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Research Notes

Technical Note

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Advantages of Multispecies Grazing: Perceptions of Idaho and Wyoming Producers

Kitri Falxa[1], Larry W. Van Tassell[2,4], and John P. Hewlett[3]

Summary

This study reports findings of a survey aimed at examining whether complementarity in sheep and cattle production is recognized by producers and is an important factor in the maintenance of both enterprises by ranchers in Idaho and Wyoming. Over 80% of respondents felt their cattle and sheep enterprises had some degree of integration and complemented one another. This complementarity was created by the dietary selection, grazing behavior and the social structure of sheep and cattle. While the sheep enterprise was the most labor intensive, labor and equipment requirements of the two enterprises were seen as being complementary. Profitability and cash flow additionally were aided by the diversification provided from maintaining both a sheep and cattle enterprise. The majority of producers felt that fluctuations in prices and production between sheep and cattle enterprises were somewhat offsetting. While 70% of respondents felt sheep had been historically more profitable than cattle, more respondents assigned a higher probability that they would abandon the sheep business before the cattle business because of recent trends in the industry.

Key Words: Survey, Multispecies grazing, Complementary products, Diversification.

Introduction

When grazing the same rangeland, sheep and cattle have been shown to exhibit complementary, supplementary and competitive relationships depending upon the stocking ratios of the two species and the type of rangeland involved. A competitive relationship implies that cattle and sheep will compete with each other for limited resources while a supplementary relationship exists when one species can be added to the grazing mix without decreasing the stocking rate of the other species. A complementary relationship evolves when adding one species to the grazing mix will result in also being able to increase the stocking rate of the original species. To demonstrate these relationships, assume a producer has 5,000 acres that can be grazed. Figure 1 contains a hypothetical production possibilities curve that shows different combinations of sheep and cattle that can graze on the 5,000 acres. If only sheep graze the forage, Figure 1 depicts that 1,000 ewes can be maintained. If only cattle graze the forage, Figure 1 assumes that 200 cows can be supported. A supplementary relationship exists when the range is stocked at the maximum to accommodate one species and the other species can be added to the range without decreasing the stocking rate of the original species (Supplementary Region). As numbers of the added species are increased, the two species begin to compete for resources and the supplementary relationship evolves into a competitive relationship (Competitive Region). Under the competitive relationship, numbers of one species cannot be increased without decreasing numbers of the competing species. The curvature of the line in the competitive region also indicates diminishing returns. After a certain point, as more of one species is added, they displace more of the other species (i.e., competition for the resource gets more intense).

A complementary relationship is demonstrated in Figure 2 (Complementary Region). If the range is stocked at the maximum to accommodate one species and

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Figure 1. Hypothetical production possibilities frontier for cattle and sheep showing supplementary and competitve regions.

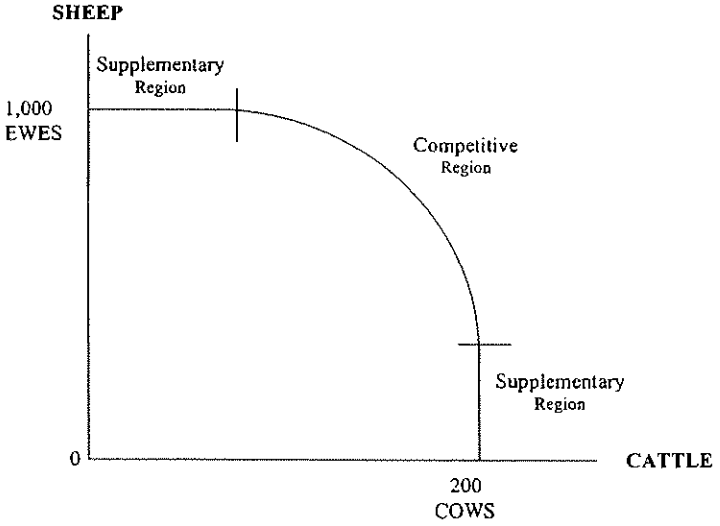
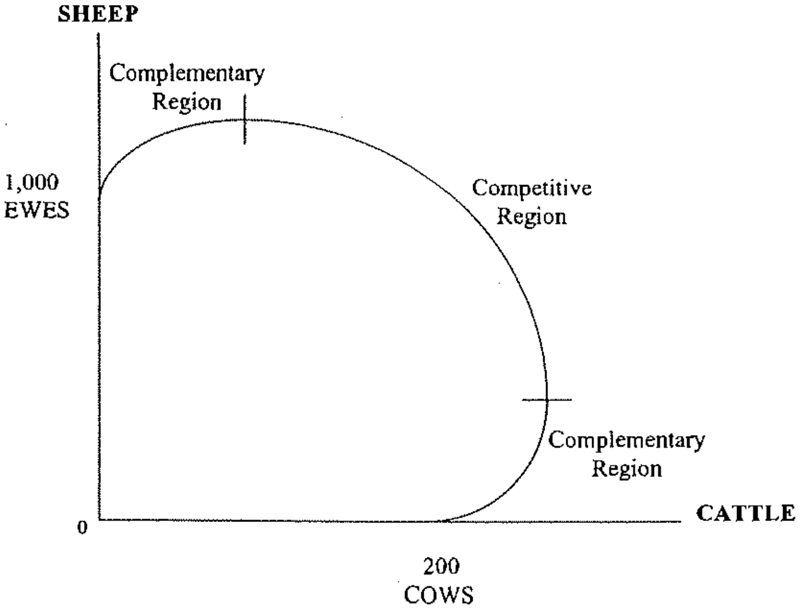


Figure 2. Hypothetical production possibilities frontier for cattle and sheep showing complementary and competitve regions.



another species is added to the range, the stocking rate (or production level) of the original species can be concurrently increased. This relationship will eventually evolve into a competitive relationship as additional numbers are added and the two species compete for scarce resources. These relationships typically exist because cattle and sheep display different dietary selection, grazing behavior, and social structure (Jarman, 1974; Schwartz and Ellis, 1981; Hanley and Hanley, 1982). On many ranches, two to three sheep can be added per cow without decreasing cattle numbers (Hulet et al., 1992a). The scientific literature is full of experimental studies where researchers have found complementary and supplementary relationships between cattle and sheep. For example:

- Van Dyne et al. (1980) summarized over 200 studies and concluded that sheep and cattle, respectively, consume 50 and 70% grass, 30 and 15% forbs, and 20 and 15% browse. Sheep and cattle overlap least in the spring (55%) and most in the summer and fall (75%) as grasses take dietary place of forbs for sheep due to defoliation of leaves (Walker, 1994).
- Topography is another consideration of livestock selectivity. Sheep can access forages on rough terrain, ridges, and steep slopes more easily than cattle (Rector, 1983).
- Increased efficiency from grazing different types of animals occurs when one species increases accessibility of high quality plant regrowth for consumption by a second species (Rector, 1983). Animal production and performance concurrently improves (Esmail, 1991).
- Sheep will consume weeds and forage near dung that cattle will not, thereby increasing total available feed (Abaye et al., 1993).
- The anatomical structure of the mouth allows sheep to graze closer to the soil surface and be more selective in their grazing preference than cattle (Walker, 1994).
- The production level of sheep, and at times cattle, has been shown to increase when social bonds have been developed between cattle and sheep, and they are grazed jointly (Hulet et al., 1992b; Abaye et al., 1993; Arnold, 1985; Esmail, 1991; Walker, 1994).
- Multispecies grazing may help control internal parasites, because stocking rate per species decreases thereby decreasing overall contamination. Cross-immunity between sheep and cattle also helps control gastrointestinal parasites. If one species ingests a host specific parasite of another species, it stimulates their own immune response to challenge their own parasite species (Esmail, 1991).

As shown in the literature, certain supplementary or complementary relationships are developed between cattle and sheep whether the two species simultaneously or alternately graze the same rangeland. Gee and Magleby (1976) found that two-thirds of sheep producers in the United States also raise cattle. They did not specify if the livestock species graze together or if any supplementary or complementary relationships were underlying reasons for simultaneously producing sheep and cattle.

This study was undertaken to examine the perceptions of sheep producers in Idaho and Wyoming regarding the complementarities of producing cattle and sheep on the same ranching operation to determine the major sources of the complementarities. The term complementary will be used in this study to describe both supplementary and complementary relationships.

Figure 3. Respondents' (sheep only and multispecies producers) estimation of the probablility that they will still be in the sheep or cattle business in 10 years.

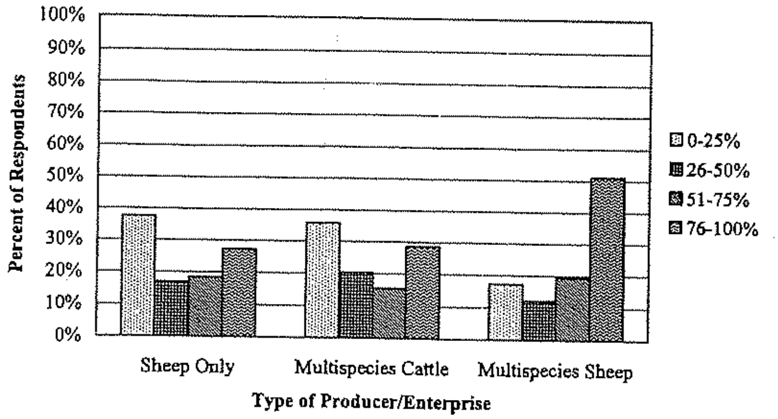
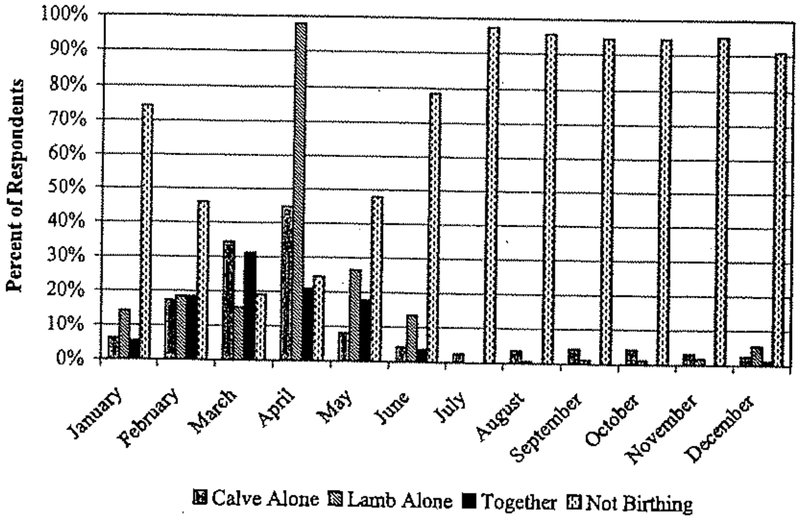


Figure 4. Respondents timing of lambing and calving by month.



Materials and Methods

A survey of Idaho and Wyoming sheep producers was conducted during the winter/spring of 2000. Wyoming currently ranks 2nd nationally in number of breeding sheep and 3rd in number of all sheep and 4th in the number of market sheep and lambs (NASS, 1999). Idaho ranks 8th nationally in number of breeding sheep, 8th in number of all sheep and 10th in the number of market sheep and lambs (NASS, 1999).

The survey instrument was used to obtain information regarding ranch size and resources, relative profitability of sheep and cattle enterprises, perceptions of producers, grazing management strategies, and complementarities of producing both sheep and cattle.

Surveys were mailed during February 2000. A reminder post card was sent two weeks later, followed by a second mailing of the survey four weeks after the original survey mailing. Budget constraints did not permit a telephone follow-up to determine producer bias.

Members of the Wyoming and Idaho Wool Growers Associations constituted the survey population. Each association provided names and addresses of member sheep producers. Most non-producers such as 4-H clubs, FFA clubs, and agricultural extension offices were deleted from the survey population.

Results and Discussion

Respondent and Resource Characteristics

Out of 815 individuals surveyed, 406 responded, for a 49.8% response rate. Of the 406 respondents, 69 were eliminated from the statistical analysis because they had retired and sold their operation, had received duplicate surveys, were feedlot operators, or no longer raised sheep. Of the remaining 337 completed surveys, 189 respondents produced sheep and cattle, and 142 produced sheep only. Twenty-nine percent of the sheep-only producers had previously owned cattle.

Table 1. Reasons producers gave for favoring cattle over sheep or sheep over cattle if they were required to liquidate one of the enterprises.[a]

Reasons for Keeping Cattle	% Respondents	Reasons for Keeping Sheep	% Respondents
Fewer predator problems	85	Matches my management expertise	68
Better outlook for the industry	62	Personal preference	68
More available markets	57	Ease of handling	65
Easier to get labor	37	Our traditional operation	62
Ease of handling	31	Better cash flow	41
Better profitability	26	Better profitability	34
Better cash flow	24	Fewer environmental concerns	22
Matches my management expertise	23	More available markets	9
Our traditional operation	20	Better outlook for the industry	8
Fewer environmental concerns	14	Easier to get labor	8
Personal preference	11	Fewer predator problems	3

[a] Fifty-five percent of respondents stated that if they were required to liquidate one enterprise, they would liquidate the sheep enterprise. Forty-five percent stated they would liquidate their cattle enterprise.

Table 2. Respondents' perceptions regarding how well cattle and sheep enterprises complement one another.

Issue	Strongly Agree	Agree	Neutral	Strongly Disagree	Disagree
			%		
A. Cattle and sheep are run as separate operations and do not complement each other.	2	1	10	33	**45**
B. Cattle and sheep complement each other by the way they graze our terrain.	42	**43**	12	2	0
C. Cattle and sheep complement each other by their selection of grazed forages.	42	**46**	10	2	0
D. Sheep reduce noxious weeds on our operation.	29	**51**	15	5	14
E. Sheep grazing before or with cattle reduces poisonous plant toxicity in our cattle.	13	24	**54**	8	1
F. Sheep grazing with cattle reduces sheep predator losses.	7	24	**31**	23	14
G. Running both cattle and sheep helps diversify income because when prices are low for one, they are usually higher for the other.	34	**45**	17	4	0
H. Running both cattle and sheep helps diversify our income because when production is down for one enterprise, it is usually up for the other.	19	33	**36**	9	2
I. Running both cattle and sheep helps our cash flow, because we market their products at different times.	18	**50**	23	8	1
J. Running both saves on expenses, because equipment needs overlap.	16	**55**	19	8	2
K. Running both saves on expenses, because labor needs overlap.	14	**54**	24	7	1
L. Running both saves on expenses, because facility needs overlap.	13	**46**	27	11	3

Respondents indicated they have been producing livestock for an average of 40 years. Sheep only producers tended to have smaller flocks (603 ewe average) compared to producers who ran both cattle and sheep (1,465 ewe average). The average beef cattle inventory for multispecies producers (had both cattle and sheep) was 236 beef cows. Over 95%

of producers indicated they also maintained a yearling enterprise and/or a feeder lamb enterprise. For multispecies producers, cattle comprised an average of 52% of their AUM mix.

Much of the grazing occurred on non-irrigated pasture. Sheep only producers grazed an average of 8,010 acres of non-irrigated rangeland and 68 acres of irrigated forage while using 330 AUMs of crop aftermath. They also leased an average of 210 AUMs from their respective State Land Board. Multispecies producers were typically larger operations with an average of 20,491 acres of non-irrigated rangeland, 192 acres of irrigated forage and 376 AUMs of crop aftermath. State leases accounted for 477 AUMs of their forage.

Federal lands were important forage contributors to many of the operations. Fifty-one percent of the multispecies ranchers used Bureau of Land Management (BLM) lands for an average of 2,047 AUMs while 16% of sheep only producers maintained a BLM lease for an average of 1,982 AUMs. United States Forest Service (USFS) leases were operated by 31% of multispecies producers (1,033 AUM average) and by 15% of sheep only producers (846 AUM average).

Many producers raised hay (66% of respondents) and some small grains (36% of respondents). In addition, 19% of the producers stated they raised some other type of crop.

Profitability

When asked which was their most profitable enterprise on average, cattle or sheep, 70% of respondents stated sheep were more profitable. Some respondents wrote that cattle are presently more profitable, but that sheep were more profitable before the Wool Incentive Program ended and before predators became a major hindrance.

