *Prof. Anim. Sci.* **9**:153–158. doi:10.15232/S1080-7446(15)32083-0

Wang, C. T., and G. E. Dickerson. 1991a. A deterministic computer simulation model of life-cycle lamb and wool production. *J. Anim. Sci.* **69**:4312–4323. doi:10.2527/1991.69114312x

Wang, C. T., and G. E. Dickerson. 1991b. Simulated effects of reproductive performance on life-cycle efficiency of lamb and wool production at three lambing intervals. *J. Anim. Sci.* **69**:4338–4347. doi:10.2527/1991.69114338x

Wang, C. T., and G. E. Dickerson. 1991c. Simulation of life-cycle efficiency of lamb and wool production for genetic levels of component traits and alternative management options. *J. Anim. Sci.* **69**:4324–4337. doi:10.2527/1991.69114324x