Figure 5. Total amount of time by month spent with the cattle, sheep and other enterprises.

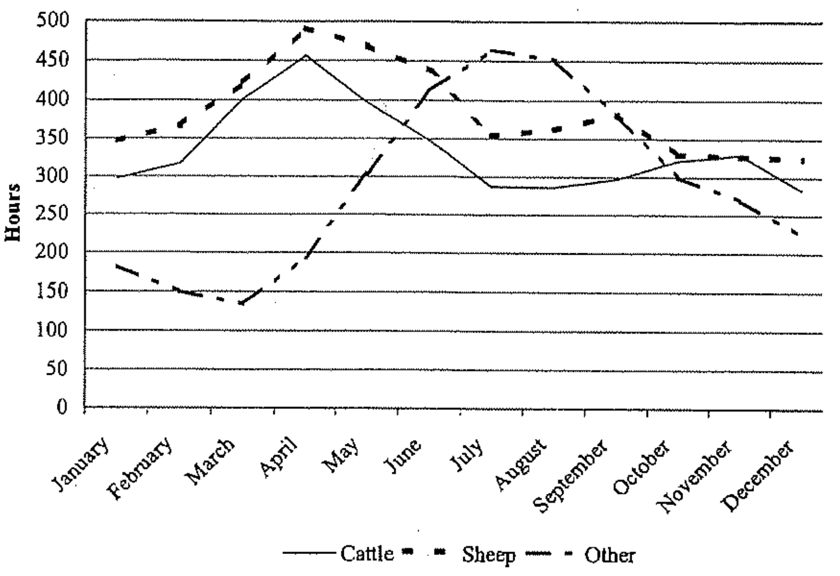
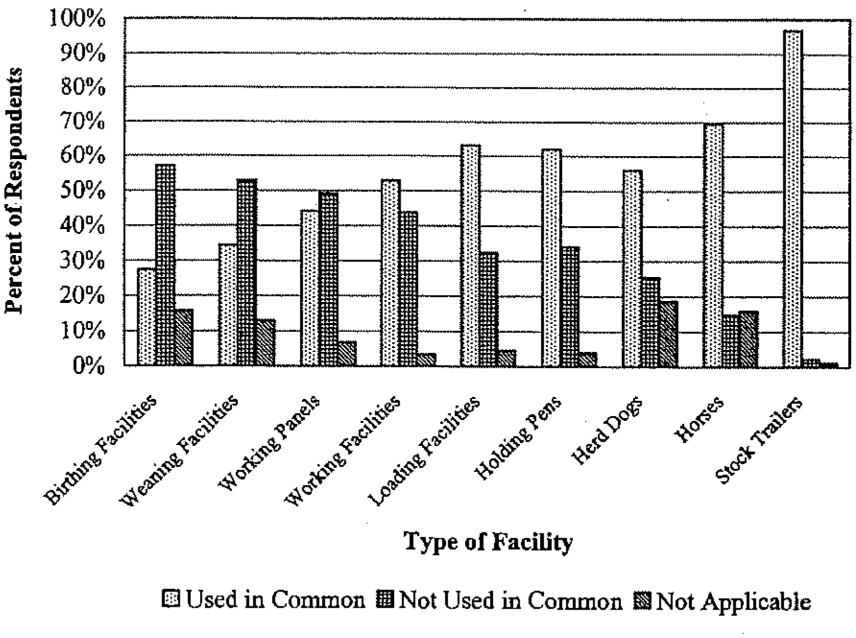


Figure 6. The percent of time facility and equipment are used in common by the cattle and sheep enterprises.



Respondents were asked to state the probability that they would still be in the sheep or cattle business 10 years from now. They were given categories of 0% to 25%, 26% to 50%, 51% to 75% and 76% to 100% probability. Responses were quite similar with respect to sheep enterprises for both sheep only and multispecies producers (Figure 3). Nearly 40% of producers felt there was a low (0% to 25%) probability they would still be in the sheep business 10 years from now. Just under 30 percent felt confident they would remain in business (75% to 100% probability). Conversely, over 50% of the multispecies producers assigned a 75% to 100% probability they would still be in the cattle business in 10 years and less than 20% gave a 0% to 25% probability of being in the cattle business.

Table 3. Respondents' average labor allocations per month by percentage of total hours.[1]

Month	Cattle	Sheep	Other
		%	
January	36	**42**	22
February	38	**44**	18
March	42	**44**	14
April	40	**43**	17
May	34	**40**	26
June	29	**37**	34
July	26	32	**42**
August	26	33	**41**
September	28	**36**	**36**
October	34	**35**	31
November	**36**	35	29
December	34	**39**	27

[1]Highest labor allocations per month are in bold.

Sheep producers, additionally, were asked to approximate their break-even lamb price at weaning. The average break-even lamb price at weaning was $0.73/pound with a range of $0.43/pound to $0.97/pound. There was a slight difference in the break-even price between sheep only producers ($0.74/pound) and multispecies producers ($0.72/pound).

Producers appeared to have more economic reasons for raising cattle but had more sentimental reasons for raising sheep. Fifty-five percent of respondents stated they would choose cattle over sheep if required to liquidate one of their enterprises. The main reasons for choosing cattle were fewer predator problems, better industry outlook, and more available markets (Table 1). Additional comments offered by respondents as to why they would keep their cattle enterprise included: less theft; less labor, time, and management involved; no shearing involved; fewer BLM problems; and their federal grazing permits are only for cattle. The top four reasons given by producers who would choose to liquidate their cattle enterprise were: sheep production matched their management expertise; sheep were a personal preferences; sheep were easier to handle; and sheep production was their more traditional enterprise.

Additional reasons offered by producers for favoring sheep over cattle included: fewer health problems; less "outside" help needed; the ability of sheep to control weeds and brush; better use of range resources; sheep are better suited to their range/pasture; sheep are a "superior grass fed product"; their federal grazing permits are only for sheep and can not be changed; and "we are sheep people".

Multispecies Grazing

Respondents stated that 53% of their grazing land was used in common by cattle and sheep. The amount of grazing land used in common ranged from a low of 20% to a high of 100%.

The majority of respondents (63%) stated that sheep and cattle graze together at least part of the year. When grazing together, the cow-to-sheep ratio averaged 1:10. The cow-to-sheep ratios most frequently used by respondents were 1:5 (35% of respondents) and 1:10 (15% of respondents). Eleven percent of respondents stated their cow-to-sheep ratio was less than 1:1 (i.e., more than one cow per ewe).

Reasons offered by respondents regarding why they graze cattle and sheep together included: they utilize different forages; it is more economical to winter feed in the same area; they like each other; for convenience; limited land; predator control; and good range management. Reasons offered by respondents for not having their cattle and sheep graze together evolved around problems regarding nonbonding of the two species, lack of sheep fencing, and supplementation (copper) needed for the cattle was toxic to sheep.

Many of the respondents stated their sheep and cattle were grazed on the same land but at different times. When this occurred, 54% of respondents stated they had sheep graze first followed by cattle, while 46% stated they had cattle graze first. The main reason listed by producers for grazing sheep first was that sheep prefer or need young and short spring forage while cattle can cleanup older grasses. Other reasons included: sheep eat and trample noxious weeds before cattle are turned out; ewes are flushed on alfalfa aftermath before breeding; better livestock gains occurred when sheep have first pick; and "this best fits our resources". Reasons respondents offered for why they have cattle graze first were: sheep clean up what cattle will not eat; sheep will eat the forage down lower; cattle graze down tall, rank plants; reduces sheep bloat; fits their rotational plan; sheep will graze creek bottoms after flies leave; sheep will utilize the browse; and "cattle need first choice of forage since sheep can survive on anything".

Complementarity Between Cattle and Sheep

To examine multispecies producers' perceptions regarding how well sheep and cattle enterprises complement one another, respondents were asked to state whether they strongly agreed (SA), agreed (A), were neutral (N), disagreed (D), or strongly disagreed (SD) with 12 statements regarding the complementarity of cattle and sheep (Table 2). Almost half (45%) of the survey respondents strongly disagreed and 33% disagreed that cattle and sheep were run as separate enterprises on their operation and did not complement each other. Respondents either agreed or strongly agreed that both species complement each other by the way they graze terrain (85%) and by their selection of forages grazed (88%). Eighty percent of respondents strongly agreed or agreed that sheep reduced noxious weeds, but the majority (54%) were indifferent as to whether sheep grazing reduced poisonous plant toxicity in their cattle. Respondents were likewise indifferent as to whether sheep grazing with cattle reduced sheep predator losses, with 31% of respondents on the agree side, 37% on the disagree side, and 31% being neutral.

Theoretically, one of the main reasons for diversifying enterprises is to reduce price and production risks. Price and production will ideally be reduced if income streams from the two enterprises move in opposite directions during a given time period (i.e., are negatively correlated). When asked how sheep and cattle enterprises aid in diversifying income, 79% of respondents agreed or strongly agreed that when prices are low for one enterprise, they are usually high for the other. The majority of respondents (53%) likewise agreed that fluctuations in production between sheep and cattle enterprises were generally offsetting. With respect to cash flow considerations, 71% of respondents felt that the ability to market sheep and cattle products at different times of the year aided their cash flow situation. In most cases, respondents also agreed or strongly agreed their operating expenses were reduced because equipment needs, labor requirements, and facility needs of their cattle and sheep enterprises overlapped.

Several respondents added additional reasons why they maintain both sheep and cattle enterprises. These reasons dealt with issues such as banks would only lend money for cattle expansion, sheep better utilize winter pastures because they can effectively use snow as a water source, cattle can graze the remote parts of the ranch without hindrance from predators and greater carrying capacity of the land is obtained from using both enterprises equaled increased income.

To more thoroughly examine the complementarity of cattle and sheep enterprises with respect to labor, respondents were asked to state the months in which they lambed and calved. Producers were additionally asked to indicate the number of hours of labor that were available each month on the ranch and how those hours were allocated between sheep, cattle and other enterprises. As may be expected in the western U.S., most of the lambing and calving occurred in early spring (Figure 4). By far, April appeared to be the most opportune time for lambing or calving. Over 66% of respondents were lambing and/or calving three or more months out of the year.

Forty-five percent of respondents planned their lambing and calving so they did not overlap while 12% did all of their lambing and calving concurrently. Approximately 27% of respondents overlapped their lambing and calving by 1 month and 24% concurrently lambed and calved over a 2-month period. Concurrent lambing and calving occurred most frequently in March.

When total labor requirements were examined, more labor was expended on the sheep enterprise than cattle in all months except November (Figure 5 and Table 3). Sheep accounted for 32% to 44% of the monthly labor requirements of the whole ranch. Calving and lambing season required the greatest amount of labor followed by farming during the summer months. Other activities (e.g., farming) used the highest percentage the labor available in July and August.

The facilities required for beef and sheep production may or may not always be complementary between the two enterprises. Respondents were given a listing of assets that are typically found on cattle and sheep operations and were asked to state if they were used in common, not used in common, or were not applicable to their ranching operations. Approximately 50% to 60% of respondents used the same working facilities, loading facilities, holding pens, and herd dogs for both their sheep and cattle enterprises. Stock trailers were used most in common (97% of respondents) along with horses (70% of respondents). Separate birthing and weaning facilities were maintained for sheep and cattle by 57% and 53% of respondents, respectively.

Conclusions

Complementarity was found to play an important role in the maintenance of multispecies cattle and sheep operations in Idaho and Wyoming. Better utilization of forages appears to be a major reason why producers maintain both enterprises. While maintaining two separate livestock enterprises frequently requires additional investment in facilities and equipment, this overlap apparently is kept at a minimum with most producers. Sheep and cattle labor requirements additionally were considered to be complementary.

While minimal economic analysis has been conducted to determine the economic advantages of integrating a sheep and cattle enterprise, respondents perceived an economic advantage from diversification. Most producers felt cattle and sheep outputs and prices ran counter enough to diversify income and even out cash flows.

Despite the complementarity found between cattle and sheep enterprises, a continued reduction in sheep numbers is expected as nearly 40% of respondents stated there was a high probability (75% to 100%) they would not be in the sheep business 10 years from now. A better industry outlook, more available markets, fewer predator problems and less labor concerns were the major reasons producers picture a brighter future for the cattle industry.

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Prickle Factor in Fleeces of Performance-tested Fine-wool Rams[1,2]

C.J. Lupton[3,4], D.F. Waldron[3], and F.A. Pfeiffer[3]

Summary

Prickle factor (PF, % of fibers > than 30 µm) is an indicator of the relative comfort of wool fabrics worn next to the skin. Fiber diameter distributions were measured (with an Optical Fibre Diameter Analyser) in three consecutive years on core samples of unskirted fleeces from 524 fine-wool rams completing a central performance test. These measurements were used to establish PF, average fiber diameter (AFD), SD, and CV in fleeces produced under the unfavorable (from a wool fineness and uniformity perspective) test conditions and to determine relationships among PF and fiber fineness and variability. As part of the normal performance test routine, AFD, SD, and CV were measured on side and britch samples for each fleece. The AFD of side samples was used in the index of overall merit and AFD of side and britch samples constituted an independent rejection criteria for ram certification. Core sample PF, AFD, SD, and CV averaged 5.5%, 22.3 µm, 4.4 µm, and 20.0% and ranged from 0.4 to 25.3%, 17.3 to 26.8 µm, 3.1 to 6.4 µm, and 15.2 to 28.6%, respectively. The PF, SD, and CV did not differ among years ($P > 0.05$). It has been suggested that only wools having low PF (< 2%) be used in apparel worn next to the skin. Only eighteen percent of the fleeces were in this category. Stepwise multiple regression analysis was used to predict PF using all measured variables plus AFD squared (AFD^2) and differences between side and britch AFD resulted in core AFD^2, core AFD, britch SD, core SD, side CV, and core CV entering the equation. No other variable met the 0.01 significance level for entry into the model. Partial r^2 values for the first three variables were 0.82, 0.10, and 0.03, respectively. This result was essentially unchanged when fleeces (349) having core, side, and britch AFD > 23.6, 24.9, and 27.8 µm, respectively (i.e., from coarse, uncertifiable rams) were excluded from the analysis. Most of the variability in PF can be accounted for by core data alone, i.e., $PF = 199.57 + 0.46{*}AFD^2 - 19.33{*}AFD + 6.01{*}SD - 1.01{*}CV$, $r^2 = 0.94$.

Key Words: Prickle factor, Wool, Ram performance testing

Introduction

In a survey conducted in the U.S. several years ago (Margerum, 1984), 30% of consumers polled claimed to be allergic to wool while 70% considered wool to be too "scratchy" for apparel intended to be worn next to the skin. These types of perceptions caused wool researchers in Australia to focus on the causes of fabric prickle and attempt to quantify the effects and relative importance of fiber, yarn, and fabric properties on skin comfort. Because lightweight apparel is a potentially substantial and lucrative market for wool, numerous studies were initiated over the past 15 yr to try and understand this problem. Garnsworthy et al. (1985; 1988a and b) concluded that the prickle sensation (also referred to as "itchy" and "scratchy") experienced by some people when wearing some fabrics next to the skin is caused by a mechanical triggering of pain nerve sensors which are situated close to the surface of the skin. The nerves are triggered when stiff fiber ends exert a force > 0.00017lbf (75 mgf) on soft skin. When the mechanical stimuli (stiff fiber ends) are removed or reduced, the prickle problem disappears. Meticulous studies have shown that skin temperature and moisture, length of fiber protruding above the fabric surface, and fiber diameter (but not fiber type; Naylor, 1992 a and b) are key factors in causing prickle sensations (Mayfield, 1987;

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Kenins, 1992). Although the critical fiber diameter (26 to 32 μm) associated with skin discomfort is dependant to some degree on fabric type (worsted, woolen, woven, or knitted, etc.), percentage of fibers > 30μm, but not the distribution of these coarse fibers, is a reasonable indicator of the relative skin comfort of different wools (Naylor and Hansford, 1999).

Reducing the percentage of wool fibers > 30 μm (the coarse edge) in the diameter distribution will improve skin comfort or reduce discomfort. In principle, this can be achieved by reducing the average fiber diameter or by decreasing the distribution (coefficient of variation of fiber diameter) both options being possible in sheep selection programs. In some areas, time of shearing might also be adjusted to achieve a reduction in coarse fiber ends (Naylor and Hansford, 1999). Theoretically, zero fibers > 30 μm would be required for "absolute" skin comfort in fabrics worn next to the skin. In practice, < 5% of fibers > 30 μm in single jersey knitted fabrics has been found to reduce prickle intensity to a level that will not be perceived as skin discomfort by most (80 - 90%) people under normal conditions (Garnsworthy et al., 1988a; Naylor, 1992b). Some experienced fabric judges can consistently distinguish between fabrics containing 1 and 2% fibers > 30 μm (Naylor, 2000). Consequently, a lower level (2%) has also been suggested for ram selection (Lupton et al., 1999).

Because prickle factor has become so important to manufacturers of wool apparel, it is now reported in the annual central ram performance test (Waldron and Lupton, 2000). We began to study and measure prickle factor in ram fleeces in 1994 with the following objectives: 1) to determine PF in rams completing the test; 2) to establish mathematical relationships among PF and other fiber traits currently being measured; and 3) to determine if PF should be added to the index equation currently used to asses the overall merit of these fine-wool rams.

Materials and Methods

Side (S) and britch (B) samples shorn directly from the animals and 32 x ½-in core

Table 1. Means, variabilities, and ranges of measured traits (N=524) for all data.

Trait	MEAN	SD	MIN	MAX
Average fiber diameter, side, μm	23.6	1.9	17.8	29.6
SD of fiber diameter, side, μm	4.0	0.6	2.8	6.7
CV of fiber diameter, side, %	17.1	2.0	13.1	24.0
Average fiber diameter, britch, μm	26.6	2.4	19.4	36.3
SD of fiber diameter, britch, μm	5.0	1.1	3.1	9.9
CV of fiber diameter, britch, %	18.8	3.21	2.9	33.0
Average fiber diameter, core, μm[a]	22.3	1.5	17.3	26.8
SD of fiber diameter, core, μm	4.4	0.5	3.1	6.4
CV of fiber diameter, core, %	20.0	2.0	15.2	28.6
Prickle factor, %	5.5	4.3	0.4	25.3

[a] Core sample of unskirted whole fleece.

Table 2. Variation among years for several measures of fiber fineness and variability and prickle factor.

Trait	1994	1995	1996
Average fiber diameter, side, μm	23.7^{a}	23.3^{b}	23.9^{a}
SD of fiber diameter, side, μm	4.3^{a}	3.8^{c}	4.0^{b}
CV of fiber diameter, side, %	18.3^{a}	16.2^{c}	16.6^{b}
Average fiber diameter, britch, μm	27.0^{a}	26.2^{b}	$26.6^{a,b}$
SD of fiber diameter, britch, μm	5.7^{a}	4.5^{b}	4.7^{b}
CV of fiber diameter, britch, %	20.9^{a}	17.3^{b}	17.8^{b}
Average fiber diameter, core, μm	22.1^{b}	22.4^{a}	22.5^{a}
SD of fiber diameter, core, μm	4.4	4.5	4.4
CV of fiber diameter, core, %	20.0	20.0	19.8
Prickle factor, %	5.3	5.5	5.7
Britch - Side average fiber diameter, μm	3.3^{a}	3.0^{b}	2.6^{c}

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

samples (C) removed from the whole, unskirted fleeces of 524 rams completing the 1994 (201), 1995 (169), and 1996 (154) Texas Agricultural Experiment Station central performance tests were measured for average fiber diameter (AFD, µm), standard deviation of fiber diameter (SD, µm), coefficient of variation of fiber diameter (CV, %) and PF (core samples only; %) using an Optical Fibre Diameter Analyser (OFDA; Baxter et al., 1992). The GLM procedure of SAS (SAS, 1996) was used to identify differences in traits among years. Simple linear regression and stepwise multiple regression analyses were used to establish relationships among PF and the measured variables plus the square of AFD (AFD^2) and differences between britch AFD and side AFD.

Results and Discussion

Core sample prickle factor (PF), average fiber diameter (CAFD), standard deviation of fiber diameter (CSD), and coefficient of variation of fiber diameter (CCV) averaged 5.5 %, 22.3 µm, 4.4 im, and 20.0 % and ranged from .4 to 25.3 %, 17.3 to 26.8 µm, 3.1 to 6.4 µm, and 15.2 to 28.6 %, respectively (Table 1). The PF, CSD, and CCV did not differ among years ($P > 0.05$), though all other traits did (Table 2). Fifty eight percent of all fleeces tested contained PF < 5%. Eighteen percent of the fleeces were in the (highly desirable) low (<2%) PF category. These relatively small proportions can be partially attributed to the fleeces not being skirted and to the composition and quantity of the ram's test feed not being conducive to fine fiber production. Though this ram test was designed to measure the maximum genetic potentials of the rams (in terms of weight gain, wool production, fiber fineness, staple length, etc.), it is important to remember that yearling female offspring of these rams are typically 4 µm finer under range conditions (Waldron et al., 1998). As expected by virtue of its definition, prickle factor is significantly correlated with all 3 measures of AFD (core > side > britch) and with both measures of variability (SD > CV, Table 3). Stepwise multiple regression analysis for PF versus all measured variables plus CAFD squared ($CAFD^2$) and differences between side and britch AFD resulted in $CAFD^2$, CAFD, BSD, CSD, SCV, and CCV entering the equation (Table 4). No other variable met the 0.01 significance level for entry into the model. Partial r^2 values for the first three variables were 0.82, 0.10, and 0.03, respectively. Figure 1 shows the relationship between PF and $CAFD^2$.

Table 3. Correlation coefficients and probability values for prickle factor versus other traits.

Trait	r	P
Average fiber diameter, side, µm	0.80	0.0001
SD of fiber diameter, side, µm	0.56	0.0001
CV of fiber diameter, side, %	0.10	0.0183
Average fiber diameter, britch, µm	0.78	0.0001
SD of fiber diameter, britch, µm	0.55	0.0001
CV of fiber diameter, britch, %	0.25	0.0001
Average fiber diameter, core, µm	0.89	0.0001
SD of fiber diameter, core, µm	0.67	0.0001
CV of fiber diameter, core, %	-0.19	0.0001
Britch - side average fiber diameter, µm	0.25	0.0001

Table 4. Stepwise multiple regression analysis for prickle factor (all variables in model).

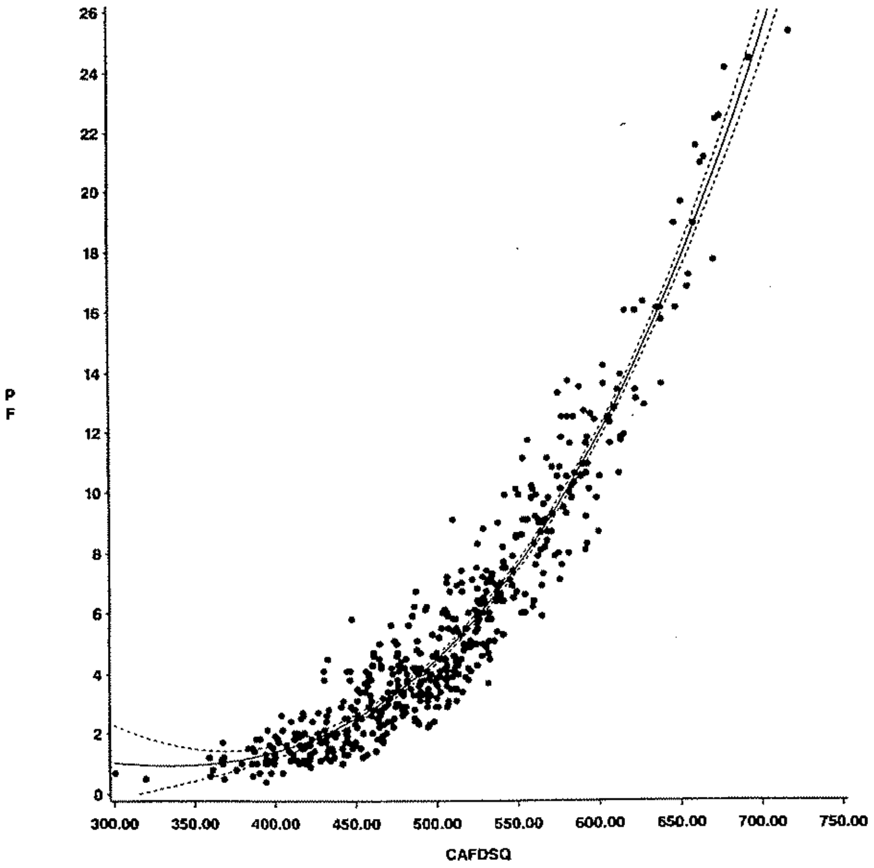
Trait	Partial r^2	P
Average fiber diameter, core, μm^2	0.8184	0.0001
Average fiber diameter, core, µm	0.1021	0.0001
SD of fiber diameter, britch, µm	0.0249	0.0001
SD of fiber diameter, core, µm	0.0121	0.0001
CV of fiber diameter, side, %	0.0023	0.0001
CV of fiber diameter, core, %	0.0007	0.0023
TOTAL	0.9605	—

Note: no other variable met the 0.01 significance level for entry into the model.

Table 5. Stepwise multiple regression analysis for prickle factor (core traits only in model).

Trait	PARTIAL r^2 (individual contributions)	MODEL r^2 (additive contribution)	P
Average fiber diameter, core, ìm^2	0.8184	0.8184	0.0001
Average fiber diameter, core, ìm	0.1021	0.9205	0.0001
SD of fiber diameter, core, ìm	0.0233	0.9438	0.0001
CV of fiber diameter, core, %	0.0012	0.9445	0.0009

Figure 1. Prickle factor (PF, %) versus the squared average fiber diameter of core samples (CAFDSQ, square microns)



This result was essentially unchanged when fleeces (349) having core, side, and britch AFD > 23.6, 24.9, and 27.8 µm, respectively (i.e., from coarse, uncertifiable Rambouillet rams) were excluded from the analysis. Most of the variability in PF can be accounted for by core data alone (Table 5).

i.e., $PF = 199.57 + 0.46*AFD^2 - 19.33*AFD + 6.01*SD - 1.01*CV, r^2 = 0.94$

Conclusions

1. About 92 % of the variability in PF can be accounted for by CAFD and CCV.
2. Because CAFD and CCV are currently used in the index equation for overall merit and since adding another trait would dilute the contributions of the existing traits, we concluded that PF should not be included into the index equation.

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U.S. Lamb Demand

Ted C. Schroeder, Rod J. Jerrick, Rodney Jones, and Clifford Spaeth*

Summary

Understanding major determinants of, and trends in consumer demand for lamb is critical for the industry to develop appropriate production and marketing strategies. Little research has empirically determined aggregate lamb demand. This study estimates a quarterly lamb demand model to assess major determinants over time. Per capita lamb consumption appears to be more responsive to lamb price than previous studies have concluded. When retail lamb price increases, comparable percentage declines in per capita consumption are likely. Beef is a significant substitute for lamb suggesting continued efforts to make lamb price competitive with other meats is important. Lamb demand tends to decline when consumer incomes and associated lifestyles change. This suggests that, in order to increase lamb demand, lamb products that are compatible with high-income consumer lifestyles are essential.

Key Words: Lamb demand, Demand index, U.S. lamb demand

Introduction

A major challenge facing the U.S. sheep industry is consumer demand for lamb. Purcell (1989) concluded that during the 1970-80 period, after accounting for changes in lamb and beef prices, per capita consumption of lamb declined significantly. Per capita consumption of lamb over time is illustrated in Figure 1. Lamb consumption has declined from about 3 lb. per person per year in the early 1970s to just over 1 lb. per person in the late 1990s. Although consumption changes do not necessarily demonstrate demand changes, the graph nonetheless illustrates the dramatic reduction in lamb consumption over time. Recently, U.S. policy makers have enacted programs to try to reverse the trend of declining lamb demand, including earmarking $5 million annually to develop and promote lamb products to increase demand. This is part of an overall $100 million multi-year effort to revitalize the domestic lamb industry (American Sheep Industry Association). Whether this investment will be successful remains to be seen, but this clearly demonstrates the importance placed on increasing lamb demand by policy makers.

To efficiently allocate limited resources to programs intended to stimulate lamb product demand, an understanding of lamb demand over time is required. In particular, a better understanding is needed regarding demand determinants for lamb. The lamb industry has at least some control over several of the factors presumed to influence demand such as relative price of lamb and product offering. However, industry participants have less control over other factors such as consumer income or lifestyle changes. The most efficient management strategy for the industry is to understand the major determinants of lamb demand over time to develop strategic plans to address issues that they can influence.

The purpose of this study is to estimate major determinants of demand for lamb. In particular, factors including retail lamb, beef, pork, and broiler prices, consumer income, and changing consumer lifestyles will be examined for their impact on long-run lamb demand. In addition, a history of the demand for lamb over the last 20 years is examined and strategies for the industry to influence demand are identified.

Previous Research

There is a noticeable lack of research regarding lamb demand. Purcell (1998a) defined the term "demand" and suggested that it is a complex interaction of quantity and price that is often misun-

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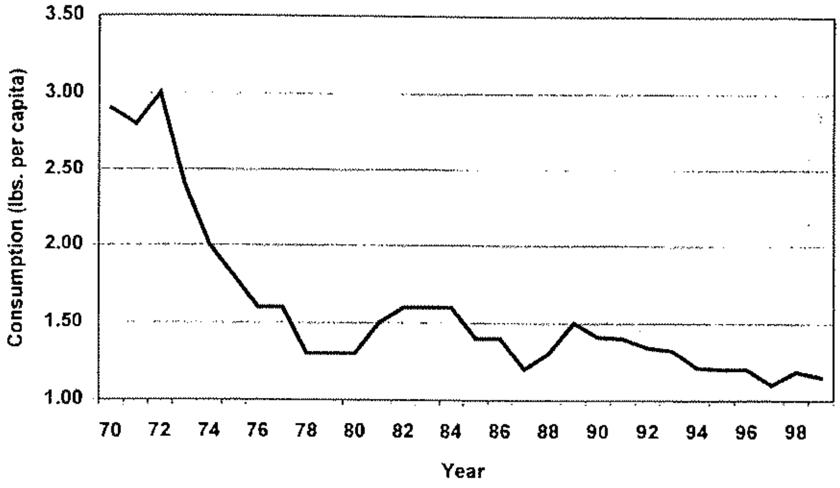
Figure 1. Annual Per Capita lamb Consumption, 1970-99



derstood. He clearly demonstrates the fallacies of drawing inferences regarding demand changes from just observing prices or per capita consumption alone.

Only two relatively recent studies have empirically estimated demand for lamb over time. Purcell (1989) estimated quarterly demand using various models over the 1970-1987 period. He found that few of the typical economic factors considered relevant in demand models were important lamb demand determinants. In particular, lamb price was only a marginally significant lamb consumption determinant (and, its significance was sensitive to model specification) and no effective substitutes existed. Lamb consumption declined as consumer income increased.

Byrne, Capps, and Williams (1993) estimated a quarterly lamb demand model over the 1978-1990 period.[1] They concluded that per capita lamb consumption was significantly related to lamb price with a short run elasticity of –0.63 and a long-run elasticity of –0.79. Pork price was marginally significant suggesting it was a weak substitute for lamb.

These time series demand estimates were important because they suggested that few of the typical demand determinants (i.e., prices of substitutes, consumer incomes, etc.) were important in lamb. However, more information is needed regarding lamb demand. First, both of these studies relied on data that are now at least 10 years old. Given the rapid changes in the U.S. economy and consumer lifestyles, an updated demand analysis is past due. Second, consistent retail lamb price series were problematic in both studies, making results conditional on questionable price data that were available at the time. Additional analysis with a more consistent retail lamb price series is needed. Third, results of the two studies are not entirely consistent (e.g., Purcell found lamb demand declined as income increased it had no substitutes, whereas, Byrne, Capps, and Williams found income to have no impact and pork to be a weak substitute) warranting further analysis. Using more detailed weekly retail scanner data over a shorter time period (January 1987 – November 1988), the TAMRC lamb study team (1991) concluded that aggregate retail lamb prices were important lamb consumption determinants. More importantly, they concluded that individual lamb cuts had elastic demands, suggesting consumers readily switch between cuts of lamb based upon relative prices.

Methods

Demand for lamb products can be modeled in a quantity-dependent framework as: $LQ = \beta_0 + \beta_1 LP + \beta_2 BP + \beta_3 PP + \beta_3 CP + \beta_4 INC + \beta_5 W + \epsilon$, (1) where, LQ is per capita lamb consumption, LP is retail lamb price, BP is retail beef price, PP is retail pork price, CP is retail chicken price, INC is per capita disposable income, and W is the percentage of women employed in the labor force. The β 's are parameters to be estimated and ϵ, is an error term.

The model includes standard demand components of lamb price, prices of substitute meats (beef, pork, and chicken), and per capita income. Lamb price is expected to have a negative impact on per capita consumption, prices of competing meats are expected to be positively associated with lamb consumption, and income may be positive or negative depending upon how income affects lamb consumption. The percentage of women employed in the workforce is included in the model to capture changing demographics over time. This variable attempts to capture the impact of food eaten away from home, demand for product preparation convenience, and other related lifestyle changes (e.g., McGuirk et al. 1995 and Schroeder, Marsh, and Mintert 2000).

Data

The United States Department of Agriculture (USDA) stopped collecting retail lamb prices in 1981. Wholesale lamb price data are available, but these data are not appropriate for retail demand estimation because wholesale prices are not what consumers pay for retail product, and changes, over time, in the wholesale-to-retail price margin make the wholesale series a poor proxy for retail prices. Byrne, Capps, and Williams (1993) used wholesale prices, time trend variables, and seasonal dummy variables to generate proxies for retail lamb prices. How well this proxy mirrored actual retail prices is unknown but questionable. In this study, retail lamb price data were collected from the Bureau of Labor Statistics (BLS).[2] The BLS series was only available from 1978 forward. Therefore, the meat demand model (equation 1) was estimated using

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[1] This study was a formalization of earlier work by the TAMRC lamb study team (1991).

Table 1. Summary Statistics of Data Used in Lamb Demand Estimation, Quarterly 1978-1999.

	Average[1]	Standard Deviation	Minimum	Maximum
Lamb Consumption (lb./capita)	0.34	0.05	0.20	0.40
Lamb Price (cents/lb.)	481.88	56.17	434.47	668.00
Beef Price (cents/lb.)	362.87	60.84	281.35	539.61
Pork Price (cents/lb.)	264.93	36.27	208.17	376.42
Chicken Price (cents/lb.)	119.81	19.02	98.87	177.76
Disposable Income ($/capita)	20,264.13	2,003.72	16,737.05	24,550.01
Women in Work Force (%)	52.25	3.56	45.30	57.70

[1] Prices and Income are in cents per retail pound in constant 1999 dollars, deflated using the Consumer Price Index. Lamb Consumption is retail weight equivalent.

quarterly data from 1978 through 1999.

Retail prices of beef, pork, and chicken and per capita lamb consumption were obtained from USDA. Personal disposable income per capita was collected from the U.S. Department of Commerce and the percentage of women employed in the labor force was obtained from the Bureau of Labor Statistics. All prices and income were deflated to constant 1999 dollars using the consumer price index (Bureau of Labor Statistics). Summary statistics of the data are reported in Table 1.

Results and Discussion

Demand Model Estimates

The demand equation specified in equation (1) was estimated with ordinary least squares regression using quarterly data over the 1978 to 1999 period. Quarterly dummy variables were added to the model to account for seasonal differences in demand. The model was initially estimated including both the disposable income (INC) and the women in the work force (W) variables in the model. Neither of the coefficients was statistically different from zero and because both variables exhibit similar upward trends over the time period, multicollinearity problems were suspected. Therefore, the model was estimated two more times dropping one of the variables each time and retaining the other. Comparisons of the estimates indicated that the model including income (and excluding W) better explains lamb consumption than the model including women in the labor force, therefore, W was dropped from the final model. Therefore, degrading multicollinearity was apparent between women participation in the workforce and disposable income during this time period.

Two partial adjustment models were also estimated; one using one-quarter lagged lamb consumption and another using a one-year (same quarter a year earlier) lag on the dependent variable. These models were estimated to determine whether habit-persistence found by Byrne, Capps, and Williams (1993) was present. The lagged dependent variables were not statistically different from zero suggesting habit-persistence was inconsequential during this time period.[3]

Demand model parameter estimates are presented in Table 2. The model explains 57 percent of the variability in lamb consumption. The Durbin-Watson statistic indicates that autocorrelation, often present in time series regression analysis, is not a problem in the model, suggesting a well-specified model. Several important findings are revealed. First, lamb price is an important determinant of lamb consumption. The own-price elasticity estimate indicates that a one percent increase in lamb price reduces per capita consumption by 1.09 percent. This elastic demand response differs from those estimated by other studies. Byrne, Capps, and Williams (1993) found a short-run elasticity of –0.62 and a long run elasticity of –0.79. Purcell (1989) estimated the elasticity to be –0.51.

Several factors likely make the elasticity measures estimated here different from those of earlier studies. First, our study is the only one to use recent lamb retail price data (Purcell's data only went through 1980 with a consistent price series and through 1987 with a modified series using wholesale prices and Byrne, Capps, and Williams used a modified series based on wholesale prices through 1990). If our elasticity estimate reflects more recent behavior, lamb consumers are becoming more sensitive to price than has been suggested by previous research. Thus, lamb producers will benefit from increased production efficiency both from the standpoint of being more price competitive in world markets as well as helping to keep retail lamb prices lower relative to competing meat prices. Alter-

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[2] The BLS reports a monthly retail lamb price index (and they also reported a U.S. city retail lamb price average from January 1991 to August 1991 and August 1993 to December 1993). The index was converted to a retail price by using the January 1991 retail lamb price. The monthly data were averaged to obtain quarterly average lamb prices.

[3] Parameter estimates of these model variations are not reported here but are available from the authors upon request.

Table 2. Parameter Estimates of Quarterly Lamb Demand Model, 1978-1999.

Variable	Parameter Estimate	Standard Error	t-statistic	Elasticity[1]
Intercept	0.679*	0.132	5.16	-
Lamb Price	-0.00076*	0.0013	-5.81	-1.09
Beef Price	0.000523*	0.000202	2.59	0.57
Pork Price	0.000215	0.000189	1.13	0.17
Chicken Price	-0.000135	0.000464	-0.29	-0.05
Income	-0.000009*	0.000004	-2.06	-0.54
Q2DUM	-0.0368*	0.0101	-3.66	-
Q3DUM	-0.0439*	0.0100	-4.37	-
Q4DUM	-0.0238*	0.0100	-2.37	-
R-squared	0.57			
Durbin-Watson	1.95			
Observations	88			

[1] Elasticities are calculated at the averages of the variables over the time period.

* indicates that the parameter is statistically different from zero at the 0.05 level.

natively, if U.S. producers do not improve production efficiency, and import restrictions continue to curtail cheap imports (supporting higher domestic than world prices), per capita consumption is likely to continue to decline.

The only statistically significant substitute for lamb is beef (Table 2). A one percent increase in the price of beef increases per capita lamb consumption 0.57 percent. This suggests that recent high retail beef prices likely have helped strengthen lamb demand relative to what it would have otherwise been. In addition, this indicates lamb price relative to beef price is an important demand determinant. Lamb price must be competitive with beef prices if cost is to be used to enhance lamb demand.

Pork price is marginally statistically different ($p<0.26$) from zero with an elasticity of 0.17 (similar to Byrne, Capps, and Williams (1993) estimate of 0.13). Purcell (1989) found no substitutes and Byrne, Capps, and Williams (1993) found only pork to be a weak substitute. Using our more recent data time period, pork remains a weak substitute and chicken is not a substitute for lamb.

Lamb is what economists refer to as an "inferior meat product". This refers to lamb demand declining when consumer income increases. The income elasticity indicates a one percent increase in per capita disposable income, reduces lamb consumption by 0.54 percent, with all else constant. Purcell (1989) similarly found lamb demand to be inversely related to income in one of his models whereas, Byrne, Capps, and Williams (1993) found income not to be statistically different from zero. If our estimate and that of Purcell are correct, this does not bode well for lamb demand as real U.S. consumer incomes have grown consistently for many years. Schroeder, Barkley, and Schroeder (1995) found that in low-income countries, lamb consumption responds strongly in a positive direction to consumer income growth. However, they also determined that as income growth continued over time, or when compared to countries with higher income levels, lamb demand declined at lower income levels than did demand for pork, beef, and poultry (i.e., additional increases in income led to substitution away from lamb consumption to other meats). This is consistent with our results indicating lamb demand tends to decline as U.S. consumer income increases.

These results suggest aggregate lamb demand is likely to decline during periods of economic strength like those experienced of late in the U.S. One important point regarding the income elasticity is worthy of further consideration. Income was positively correlated with the percentage of women in the workforce variable, and likely with other consumer lifestyle changes over time. Therefore, the negative income elasticity estimate could reflect the effect of changes in income, as well as changes in other demographic factors, over time. Thus, the magnitude of the income elasticity could be over-stated. But, if similar trends continue among these factors, which is likely because they are all related, the overall impact of income growth on lamb demand is likely to be consistent with our estimate.

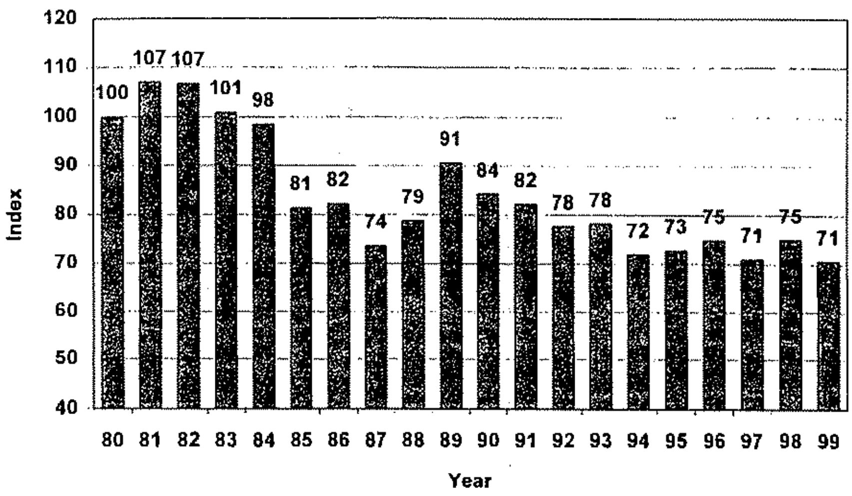
Statistically significant seasonal dummy variable estimates indicate lamb demand varies seasonally. Strongest demand is in the first quarter of the year during holiday seasons traditionally favoring lamb consumption (e.g., Easter). Weakest demand is during the third quarter of the year when beef demand is typically strong (Schroeder, Marsh, and Mintert, 2000).

Lamb Demand Index

The demand model estimates are important for assessing factors that have caused aggregate-lamb demand to change. To examine how lamb demand has changed over the past twenty years, a lamb demand index was constructed. The index summarizes the complex interaction of price and quantity discussed by Purcell (1998a) into a single number for each year. The index was calculated by assuming a constant own-price demand elasticity of −1.09 and calculating the annual percentage vertical shift in demand that occurred.[4]

An index value of 100 is the level of lamb demand in the base year 1980 (Figure 2). An index value greater than 100 indicates lamb demand increased relative to 1980 and an index value less than 100 indicates lamb demand was lower that year relative to 1980. For example, the 1990 index is 84 indicating that in1990, lamb demand was only 84% of its 1980 level. What is most revealing about the index is that 1999 had the lowest demand level of the past 20 years at 71% of 1980. In other words, the lamb industry experienced a 29% decline in demand over the past 20 years. Interestingly, a similar demand index calculated for beef indicates that beef demand declined more consistently and severely over the 1980-1998 period than lamb, dropping from 100 to 52. However, the beef demand index rebounded for the first time in 1999 to a value of 54 (Schroeder, Marsh, and Mintert, 2000) and was higher again in 2000. Thus, the beef industry appears to be developing an effective multi-faceted strategy to reverse its long run demand decline.

Figure 2. Lamb Demand Index, 1980-99 (1980=100)



Conclusions

Historically, lamb has represented a minor component of U.S. meat consumption. In recent years, lamb demand declined such that by 1999, lamb demand was only 71% of what it had been in 1980. Poor demand, together with stiff competition from foreign supplies are significant challenges facing the domestic lamb industry (Purcell 1998b). Results of this study reveal several strategies for the lamb industry:

- The quantity of lamb consumed is sensitive to lamb price. Reductions in lamb price will result in comparable percentage increases in per capita consumption. This together with world market pressure, suggests that production cost reduction is critical for survival of the domestic lamb industry.
- Beef is a substitute for lamb. If domestic lamb producers do not improve production efficiency at least at the rate achieved by the beef industry, relatively cheaper beef will replace expensive lamb in consumer diets.
- Demand for traditional lamb as an aggregate commodity declines as consumer income rises. The industry must recognize that as consumer income has increased, traditional aggregate lamb demand has declined. The lamb industry cannot change consumer income. However, this result indicates that lamb products must be adapted to fit modern high-income consumer lifestyles. Development of lamb products that are convenient to prepare, offer a high-quality eating experience, and that are well suited for food-away-from home consumption (with products targeted for lower-priced as well as higher-priced restaurant markets), is essential for halting declining lamb demand.

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Comparison of Three Measuring Techniques for Staple Length and Strength in U.S. Wools[1,2]

F.A. Pfeiffer[3] and C.J. Lupton[3,4]

Summary

Twenty-nine consignments of greasy wool in Texas warehouses were used to compare three measuring techniques for staple length (SL) and strength (SS) and to assist the U.S. wool industry in deciding which techniques to adopt for commercial testing. Samples (~10 lb/lot) were obtained using a bale grab sampler and were subsampled at the Texas Agricultural Experiment Station (TAES) Wool and Mohair Research Laboratory (WMRL) to provide three sets of comparable subsamples. One complete set of subsamples (29 subsamples x 65 staples/subsample = 1,885 staples) was sent to the Australian Wool Testing Authority (AWTA) for measurement using the Automatic Tester for Length and Strength (ATLAS) while another set was sent to SGS Wool Testing Services (SGS) in New Zealand for testing with the Agritest Staple Breaker Model 2. A third set was measured at WMRL using the American Society for Testing and Materials (ASTM) manual method for SL and an Agritest Staple Breaker (manual model) for SS. Each testing lab used the same wool base and vegetable matter base values to convert "greasy" to "clean" SS. Paired t tests and linear regression analyses were conducted to test for differences and calculate r^2 values between test methods. Warehouse personnel provided visual estimates of SL. Mean values of SL determined by AWTA and the visual assessments were not different (3.20 and 3.21 in, respectively, $P > 0.05$; $r^2 = 0.63$). Measurements of SL made by SGS and WMRL were not different (3.07 and 3.12 in, respectively, $P > 0.05$; $r^2 = 0.74$) but were shorter ($P < 0.05$) than the AWTA and visual results. Mean values of variability in staple length (CV) were not different ($P > 0.05$) among the three measuring techniques. The AWTA and SGS means of SS were not different (32.1 and 31.8 N/ktex [a textile measure of strength, newtons per kilotex, literally kilogram-force per unit of staple thickness expressed in ktex, kg per km], respectively, $P > 0.05$; $r^2 = 0.41$). The WMRL mean value, 41.7 N/ktex, for SS was greater ($P < 0.05$) than the other two labs, which strongly suggests that either the manual instrument and/or the WMRL technique produced excessively high values. Further testing incorporating a broader cross-section of U.S. wools is required before an authoritative recommendation can be made to the U.S. wool trade.

Key Words: Staple length, Staple strength, Wool

Introduction

The U.S. wool industry has expressed an interest in having some of its staple wools objectively measured for staple length (SL) and staple strength (SS) before the time of sale of greasy wool to further describe the wool being sold and to achieve maximum price discovery. According to Adams (1997), SS is second only to fiber diameter in determining the value (expressed on a clean basis) of raw wool because it is an important contributor to Hauteur, i.e., average fiber length in the wool top after early stage processing. Qi et al. (1994), reported that SL is the third most important characteristic of wool after scoured yield and fiber diameter. Australian methodology and machinery are currently available for obtaining staple samples for measuring SL and SS but as yet are not easily adapted for most U.S. wool packages (i.e., 6 and 8 ft wool bags). The ATLAS instrument used in Australia for measuring SL and SS is very expensive and, even if it were available, may

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not be cost-effective in the U.S. commercial testing laboratory. Fortunately, less expensive instrumentation is available from Agritest for measuring SL, SS, and position of break but it requires further evaluation to establish its equivalency with both the now accepted ATLAS technique and the established ASTM and manual Agritest methods.

Materials and Methods

Twenty-nine commercial lots of sound, staple length wool were identified in member warehouses of the Producers Marketing Coop, Inc. (San Angelo, Texas). An Australian bale grab sampler was used to obtain approximately 10 lb of sample from each lot. Each grab sample was inspected by the warehouse manager and the cooperative manager and a consensus visual staple length was established for each lot. Subsequently, the samples were transported to the Texas Agricultural Experiment Station's Wool and Mohair Research Lab (WMRL) and subsampled to provide three sets of comparable subsamples for each of the 29 lots. One set of subsamples consisted of 65 individual staples each being suitable for measurement of SL and SS. This number (65) of staples representing a single lot has been established as the minimum necessary to produce the desired degree of accuracy when measuring SS and SL.

One complete set of subsamples (29 subsamples x 65 staples/subsample = 1,885 staples) was sent to the Australian Wool Testing Authority (AWTA) in Guildford, New South Wales for measurement using the Automatic Tester for Length and Strength (ATLAS) instrument. Another set was sent to SGS Wool Testing Services (SGS) in Wellington, New Zealand for testing with the Agritest Staple Breaker Model 2. A third set was measured at the WMRL using a manual method (ASTM, 1999b) to measure SL and an Agritest Staple Breaker (manual model) for measuring SS. Wool and vegetable matter bases were determined for each lot (ASTM, 1999a) by Yocom-McColl Testing Labs, Inc. in Denver. Each testing lab used the same wool base and vegetable matter base values to convert "greasy" to "clean" SS. Paired t tests and linear regression analyses were used to test for differences and calculate r^2 values between test methods (SAS, 1996).

Results and Discussion

The results of testing at the three locations using the different methods are summarized in Table 1. We have assumed that 65 staples/lot were measured by AWTA, as they were by TAES technicians. The SGS lab measured 57-59 staples per lot. Table 2 indicates that overall mean values of staple length determined by AWTA and visual assessments made by warehouse personnel were not different ($P > 0.05$). Similarly, measurements of staple length made by SGS and TAES were not different ($P > 0.05$) but were slightly smaller (~ 0.1 in) than the AWTA and visual results. Mean values of variability in staple length as measured by coefficients of variation were not different among locations. Overall means of SS were not different between AWTA and SGS. The TAES values for SS were considerably higher than the other two labs strongly suggesting that the instrument and/or our technique is producing excessively high values.

Conducting t tests using mean values of each of the 29 lots is only one method of comparing results from the three instruments. Regression analyses were also conducted and our results are summarized in Table 3. Somewhat surprisingly considering the general acceptance of these test procedures by the testing community and elsewhere in the past few yr, SL and SS values obtained using the three different sets of methods were not highly correlated. The r^2 values between labs for SL range from 0.74 to 0.81 ($P = 0.0001$) for the three objectively measured sets of data. Values for visually appraised vs objectively measured SL are lower (0.48 to 0.63, $P = 0.0001$). Coefficients of determination for the SS data are even lower (0.41 to 0.61, $P = 0.0001$ to 0.0002) while those for CV of SL are still smaller (0.11 to 0.39, $P = 0.0003$ to 0.0849). These r^2 values would probably have been higher if unsound, very strong, very short, and very long wools had been included in the study. We chose to use typical, sound, staple-length West Texas wools only. In fact, the AWTA and SGS strength data are remarkably similar for 21 of the 29 lots measured (0 or 1 N/ktex difference between labs). The differences for the other eight lots range from 2-5 N/ktex with no apparent bias.

The relative costs of conducting these tests and the time required to get results from overseas are documented in Table 4. Currency conversion rates effective on 10/21/99 were used in the calculations.

Conclusions

This study indicates that results of testing sound U.S. wool for SS and SL were not highly correlated among the three testing locations (methods). The visual appraisals of SL and measurements using the ATLAS instrument were not different but were greater than (~ 0.1 in) the SL results, obtained using the ASTM standard method and SGS measurements. Mean values of SS were not different between the SGS and AWTA labs but were significantly higher at the TAES lab.

Implications

The U.S. wool industry had anticipated that results from this study would have been close to identical from each of the three labs participating using different methods and instruments. Further investigations and analyses will be required to help us identify reasons for these disagreements.

Table 1. Individual, mean, minimum, maximum, and standard deviation values for the 29 wool lots used in this study.

Lot number	Visually assessed staple length, in	AWTA Staple length, in	AWTA CV of staple length, %	AWTA Staple strength, N/ktex	SGS Staple length, in	SGS CV of staple length, %	SGS Staple strength, N/ktex	TAES Staple length, in	TAES CV of staple length, %	TAES Staple strength, N/ktex
1	3.1	3.0	22	29	3.0	17	29	3.1	16	37
2	3.1	3.4	13	31	3.1	11	32	3.3	10	45
3	3.2	3.3	14	31	3.1	13	30	3.3	16	44
4	3.3	3.4	13	32	2.8	15	30	3.3	9	39
5	3.2	3.0	18	31	2.8	15	30	3.0	17	42
6	3.0	2.8	15	29	2.7	12	28	2.7	12	37
7	3.1	2.7	12	28	2.6	15	29	2.2	14	32
8	3.3	3.4	12	31	3.2	13	30	3.2	15	40
9	3.3	3.3	11	29	3.1	11	30	2.8	15	35
10	3.4	3.3	12	33	3.3	13	29	3.3	13	40
11	3.6	3.7	16	30	3.5	17	31	3.5	15	37
12	3.2	3.3	13	36	3.2	15	35	3.3	11	46
13	3.2	3.3	12	34	3.1	11	32	3.2	11	37
14	2.8	2.7	11	32	2.8	14	32	2.6	15	37
15	3.3	3.3	11	33	3.3	12	33	3.1	15	42
16	3.2	3.1	18	29	3.0	24	29	2.8	19	36
17	3.2	3.0	17	35	2.9	15	30	3.0	12	42
18	3.0	3.0	13	31	3.0	11	34	2.9	12	47
19	3.1	2.7	13	34	2.6	11	33	2.5	13	45
20	3.3	3.2	17	33	3.1	14	32	3.1	13	47
21	3.4	3.6	12	37	3.5	14	37	3.6	14	50
22	3.3	3.1	12	35	3.1	11	36	3.1	15	44
23	3.3	3.5	16	32	3.4	16	32	3.7	15	41
24	3.4	3.4	11	36	3.3	13	36	3.4	13	48
25	3.3	3.3	17	30	3.1	16	29	3.2	14	41
26	3.2	3.5	13	33	3.3	13	30	3.3	19	40
27	3.3	3.3	18	34	3.2	16	39	3.5	16	53
28	3.4	3.3	14	35	3.3	11	31	3.5	12	44
29	3.0	2.8	16	28	2.7	14	33	2.7	16	40
Mean	3.21	2.30	14.2	32.1	3.07	13.9	31.8	3.12	14.0	41.7
SD	0.16	0.26	2.7	2.5	0.25	2.7	2.7	0.35	2.4	4.7
Min	2.8	2.7	11	28	2.6	11	28	2.2	9	32
Max	3.6	3.7	22	37	3.5	24	39	3.7	19	53

Table 2. Mean values for the 29 wool lots.

	AWTA	SGS	TAES	(Visual)
Staple length, in	3.20^a	3.07^b	3.12^b	3.21^a
CV of staple length, %	14.2	13.9	14.0	–
Staple strength, N/ktex	32.1^b	31.8^b	41.7^a	–

^{a,b}Within a row, means without a common superscript differ ($P < 0.05$).

Table 3. Coefficients of determination (r^2 values with P in parenthesis) for the indicated relationships.

Staple length			
	AWTA	SGS	TAES
Visual	.63 (0.0001)	.53 (0.0001)	.48 (0.0001)
AWTA	–	.81 (0.0001)	.81 (0.0001)
SGS	–	–	.74 (0.0001)
Coefficient of variation of staple length			
		SGS	TAES
AWTA		.39 (0.0003)	.11 (0.0849)
SGS		–	.21 (0.0128)
Staple strength			
		SGS	TAES
AWTA		.41 (0.0002)	.46 (0.0001)
SGS		–	.61 (0.0001)

Table 4. Financial and time considerations.

	AWTA	SGS
Samples sent via Federal Express	5/17/99	5/17/99
Cost of Fed-Ex shipping, US $ (~ 20 lb)	223.25	213.05
Results received by airmail	6/3/99	6/8/99
Cost of length/strength test, US $ / sample	25.15	22.24
MAF clearance and fumigation (29 samples)	–	30.17

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Research Note

Survival and Serum IgG Levels in Twin Born LambsSupplemented with Vitamin E Early in Life[1]

Patrick G. Hatfield[†,2], John T. Daniels[†,3], Rodney W. Kott[†], and Donald E. Burgess[*]

Key Words: Lambs, Vitamin E, Lamb survival, Immunoglobulin G

Lamb mortality is a major factor limiting profitability in sheep operations. Estimates of pre-weaning losses range from 15 to 51% (Rook, 1997), with mortalities as high as 35% considered normal for large sheep operations (Rowland et al., 1990). Rowland et al. (1990) also reported that 50% of mortality occurs in the first 24 hours of life.

Supplemental vitamin E given orally to the ewe during late gestation has been shown to decrease lamb mortality (Kott et al., 1998). In addition, when lambs were injected with vitamin E shortly after birth, Gentry et al. (1992) noted an increase in lamb serum immunoglobulin G (IgG) concentration that could be indicative of enhanced immune function (Besser and Gay, 1994). However, no advantages in survival or lamb body weight gain were observed when supplemental vitamin E was given to lambs at birth (Gentry et al., 1992; Williamson et al., 1996).

Many studies assessing the role of vitamin E in immune function and/or survival in sheep lack sufficient numbers, and have not addressed pathological and/or environmental stresses common to Western sheep operations. Therefore, our objectives were to examine the effects of supplemental vitamin E to newborn twin lambs on lamb survival, serum vitamin E concentration, and serum IgG concentration. Sheep used in our study were part of a production lambing operation, thus the labor constraints and lambing environment used in this experiment were typical of a western sheep production system.

Twin born lambs (n = 960) were used in this 2-year study. Research was conducted at the Montana State University, Red Bluff Experimental Ranch located 50 km west of Bozeman, Montana. Ewes grazed dormant native range until 30 d before lambing when they were confined and fed approximately 2.5 $kg \cdot ewe^{-1} \cdot day^{-1}$ grass hay and .14 $kg \cdot ewe^{-1} \cdot day^{-1}$ of a grain-based supplement (20% CP). Ewes had ad libitum access to water and a trace mineral salt mix. Ewes were shed lambed in 1.5 m^2 individual pens starting April 11 in both 1997 and 1998. Lambs were ear tagged and tails docked approximately 24 hours after birth. Twin born lambs received one of three experimental treatments. Treatments were 1) one twin lamb assigned randomly to orally receive a single dose of 400 IU supplemental vitamin E within 1 hour of birth (1 g of Rovimix E-40%, 400 IU α--tocopherol acetate; Roche Vitamins, Parsippany, NJ), 2) the other twin lamb received no supplemental vitamin E, 3) of those lambs that received the single dose, half were randomly assigned to orally receive a second dose (400 IU) of vitamin E 16 to 24 hours after the first dose. Lambs and ewes remained in individual pens for approximately 24 hours and then moved to larger pens where they remained until turnout to summer range approximately 30 d post-lambing.

At 3 d post-partum, blood was collected from a total of 223 lambs via jugular venipuncture. Sera were frozen for later determination of serum α-tocopherol and IgG concentrations. Lamb sera were analyzed for α-tocopherol concentration at the Wyoming State Veterinary Laboratory using flourometric determination. Lamb sera was analyzed for IgG concen-

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Table 1. Effect of oral vitamin E supplementation to twin born lambs on serum vitamin E and immunglobulin G (IgG)[a]

	Supplemental vitamin E[b]			
	Control	Single	Double	SEM
N[c]	111	63	49	
Serum α-tocopherol, μg/mL	1.32[v]	3.48[w]	5.26[x]	.201
Serum IgG, μg/mL	8.77	7.72	9.69	.743
N[d]	480	258	222	
Body weight, kg[e]				
Turn out (avg age = 40 days)	11.2	11.0	11.3	.22
Weaning (avg age = 120 days)	26.2	26.0	27.2	.73
Body weight, kg[f]				
Turn out (avg age = 40 days)	12.6	12.8	2.5	.14
Weaning (avg age = 120 days)	30.2	30.1	30.5	.32
Mortality, %[g]	10.8	12.4	9.9	—

[a] No supplement x year interactions (P > 0.30).

[b] Control = no supplemental vitamin E; Single = 400 IU supplemental vitamin E within 6 hours of birth; Double = Two doses of 400 IU of supplemental vitamin E. The first within 6 hours of birth, the second dose of 400 IU of supplemental vitamin E within 10 to 18 hours after the first dose.

[c] Observations for serum α-tocopherol and IgG data

[d] Observations for bodyweight and mortality data.

[e] Body weight means calculated with a '0' for lambs that died, thus values represent weight of lambs weaned/treatment.

[f] Bodyweight means calculated with 'no entry' for lambs that died, thus values represent live animal performance.

[g] Mortality observed at turnout.

[vwx] Within Supplemental Vitamin E treatment, means without a common superscript letter differ (P < .01).

tration using an ELISA procedure (Daniels et al., 2000).

Lambs were weighed at birth, approximately 30 d post-partum (turnout to summer range) and at 120 d post-partum (weaning). Percent lamb mortality at turnout was also recorded. Lamb was the experimental unit. Lamb BW, and serum IgG, and α-tocopherol concentration were analyzed using the GLM procedure of SAS (1993). The model included treatment, sex, year, and all possible interactions. Lamb birth weight and birth date were included in the model as covariates. Lamb mortality was analyzed using Chi square procedure of SAS (1993).

Supplemental vitamin E x year interactions were not detected (P > .30). In addition, lamb sex did not impact (P > .50) percentage mortality, serum α-tocopherol, or serum IgG concentrations. Similar to results reported by Jneru et al. (1994), serum α-tocopherol was greater (P< .01) for lambs receiving two doses of supplemental vitamine E compared to those given one dose, which was greater (P< .01) than for lambs receiving no supplemental vitamin E (Table 1).

Afzal et al. (1984) and Ritacco et al. (1986) reported positive impacts of supplemental vitamin E on the ability of older animals to mount an immune response. Serum or plasma IgG levels in newborn ruminants have been reported to be good indicators of an animal's ability to mount an immune response (Besser and Gay, 1994). In our study, serum IgG concentrations did not differ (P > .50) among treatments (Table 1). These results are counter to the findings of Gentry et al. (1992) who noted an increase in lamb serum IgG when lambs were injected with vitamin E shortly after birth. Increased serum α-tocopherol in newborn lambs may not always affect survival and IgG levels. Potential explanations for the different results in these studies include the method of administering vitamin E, colostral vitamin E concentration, a lack of exposure to environmental or pathogenic stress sufficient to elicit an immune or production response, and the different breeds of sheep used in each study.

Hidiroglou and Karpinski (1987) examined the route of administration of supplemental vitamin E and its effect on uptake of vitamin E by sheep and found that oral administration of vitamin E via gelatin capsules resulted in decreased bioavailability compared to either intramuscular, or intravenous administration. Gentry et al. (1992) reported mean serum α-tocopherol concentrations of 43.9 μg/mL at 1 day of age for lambs injected with 1500 IU of α-tocopherol at birth.

This value is 8 times greater than the serum concentration in lambs given an oral double dose (5.26 µg/mL, Table 1) in our study.

Gentry et al. (1992) used Suffolk sheep while we used western white face range breeds. Since Bradley et al. (1972) reported higher mortality in Suffolk compared to Targhee sheep it may be reasonable to speculate that the ability of supplemental vitamin E to influence immunocompetence would be more pronounced in a less vigorous breed such as Suffolk that may be more susceptible to environmental and pathogenic stress.

Lamb body weight and survival did not differ (P > .40) among vitamin E supplemental treatments (Table 1). Kott et al. (1998) evaluated the effects of supplemental vitamin E to the ewe on lamb survival. These authors reported that mortality was decreased by vitamin E supplementation over the 3-yr study period. The reasons for differences noted between studies in which supplemental vitamin E was given to the late gestating ewe or the newborn lamb are not clear. Possibly, supplemental vitamin E may havemore benefit as an agent of positive physiological change in the dam rather than as a nutrient provided directly to the neonate.

Implications

Although supplemental vitamin E given to the lamb at birth will increase lamb serum a-tocopherol levels, this practice does not appear to be effective in reducing lamb mortality, increasing lamb performance, or improving indices of immunocapacity (such as IgG levels) in a production environment typical of the Western United States using white face sheep.

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Research Note

Is There an Influence of Individual Rams on Ewe Prolificacy?

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Key Words: Ram, ewe, prolificacy, lambing rate

Previous studies have shown that ram introduction near the onset of the breeding season stimulates the initiation of estrous cycles (Sebastian and Inskeep, 1988) and ram libido influences flock conception and flock lambing rates (Fitzgerald, 1992). Twin- and triplet-born rams produce more multiple births than single-born sires (Hodgson et al., 1965; Vakil et al., 1968; Botkin et al., 1988), an effect generally attributed to increased libido (Fitzgerald, 1992) and serving capacity (i.e. testis size; Snowder et al., 1981). Sexual behavior also varies among individual rams (Price, 1987; Fitzgerald and Perkins, 1993; Alexander et al., 1999) and among males of other species (Meisel and Sachs, 1994).

Ovulation rate and prolificacy of ewes are characterized as being lowly heritable characteristics (Botkin et al., 1988) inherent to a ewe's reproductive cycle. In spite of this generalization, limited data (Hodgson et al., 1965; Botkin et al., 1988; Burfening and Davis, 1996) and emperical observations support a role for the male in influencing prolificacy of individual ewes. The observation that clitoral stimulation advanced timing of ovulation in cows (Randel et al., 1973) supports the concept that stimuli associated with mating may influence time and perhaps rate of ovulation in spontaneously ovulating species such as cattle or sheep. Alternatively, in vitro fertilization studies with rabbits led to the conclusion that semen from selected bucks differentially influenced embryo survival in vivo (Burfening and Ulberg, 1968). More recently, "service sire" was indicated as a significant source of variation for number of lambs born per ewe exposed (Burfening and Davis, 1996) and a paternal effect on initiation and length of the S-phase of embryo development was reported for bulls (Eid et al., 1994). Therefore, the precedence for a sire effect on number of offspring born to individual ewes exists, but mechanisms through which such an effect may be mediated remain an enigma.

Data from single-sire matings performed in a flock of ewes over a ten-year interval were analyzed to determine if individual rams do indeed differ in their ability to sire multiple offspring. This flock consists of approximately 200 western whitefaced ewes that had historically been selected for uniformity and multiple births (Saboulard et al., 1995). Ewes were randomly allotted to groups of 20-32 for pen mating to a single ram during the fall breeding season each year. Conception rates averaged 97.1 ± .4 percent (range = 90 to 100%) and duration of the lambing season was 31 ± 2 days overall years and ram groups. The 4 to 6 rams used each year were either 2 (n = 32) or 3 (n = 16) years of age and were replaced annually. Over the ten-year interval, data for 1383 ewe lambing events and 48 sires were accumulated and analyzed. Age of ewes in this data set ranged from 2 to 10 years.

Data for ewes that conceived to the single-sire matings were analyzed by GLM procedures (SAS, 1990) to evaluate effects of year, ram within year, and age of ewe. The effect of ram age was tested separately from ram within year because of the inherent confounding among year, ram age, and ram within year when included together in the same model. Possible interactions were evaluated and found not significant. Differences among means were tested by Fisher's protected LSD procedure (Steel and Torrie, 1980). For purposes of statistical analysis, ewes were grouped into the ages of 2 (n = 338), 3 (n = 278), 4-7 (n = 729), and 8-10 (n = 38) years of age.

Mean numbers of lambs born per ewe lambing differed (P = .0008) by year and ranged from 1.7 ± .06 to 2.0 ± .06. Similarly, age of ewe influenced (P = .0001)

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numbers of lambs born with 2, 3, 4 to 7, and 8-10 year-old ewes producing 1.8 ± .03, 1.9 ± .04, 2.0 ± .02, and 1.8 ± .09 lambs per ewe, respectively. Effects of ewe age and year on prolificacy are not surprising because of differences in ewe maturity, environmental conditions and feed availability (Botkin et al., 1988). Age of ram did not influence individual ewe lambing rates and averaged 1.9 " .03 and 1.9 " .05 lambs per ewe lambing for 2 and 3 year old rams, respectively.

Of most interest, was the observation that the effect of ram within year on ewe prolificacy was highly significant (P = .001). Rams differed in the number of offspring born per ewe lambing with a magnitude of nearly .8 lambs per ewe lambing (Figure 1). Although our analyses do not provide insights into mechanisms through which such effects could be mediated, the large differences observed among rams could have dramatic effects on profitability of a sheep enterprise. These results prompt numerous important questions that warrant further investigation. In addition to determining how such effects may be mediated, it is important to determine if such effects are heritable, are repeatable in individual rams used over several breeding season, and perhaps most importantly, how rams which excel in this trait can be identified.

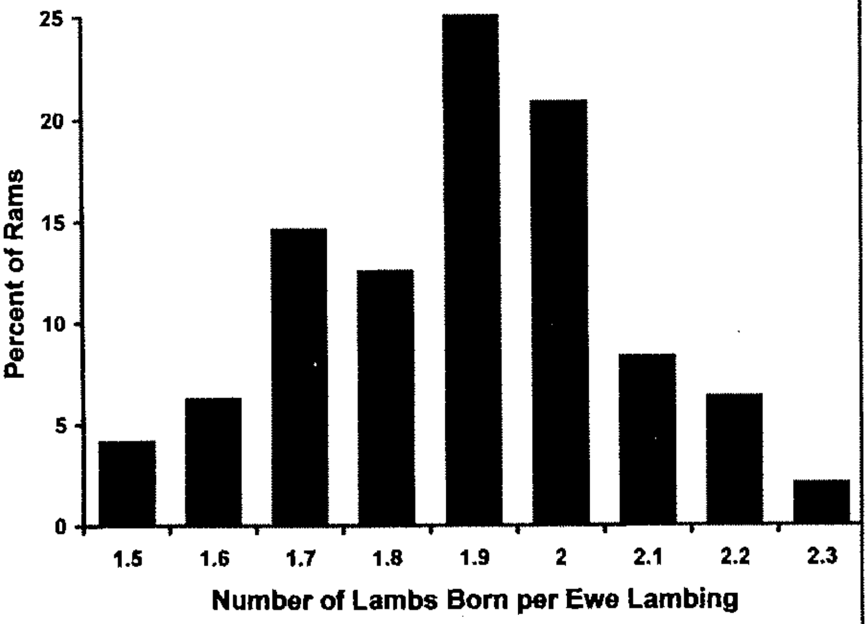

Figure 1. Distribution (%) of rams (n=48) that sired 1.5 through 2.3 lambs per ewe lambing.

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Technical Note

Enterprise Budgeting for Ewe Flock Operations

Duane Griffith*, [1], Patrick Hatfield† and Rodney Kott†

Enterprise budgeting is a tool producers can use to evaluate current and alternative enterprises for profitability. Enterprise budgets are typically completed for operations that are not undergoing significant change. This ignores any transition or implementation phase necessary to make changes or start an entirely new enterprise. While some changes may take several years to implement, others can be accomplished in one production period. EweCost is a tool that assists sheep producers in analyzing current and potential future alternative operating procedures for an ewe flock. The end point in this enterprise is feeder lambs and wool.

The EweCost program is divided into four sections; 1) revenue calculation and inventory check, 2) enterprise operating costs, 3) enterprise ownership costs, and 4) results. To save space, only a portion of the results and input are presented here. Not shown are inputs required for the leasing analysis, sensitivity tables that vary prices, weights and weaning percentage from the results section, graphs showing breakdowns of income and expense and the results of the share and cash lease analysis. While there is extensive use of color in the software, some information that color is designed to enhance is lost when printed in black and white. Information the user is either allowed or required to enter is displayed in blue text and outlined in double lined boxes. Numbers or labels outside of a double lined box are calculated or fixed and cannot be changed.

The sample printout indicates "Help" and other explanatory information is available in the left margin. Help messages are built into this program in several locations, some of which do not show when printed. The help messages are included to help clarify input required by the user and how to interpret results generated by the program. The user can access these help messages by pointing to cells that have a Help, or similar label, and to cells that have a red triangle in the upper right corner. The red triangles do not show on a printout.

The EweCost program is provided as an Excel spreadsheet, in Excel 97 format. This program can obtained from the authors or can be downloaded from the web site: http://www.montana.edu/extensionecon.

The first section requires the user to enter basic production parameters about number of ewes, weaning percentages, weaning weights, prices, etc. The program uses this information to estimate revenue generated from the enterprise. Revenue is calculated for each animal group and also per head using the parameters specified by the user. Both a cash and non-cash component is included in the revenue section. In most ewe flocks, lambs are held as replacements to maintain the quality of the ewe flock. Lambs kept for this purpose generate costs but no revenue. This software gives the enterprise credit for producing the value associated with replacements lambs but clearly separates this non-cash revenue from the cash sources. This provides a more comprehensive picture of the resource base (ewe flock) being analyzed. Purchased replacements can be analyzed as an alternative means of operation.

In addition, the first section of the program also conducts a check to assure that the enterprise budget being prepared is for a stable operation, i.e. the beginning and ending inventory of breeding ewes on hand are, or very close to identical. If the beginning and ending inventory of ewes is not similar, then the budget is for an ewe flock that is either constantly in-

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creasing or decreasing over time. This program can be used to analyze this type of expansion or contraction but the budget prepared is only valid for one production period.

The second section of the program allows users to enter operating costs for the enterprise. Operating costs are also called variable costs. These are costs that vary with the level of production. While operating costs can be collected in many different formats, they are generally considered per unit costs. For each additional unit of production the same cost is incurred, i.e. each additional sheep must be fed, vaccinated, etc. and each of these activities cost the same amount per head. The user must take care that changes made in one section of the program, i.e. number of ewes in the enterprise (revenue section) are accompanied by changes in appropriate operating costs. This program collects these costs for the total enterprise and then calculates the per head costs. Brief summaries of total operating costs for the enterprise and per head are given at the end of the operating cost input section.

The third section of the program allows the user to enter ownership costs for the enterprise. Ownership costs are also referred to as fixed costs. While operating costs vary with the level of production (linear in most economic budgeting techniques) fixed costs do not vary with the level of production and per unit values vary inversely with the level of production. An example would be the costs to own a tractor. If you add an additional 50 head of ewes to the breeding flock, the taxes or insurance on the tractor will not change. Enterprise operating costs would change (fuel, repairs, feed, vet & medicine, etc.) but the same tax and insurance cost would be charged against the ewe flock. The tax and insurance cost per ewe would decline.

Ownership costs are typically divided into four categories. These are depreciation, interest (or opportunity costs), taxes, and insurance. Each of these four categories is listed for the basic set of resources used for an ewe flock operation. The basic set of resources includes machinery and equipment, buildings and improvements, land, and the ewe flock. The user must enter information for resources used for the ewe enterprise on their operation.

The treatment of depreciation for the ewe flock, or any raised livestock enterprise, is a special case. Since this program is designed to handle estimating cost of production and calculating equitable share and cash lease arrangements, additional consideration must be given to how depreciation is charged to the ewe flock enterprise. If the program is used to estimate the cost of your own ewe flock operation and replacements are held from annual production, no depreciation should be included. The cost of replacement ewe development is already included in the budgeted expenses and the ewe flock is maintaining its value. While individual animals may be "wearing out" similar to a tractor, the ewe flock is not. Including both depreciation and replacement ewe development expenses would double count some expenses for the ewe flock. If replacements are purchased, then depreciation is used as a proxy for the annual cost associated with maintaining the ewe flock at its average value. The program includes significant help messages to guide the user as to when and how to enter depreciation expense. The same procedure for depreciation is used in both leasing analysis and estimating cost of production. The example printout is for an owned ewe flock and does not include a deprecation charge for the ewe flock but does for the purchased rams. Total ownership costs are summarized at the end of this section of the program.

Only a partial listing of the results, the fourth section, is included in this article. Shown is a summary of the incomes and expenses presented in both a profit and loss and cash flow format. Profitability includes all income and expenses incurred during the enterprise production process. These incomes and expenses include both cash and non-cash items. Depreciation is a common and well-understood non-cash expense. Depreciation is claimed as an expense for the operation but cash is not required to cover this expense. A detailed cash flow analysis looks at cash income and expenses as well as other cash inflows and outflows that are paid or received in cash. The most common example of a cash outflow that is not an expense is principal payments. While the Cash Flow format is presented here, caution must be used in its interpretation. This spreadsheet does not collect enough information to analyze an individual's actual debt situation. That would require information for each individual loan, which has some relevance for this enterprise, and prorating the loan information (principal and interest) to this enterprise. That level of detail is beyond this spreadsheet. User can visit the web site listed above for other software that will allow through cash flow analysis. The interpretation of the Cash Flow results presented in this template is then, a best-case scenario, i.e. a debt free enterprise. The Cash Flow results are useful for risk assessment for the enterprise and providing a number that can be used to calculated debt servicing ability for the enterprise. The example printout indicates how Profitability and Cash Flow analysis can provide a very different picture of the enterprise. Profitability analysis indicates the enterprise is losing approximately $87.17 per head. The Cash Flow analysis indicates the enterprise is making $5.62 per head, again a best-case scenario. What is the difference? Note that the cash flow analysis excludes the "Interest (Opportunity Cost)" charge used in the profitability analysis. The opportunity cost is a charge made to show the cost of using resources in sheep production rather than their next best alternative. In this program interest (opportunity cost) is calculated using the interest rate entered by the user in the Operating Cost section for interest on operating costs and the real rate of interest, calculated from user input on average investment entered in the ownership cost section of the program. The opportunity cost calculated for this example is $3.40 per head for operating and $95.13

per head for ownership costs. The printout indicates these are included in the Profitability analysis and excluded from the Cash Flow analysis.

Note: Be careful when budgeting that you do not assign a degree of accuracy to results that may not exist. The results are only as good as the data used to calculate the results. While a computer program will calculate numbers down to several decimal places, users should always be wary of how to interpret these calculations. An example is the treatment of interest (opportunity cost) discussed above. Eliminating all interest (opportunity costs) from the cash flow analysis may make the cash flow position look better than it actually is for an individual producer. It would be difficult to collect enough information from an individual to determine actual financing arrangements on all assets so that the true cash flows for actual principal and interest payments is include in the Cash Flow analysis. This spreadsheet is a budgeting tool and provides producers an opportunity to estimate profitability, cash flow and evaluate the impact of management changes in the enterprise.

Section 1: Renvenues and Cow Numbers Check--Cost of Production Estimates for Commercial Ewe Flock Enterprise

Double lined boxes and blue text indicate numbers that are required/allowed for data entry.

Number of ewes	1950	**Weaning Percentage**	120%
Cull Rate	20%	**Rep. Lambs Needed**	390
Value of Avg Ewe in Breeding Flock	$60	**Rep. Lambs Kept**	600

Value of Production

Value of Production for Actual Cash Sales

	Quantity	Net Market Weight	Price Per Pound	Pounds Produced	Value Per Head	Total Value
Wether	1170	94	$0.82	109,980	$77	$90,184
Ewe Lambs	570	88	$0.82	50,160	$72	$41,131
Cull Ewe Sales	350	150	$0.25	52,500	$38	$13,125
Cull Replacement Ewe Lamb Sales	200	120	$0.50	24,000	$60	$12,000
Other Income (Wool and .....)	1	17550	$1.00		$9	$17,550
Cull Ram Sales	4	200	$0.25	800	$50	$200
Totals	2295			237,440		$174,190
Total Pounds Produced From Wethers and Ewe Lambs				160,140		$131,314.80

Replacement Ewe Lambs	Quantity	Weight	Price Per Pound	Pounds Produced	Base Value Per Ewe	Total Value
Purchased Replacement Ewes/Lambs	0	0	$0.00		$0	$0.00
Raised Replacements	**Non-Cash Adjustments to the "Cash" Value of Production**					
Transferred of Raised Ewe Lambs To Breeding	390	85	$0.54	33,150	$46	$17,901.00
Death Loss of Replacement Ewe Lambs	10	115	$0.54	1,150	$62	($621)
Total Revenue (Lamb & Non-Lamb, Cash and Non-Cash)						$191,470

Since this is a "budget" for a typical years operation, ewe flock size should not vary significantly from the beginning to the end of the year. If the numbers entered show significant variation from the beginning to the end of the year in the numbers check below, adjust the cull ewe numbers, death loss, or replacement ewe lamb numbers until that variation is eliminated.

Check on Breeding Ewe Numbers (Beginning to End)	Number	Dollar Value
Beginning Inventory of Ewes	1950	$117,000
+ Raised Replacement Lambs Kept	600	$27,540
- Excess Raised Rep. Ewe Lambs Sold	200	($12,000)
+ Purchased Replacement Lambs	0	$0
- Cull Ewe Sales	350	($13,125)
- Death Loss Breeding Ewes	40	($1,500)
- Death Loss Replacement Ewes Lambs	10	($621)
= Ending Inventory	1950	$117,294

Template Options and Explanations:

This template can be used to estimate the costs of production and break-even prices for 1) Commercial Ewe Flock operations (owned or leased), 2) a feeders/backgrounding enterprise, or 3) a yearling enterprise. Each of these enterprises can be evaluated independent of the others, or you can start with the ewe flock enterprise and follow through each phase or production cycle to get to the desired end point. The "Feeders" page tab allows for both short and long term backgrounding and analysis of finished slaughter lambs, however not all at the same time. You may have to run the Feeders page info for each scenario desired if going to a finished slaughter weight through retained ownership.

This template can be used for analysis of cost share or cash leasing but if that is not your objective, simply ignore the columns and other information related to leases.

Please read the notes and helps included throughout this template to make sure you understand what number is to be entered or how to interpret a result. These notes and helps are indicated by a small red triangle in the upper right corner of a cell. Simple place your cursor on top of the cell to view the help message or note attached to that cell.

Section 2: Operating Costs for a Ewe Flock Enterprise

	Feed Costs (Raised and Purchased)	Units	Quantity	Price	Value	Value Per Head
	hay	ton	900.00	$80.00	$72,000	$36.92
Help	State lease	AUM	900.00	$3.50	$3,150	$1.62
	Forest service	AUM	600	$1.35	$810	$0.42
	Pasture Lease #2	AUM	0	$0.00	$0	$0.00
	Pasture Lease #3	AUM	0	$0.00	$0	$0.00
	Salt & Mineral	Ton	15.00	$500.00	$7,500	$3.85
	Barley	Ton	20.00	$70.00	$1,400	$0.72
	Crop Residue	AUM	1000.00	$0.00	$0	$0.00
	Straw	Ton	0.00	$0.00	$0	$0.00
	alfalfa pellets (processing)	ton	40.00	$45.00	$1,800	$0.92
	Other	Ton	0.00	$0.00	$0	$0.00
	Other	Ton	0.00	$0.00	$0	$0.00
	Subtotal of Feed Costs				$86,660	$44.44

		Price/Unit	No. of Units	Value	Value Per Head
Operating Costs Directly Associated With Livestock Care and Handling					
Help	Vet and Medicine			$2,400	$1.23
	Livestock Hauling (Not Related to Marketing)			$0	$0.00
	Professional Fees (Dues, Subscriptions, Legal, etc.)			$1,000	$0.51
	Hired Labor			$40,000	$20.51
	Marketing Costs				
	Sales Commission	$0.00	0.00	$0.00	$0.00
	Hauling to Market	$0.00	0.00	$0.00	$0.00
	Yardage	$0.00	0.00	$0.00	$0.00
	Custom Hire			$0	$0.00
	Rent or Lease (Vehicle, Machinery, Equipment)			$0	$0.00
	Utilities			$600	$0.31
	Supplies			$1,700	$0.87
	All Shearing Costs			$4,800	$2.46
	Other Operating Costs- tagging			$1,600	$0.82
Operating Costs of Facilities and Equip. Used in Lvstk Production.					
Help	Operating Costs of Equipment (Fuel, Oil, Repairs)			$1,000	$0.51
	Operating Costs on Machinery (Fuel, Oil, Repairs)			$1,000	$0.51
	Operating Costs of Vehicles (Fuel, Oil, Repairs)			$3,000	$1.54
	Facility Repairs and Maintenance				$0.00
	Fences			$30.00	$0.02
	Corrals			$0.00	$0.00
	Buildings			$650.00	$0.33
	Water Facilities			$800.00	$0.41
	Hired Labor			$0.00	$0.00
	Rent or Lease			$0.00	$0.00
	Supplies			$300.00	$0.15
	Utilities			$2,000.00	$1.03
	Other			$0.00	$0.00
	Other			$0.00	$0.00
	Other			$0.00	$0.00
SUBTOTAL OTHER VARIABLE COSTS				$60,880	$31.22

Interest on Operating Costs

Sum of Operating Costs x Months Borrowed
x Interest Rate Per Month

			Value	Value Per Head
	Annual Interest Rate (11% = .11)	9.00%		
	Avg. Number of Months Money Borrowed	6		
	Annual Inflation Rate (9% = .09)	3.00%		
Int. Formula	Total Interest Cost (Real Rate of Interest)		$6,639	$3.40
Total Operating Costs			$154,179	$79.07
Returns Above Total Operating Costs (Excluding Replacement Ewe Lambs Non-Cash Revenue; Includes Death Loss)			$19,390	$9.94

Section 3:

Ownership Costs for a Ewe Flock Enterprise

Machinery and Equipment used for Livestock

Depreciation	Item Name	Dollars Invested	Useful Life Yrs	Salvage Value	Calculated Depreciation	Value Per Head
Help	Tractor	$0	0	$0	$0	$0.00
	Tractor #2	$5,500	15	$4,000	$100	$0.05
	Pickup#1	$11,500	10	$4,000	$750	$0.38
	Pickup #2	$5,500	7	$3,000	$357	$0.18
	Lvstk Handling Equip	$0	0	$0	$0	$0.00
	Waters	$1,000	20	$0	$50	$0.03
	New Baler	$0	0	$0	$0	$0.00
	tractor #3	$0	0	$0	$0	$0.00
	Other	$0	0	$0	$0	$0.00
	Other	$0	0	$0	$0	$0.00
	Other	$0	0	$0	$0	$0.00
	Other	$0	0	$0	$0	$0.00
Dep. Formula	Totals	$23,500		$11,000		

Int. Formula	Interest (Opportunity Cost Using Real Rate of Int.)	$1,035	$0.53
	Personal Prop. Taxes on Mach & Equip Used for Lvstk	$100	$0.05
	Insurance	$200	$0.10

Buildings and Improvements Used for Livestock

	Item Name	Dollars Invested	Useful Life Yrs	Salvage Value	Calculated Depreciation	Value Per Head
Depreciation	Barn	$0	0	$0	$0	$0.00
	lamb shed #1	$3,000	20	$0	$150	$0.08
Help	lamb shed#2	$8,000	20	$0	$400	$0.21
	shed #1	$0	0	$0	$0	$0.00
	shed #2	$0	0	$0	$0	$0.00
	shed #3	$0	0	$0	$0	$0.00
	improvements	$1,500	20	$0	$75	$0.04
	Other	$0	0	$0	$0	$0.00
Dep. Formula	Totals	$12,500		$0		

Int. Formula	Interest (Opportunity Cost Using Real Rate of Int.)	$375	$0.19
	Personal Property Taxes and Buildings & Imprv.	$500	$0.26
	Insurance	$1,100	$0.56

Owned Land Used for Livestock Operations

	Parcel Description	No. Acres	Value/Acre	Total Value
Help	Pasture #1	10000	$100	$1,000,000
	Pasture #2	20000	$100	$2,000,000
	Pasture #3	0	$0	$0
	Extra	0	$0	$0
	Hay Base	0	$0	$0
	Grazing Land Purchase	0	$0	$0
	Hay Land Purchase	0	$0	$0
				$0
				$0
				$0
			Total	$3,000,000

Int. Formula	Interest (Opportunity Cost Using Real Rate of Int.)	$180,000	$92.31
	Real Estate Taxes	$12,800	$6.56
	Insurance -- Include in insurance cost under buildings and improvments		

Livestock -- Ewe Flock

Depreciation	Item Name	Dollars Invested	Useful Life Yrs	Salvage Value	Calculated Depreciation	Value Per Head
Help - Please	Rams	$18,000	4	$1,200	$4,200	$2.15
Read Important	Breeding Ewes	$117,000	0	$0	$0	$0.00
	Other Dep. Brding Stock	$0	0	$0	$0	$0.00
Dep. Formula	Totals	$135,000		$1,200		

Int. Formula	Interest (Opportunity Cost Using Real Rate of Int.)	$4,086	$2.10
	Personal Property Taxes	$1,000	$0.51

Total Ownership Costs	$207,278	$106.30
Total Costs (Operating Plus Ownership)	$361,457	$185.36
Returns Above Total Costs (Excludes Rep Ewe Lamb Non-Cash $; Includes Death Loss)	($187,889)	($96.35)
Returns Above Total Costs (Includes Rep Ewe Lamb Non-Cash $; Includes Death Loss)	($169,988)	($87.17)

Section 4: **Results-- Cost of Production and Leasing, if Leasing Analysis Utilized**

Lease share precentages based on how costs are shared	Lease Percent based on cost share
EweOwner share of Total Cost of Production	0.00%
Tenant's Share of Total Cost of Production	100.00%
check sum	100.00%

Weighted Average Sale Price	Weighted Average Sales Weight
$82.00	92.03

Interpretation of percentage split calculation

Profitability and Cash Flow Summary for the Ewe Flock Enterprise

For accurate presentation of the Profitability and Cash Flow tables below for the Ewe Owner and Tenant, sharing of cull ewe and cull ram revenue must be determined. Economic theory suggests that if the ewe owner is providing the replacement ewes and rams, he/she is entitled to all cull revenue. If however, replacements are kept from the lamb crop, and development costs are shared by the ewe owner and tenant, the cull revenue should also be shared.

	Y or N		Tenant-Owner
Is cull ewe revenue shared?	Y	If No, who receives revenue? (O or T)	O
Is cull ram revenue shared?	Y	If No, who receives revenue? (O or T)	T

Do not enter Yes or No, only Y or N, your input is not case sensative. **Enter only an O or T**

Graphics of Income and Expenses to right of this table. (Column R)

Interpretation of Profitability and Cash Flow--Caution

	For Entire Ewe Flock Enterprise			
	Profitability		Cash Flow	
Sources of Revenue	Total	Per Head	Total	Per Head
Wether	$90,184	$46.25	$90,184	$46.25
Ewe Lambs	$41,131	$21.09	$41,131	$21.09
Cull Ewes	$13,125	$6.73	$13,125	$6.73
Excess Rep Ewe Lambs	$12,000	$6.15	$12,000	$6.15
Cull Rams	$200	$0.10	$200	$0.10
Other Income (Wool, and ......)	$17,550	$9.00	$17,550	$9.00
Cash Revenue from Ewe Flock Enterprise – Subtotal	$174,190	$89.33	$174,190	$89.33
Non-Cash Revenue Adjustment - Rep Ewe Lambs	$17,901	$9.18		
Non-Cash Revenue Adjustment for Death Loss	($621)	($0.32)		
Total Revenue	$191,470	$98.19	$174,190	$89.33
	Percent total Revenue (Cash and Non-Cash) >>			
Operating Costs (Variable Costs)	Profitability		Cash Flow	
Feed Costs	$86,660	$44.44	$86,660	$44.44
Operating Costs Associated with Lvstk Care	$52,100	$26.72	$52,100	$26.72
Facilities and Equipment Operating Costs	$8,780	$4.50	$8,780	$4.50
Interest on Operating Costs	$6,639	$3.40		
Total Operating Costs of Production	$154,179	$79.07	$147,540	$75.66
Returns Above Operating Costs (Excluding Rep. Lamb N.C. Rev.)	$19,390	$9.94	$26,650	$13.67
Ownership Costs (Fixed Costs)				
Depreciation	$6,082	$3.12		
Insurance	$1,300	$0.67	$1,300	$0.67
Taxes	$14,400	$7.38	$14,400	$7.38
Interest (Opportunity Cost)	$185,496	$95.13		
Total Ownership Costs	$207,278	$106.30	$15,700	$8.05
Total Costs (Operating and Ownership)	$361,457	$185.36	$163,240	$83.71
Net Returns Above Operating Plus Ownership Costs	($169,988)	($87.17)	$10,950	$5.62
Enter the total value of unpaid family labor and management	$30,000			
Percent of unpaid labor and management for this enterprise	40%			
Return on Investment/Assets (ROI=ROA)	0.32%			

The breakeven calculations presented at right are based on the pounds of lamb actually sold. Emphasis are on costs and the breakeven is the amount lambs must sell for, to cover operating and total costs. The breakevens are calculated with and without consideration of non-lamb revenue (cull ewes, wool, etc.). Costs are adjusted for shearing.

Breakeven Calculations Excluding Non Lamb Revenue

	Operating Costs	Operating + Ownership Costs
Required Lambing Percentage (Using Weighted Averages) to Cover	101.51%	242.36%
Required Avg. Lamb Weaning Weights (Using Weighted Avg Prices)	104.70	249.97
Required Avg. Lamb Prices ($/Cwt) (Using Weighted Avg Weight)	$93.28	$222.72

Sheep and Goat Research Journal

NEWS BRIEFS

NIAA Awarded Grant to Help Implement National Scrapie Eradication Program

The National Institute for Animal Agriculture (NIAA) has been awarded a grant from the U.S. Department of Agriculture (USDA) to carryout a national producer education program for the soon-to-be launched effort to eradicate scrapie from the nation's sheep flocks and goat herds.

"NIAA's role in the program will be to communicate to producers the details of the program both directly and through trade associations and the media," explained Glenn N. Slack, NIAA president and chief executive officer. A comprehensive industry awareness and media relations campaign, labeled *Eradicate Scrapie!*, is underway and will coincide with the publication of new government regulations governing the interstate movement of sheep and goats. The regulation will be official upon publication in the Federal Register, which NIAA anticipates to be within the next 30 days.

NIAA, successor to the Livestock Conservation Institute (LCI), has played an integral role in past eradication efforts among cattle and swine, including tuberculosis, brucellosis, hog cholera and pseudorabies. The organization's Sheep Health Committee has been an advocate for scrapie eradication and has encouraged the development of a reliable diagnostic test.

"While we will be sending information directly to producers, we will also be working with the media to further disseminate information that will be important for sheep and goat producers to know and understand," said Slack. "Eradication initiatives require the support and cooperation at all levels: veterinarians, breed associations, livestock dealers and markets, meat packers and processors, show officials, transporters and producers, and it will be our job to explain what will be required by each segment," he points out.

The goal is to eradicate the disease in 10 years and to have the U.S. recognized internationally as "scrapie-free" in 17 years.

Scrapie is a degenerative and eventually fatal disease affecting the central nervous system in sheep and goats. Its control is complicated because the disease has an extremely long incubation period without clinical signs of symptoms of disease.

Scrapie is a member of the class of diseases called transmissible spongiform encephalopathies (TSE's). Other TSE's include bovine spongiform encephalopathy (BSE, a.k.a. "Mad Cow" disease) and Chronic Wasting Disease among deer and elk.

New Address

Effective January 1, 2001 all correspondence related to the *Sheep and Goat Research Journal* should be sent to the following new address:

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Our e-mail address has changed. We can now be contacted at sgrj@animalagriclture.org.

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You can visit the *Sheep and Goat Research Journal* website by logging on to www.animalagriculture.org/sgrj.

Call for Papers

Manuscripts are currently being accepted for publication in upcoming issues of the *Sheep and Goat Research Journal*. Send five copies of submitted manuscript to Sheep and Goat Research Journal, c/o National Institute for Animal Agriculture, 1910 Lyda Avenue, Bowling Green, KY 42104-5809. For more detailed information, please refer to the Guidelines for Authors on the inside back cover of this issue. Inquiries may be made via electronic mail at sgrj@animalagriculture.org, by phone at 270-782-9798, or by fax at 270-782-0188.

NIAA Announces Tour to Europe to Study Animal Health and Trade Issues

The National Institute for Animal Agriculture has announced that it will coordinate a study tour to Europe in December. Foot and Mouth Disease (FMD), bovine spongiform encephalopathy (BSE) and other animal health and trade issues will be at the center of discussions during the weeklong trip that will begin in Paris and also take participants to the French countryside.

NIAA Chief Executive Officer Glenn Slack said that NIAA is working to fill a void in continuing education and professional development opportunities for animal agriculture professionals. The international study tour will seek to provide a global perspective to the education and training process.

Participants will get a firsthand look at some of the animal health-related challenges confronting the European community, including BSE, FMD and other non-disease issues like genetically-modified organisms (GMO's). In addition, they will receive an introduction to the European Union (E.U.), explore the role of animal health in international trade, and receive an inside view of agriculture in a European country through farm visits.

Finally, the study tour, scheduled for the first week in December, will offer an incredible practical exposure to the French agricultural system, including animal identification, labeling and traceability.

Working with NIAA in the role of technical coordinator for the study tour is Dr. William Hueston, an international authority on transmissible spongiform encephalopathies. Hueston, currently the associate dean of the Virginia-Maryland Regional College of Veterinary Medicine, was recently named director of the new Center for Animal Health and Food Safety at the University of Minnesota.

Hueston said participants will meet in the conference center at the International Office of Epizootics (OIE), based in Paris. OIE is recognized by the World Trade Organization as the international standard setting body for animal health. The Director General of the OIE and others from their staff will be active participants in the meetings.

Slack said the tour is limited to only 20 participants in order to provide optimum interaction with the speakers and instructors. Activities will also be planned for spouses who attend. Reservations will be accepted on a first-come-first-serve basis; however, members of the National Institute for Animal Agriculture will be given first consideration.

Slack recommends that individuals interested in reserving a spot on the study tour, or who want to be put on the mailing list, receive a detailed brochure (including associated costs, a tentative itinerary, list of speakers (faculty), deadlines and a reservation form), contact Peggy Logsdon at NIAA headquarters (Phone: 270-782-9798; E-mail: **plogsdon@animalagriculture.org**).

NIAA Announces Scholarship for Fellowship Program

The National Institute for Animal Agriculture has announced that it will award a scholarship, equivalent to one-half the tuition fee, to a deserving individual seeking to participate in the Science, Politics and Animal Health Policy Executive Fellowship Program.

The program is designed to mold mid-career professionals into the animal health leaders of the 21st century by building their critical knowledge and skills. The fellowship program has three four-day modules examining animal health policy at the local, national, and international level. Locations for the modules are East Lansing, Mich., the Washington, D.C. area, and an international location. This year's class, the third since the program begin in 1998, will travel to Argentina for the international module.

"NIAA applauds the Michigan State University College of Veterinary Medicine, the Virginia-Maryland Regional College of Veterinary Medicine and the University of Minnesota College of Veterinary Medicine for administering and offering this executive fellowship program," said NIAA Chairman of the Board Richard D. Hull. "We support the program's objectives and are proud to offer this scholarship."

In exchange for tuition assistance, the scholarship recipient will be assigned a project dealing with a contemporary issue affecting animal agriculture. The project will be mutually agreeable between NIAA and the scholarship recipient, who will perform approximately 50-75 hours of service for NIAA in completing the assignment. The recipient will be offered an opportunity to report his/her finding or results during the 2001 NIAA Annual Meeting.

The NIAA Continuing Education Scholarship application deadline is August 15, 2001. The recipient will be announced approximately 30 days later, and all applicants notified immediately thereafter. Applications forms may be obtained on the Internet at www.animalagriculture.org or by calling (270-782-9798). Additional information on the Executive Fellowship Program may be obtained on the Internet at www.cvm.msu.edu/outreach.

The mission of the National Institute for Animal Agriculture is to be the forum for building consensus, to advance solutions for animal agriculture and to provide continuing education and communication linkages to animal agriculture professionals. Animal health is one of NIAA's primary areas of emphasis.

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Sheep & Goat Research Journal
Guidelines for Authors

Objective

The aim of the *Sheep & Goat Research Journal* is to publish timely sheep and goat research findings that can be used by scientists, educators, extension agents, and producers alike. Specifically, the *Journal* aims to encourage producer use of research that has practical application.

Editorial Policy

The *Sheep & Goat Research Journal* publishes articles of research relating to all aspects of sheep and goat production including marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and / or their products. All research articles must represent unpublished original research and conclusions reached must be supported by research results. Articles that promote commercial products or services will not be approved for publication. Articles that promote practical applied research are encouraged. The submission of review articles is accepted but will require the same review process as other submitted articles. At least one author of each submitted article must subscribe to the *Journal*. All manuscripts and correspondence should be addressed to Sheep & Goat Research Journal, c/o National Institute for Animal Agriculture, 1910 Lyda Avenue, Bowling Green, KY 42104-5809. Inquiries may also be sent via electronic mail to **sgrj@animalagriculture.org**.

Review Process

Manuscripts will be subject to critical review by an editorial board or others designated by the editor. Authors will be notified by mail of acceptance or rejection of papers. Manuscripts needing revision will be returned to authors and should be revised and returned by the deadline indicated. Papers not suitable for publication will be returned to the authors with a statement of reason for rejection. Consult the *Sheep & Goat Research Journal* Editorial Policy and Procedures for details of the technical requirements for manuscripts submitted to the *Journal*.

Manuscript Submission

Manuscripts should be mailed to the Sheep & Goat Research Journal, c/o National Institute for Animal Agriculture, 1910 Lyda Avenue, Bowling Green, KY 42104-5809. Five copies of each manuscript must be submitted. Each manuscript must be accompanied by a cover letter from the main corresponding author. The cover letter must include the mailing address, telephone and fax numbers, and e-mail address of the corresponding author. As a style reference, authors may refer to the *Publication Manual of the American Physiological Association*. Every effort is made to publish papers promptly. Normally, a paper is published approximately six months after it is received from the authors.

Format

Manuscripts must be typed and double-spaced. The lines on all pages, including those pages for Literature Cited and Figure Legends, must be numbered in the left margin beginning with the numeral one (1) at the top of the page. Submission of excessive tabular data is discouraged; tables should be limited to that data that is considered essential to the research findings. Tables must be typed, double-spaced, and placed on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

The following format should be used when submitting research manuscripts:

1st	**Summary** (250 words or less)
2nd	**Key Words** (up to 6)
3rd	**Introduction**
4th	**Materials and Methods**
5th	**Results and Discussion**
6th	**Conclusions**
7th	**Literature Cited**

When citing literature in the text, use both authors if there are only two. If there are more than two, use the first author and "et al." Please provide "interpretive summaries" for use by the sheep and goat industries in other media.

Proofing

Primary authors will receive galley proofs of articles for review. Corrected proofs should be returned by the deadline indicated. Failure to do so will result in delay of article publication.

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Fifty reprints of each article will be provided at no cost to the primary author. When galley proofs are sent, the author will be asked to complete a reprint order form.

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Technical Note

Research Note

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Research Note

Fall and Winter Grazing of Brassicas - a Value-Added Opportunity for Lamb Producers

David W. Koch[1], Conrad Kercher[2] and Ron Jones[3]

Summary

Fast-growing cold-tolerant brassicas can be grown as a second crop, providing low-cost, high quality forage for fall-grazing lambs. In this study, cultural methods on irrigated fields included species and varieties, establishment method, second-crop planting dates (July 17 to August 12) and volunteer grain control. Brassicas were planted after several primary crops. Studies were conducted at the Powell, WY, Research and Extension Center from 1986 to 1996. Lamb performance was evaluated in seven grazing studies. Brassica forage production declined about 770 kg/ha per week when planted after July 20. Two to 3 metric tons/ha of forage was available in all years, except 1992, when soil fertility was low. Average daily gain (ADG) was similar for turnips and other species (tyfon, rape, radish). Over all studies, lambs grazing brassicas gained 0.18 kg (0.13 to 0.25) per day. During the first month, lambs grazing turnips and other forages gained faster than drylot-fed lambs, but gained slower than drylot-fed lambs after the first month. Average lamb gain/ha was 308 kg. Gains of lambs grazing July-planted brassicas were 41% greater than with August-planted brassicas. The average number of lamb grazing days/ha was 1685. Brassica-grazed lambs gained subsequently as well in drylot as lambs not previously grazed. Carcass characteristics of lambs grazing brassicas were similar to those of lambs fattened in the drylot; however, grazed lambs required longer to reach target weights.

Key words: turnip, tyfon, rape, radish, sheep, weight gains.

Introduction

Each fall many lambs are sent to feedlots because quality forage is lacking. Significant value could be added if even a fraction of these lambs were retained for fall grazing on high-quality pasture for two to three months.

Fields on which irrigated small grains are grown commonly are left idle (fallowed) following harvest in late July or early August with a 2 to 2 ½ month growing season remaining for cold-tolerant crops, such as brassicas. Brassicas include turnips, rape, tyfon (a hybrid of turnip and Chinese cabbage) and related species. Planting turnips, rape and other similar fast-growing, frost-tolerant crops as a second crop can provide extended grazing with high-quality, low-cost forage. Additionally, these species can be used as break crops following plow-out of alfalfa and can be no-till seeded into herbicide-killed sod.

Brassicas require high levels of nitrogen and effectively use residual soil nitrogen from previously-grown alfalfa. In previous studies, with18 to 25 ppm soil nitrate nitrogen, turnips planted in mid-July after plow-out of alfalfa responded to nitrogen fertilizer. Greatest yield of turnips planted after alfalfa was produced with about half (56-67 kg N/ha) that needed after a small grain crop (Koch and Karakaya, 1998). Nitrogen fertilization is very important after malt barley harvest because there is generally little residual soil nitrogen. A soil test can assist in determining amount of nitrogen to apply. Brassicas require high phosphorus and potassium; however, fertilizer needs should be based on soil analyses.

The brassicas are high water-requiring crops; therefore, late-season irrigation is necessary. Although some brassicas are moderately tolerant to salt, turnips are not saline or alkaline tolerant.

Forage brassica varieties have a biennial growth habit, meaning that they produce only vegetative growth the year of planting. Tyfon produces leafy top growth like turnips but smaller fleshy roots than turnips. Both tyfon and turnips are near maximum production in about 60 days whereas rape, which produces a stalk, requires 75 days or more. Tyfon has a larger seed than turnips and requires at least twice the seeding rate for the same density of stand. Rape seed size is intermediate. Rape is potentially more productive than turnips and tyfon; however, animals do not eat its central stalk. Because residual stalks of rape mostly remain standing, rape can be seeded in mixtures with turnips and provide good winter soil protection following grazing.

There is a general lack of high-quality forage for fall grazing in many areas. Growing a second crop is a more efficient use of land, labor and capital than using the whole season to grow brassica crops. In addition to providing inexpensive high-quality forage, brassica grazing can reduce environmental problems associated with feedlots. Two unknowns related to brassica grazing are

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lamb carcass quality and performance of lambs if transferred from grazing to the feedlot.

Marten and Jordan, 1982, and Heinemann, 1979, reported lower performance with lambs than would be expected from the high nutritive value of turnips and other brassicas. Lambert et al. (1987) found that lambs fed hay, even of poor quality, while grazing brassicas performed better than lambs grazing brassica forage alone. Koch et al. (1987) reported gains of 0.21 to 0.25 kg/day with lambs grazing tyfon no-till seeded into permanent pasture, on which there was an estimated 840 kg dry matter/ha of grass.

One of the limitations of turnips and other brassicas is that they are hosts of the sugarbeet cyst nematode (Koch and Gray, 1999). In a previous study, lambs grazing 'Adagio', a nematode-resistant radish performed as well as lambs grazing turnips (Yun et al., 1999). Fall grazing did not diminish the ability of the radish crop to control soil nematodes. If sugarbeets are to be grown and the field is infested with sugarbeet nematode, a nematode-resistant radish variety should be used.

Materials and Methods

Soil and crop management.

The soil was a Garland clay loam (fine, mixed, mesic Typic Haplargid). All studies were at the Powell (Wyoming) Research and Extension (R&E) Center. Soil pH was 7.6 to 7.9, organic matter was 1.1 to 1.4%, electrical conductivity was 0.6 to 1.1 ds/m, P04-P (except in 1992) was 16 to 20 ppm, K was 178 to 202 ppm, and NO3-N was 11 to 19 ppm. In 1992, soil PO4-P was 9 ppm and both turnips and radishes showed phosphorus deficiency.

Elevation at the Powell R&E Center is 1330 m. Average date of first fall frost (0°C) is September 27; however, the brassicas grow until temperatures reach -7°C or lower. The site receives 19 cm annual precipitation. In all studies brassicas were furrow-irrigated. Annual snowfall is 33 cm, with 17 cm between September and December. In 1989, during grazing, several cm of snow fell and crusted overnight. Hay was fed for four days until the snow softened so that grazing could resume. Snow did not interfere with grazing in any other year.

All brassicas were no-till seeded into the stubble of the previous crop, except in 1990 and 1996 and one of the studies in 1987. The previous crop was 'Tangier' flatpea in 1987, small grains in 1986 and 1992, pea-oat in 1994 and 1995. The second study in 1987 was full-season, with sugar beets grown the previous year. Brassicas were planted after alfalfa was harvested and plowed out in 1990 and 1996 (Table 1). Loose straw from the previous barley grain crop in 1992 was baled and removed. In other years, the initial crop forage was removed as silage. A stubble of 15 to 25 cm, averaging 1075 kg/ha, was left.

Turnips were seeded at 2 to 3, rape at 3 to 5, tyfon at 4 to 6 and radishes at 25 to 28 kg/ha with a double-disk drill. Seeding into a stubble, in contrast to a tilled seedbed, facilitates more timely planting and reduces the cost of production. There is also less surface crusting and less erosion. The stubble also provides lambs with dry matter while grazing. Alternatively, turnips have been established successfully by aerial seeding prior to the last irrigation of the small grain crop. Also, after the previous crop harvest, turnips have been mixed with fertilizer and spun on with a fertilizer spreader or seeded with an air spreader. These broadcast seeding methods, where practical, should be followed with light tillage to improve establishment. Corrugations were cleaned before the first irrigation.

Ammonium nitrate fertilizer was broadcast at the time of brassica planting. Ammonium nitrate, rather than urea, should be used with no-till plantings because urea is subject to considerable loss of nitrogen to the atmosphere. Rates varied from 67 to 112 kg N/ha. Brassicas are high water-requiring crops. Depending on rainfall, they were irrigated two to four times.

Glyphosate (Roundup® at 1.75 l/ha) was applied before planting if weeds or volunteer plants were present (1986, 1994, and 1996). A post-emergence herbicide was applied in 1992 to control the large amount of volunteer barley germination. Volunteer forage is highly nutritious; however, if it is dense or if it germinates before brassica seed, it can be excessively competitive. A tank mix of sethoxydim (Poast®) at 1.75 and crop oil at 2.3 l/ha suppressed volunteer plants adequately. In 1987, paraquat (.28 kg active ingredient/ha) was used to control annual weeds and flatpea regrowth before planting. Trifluralin (Treflan®) at 1.75 l/ha was used in 1987 with full-season rape and stock beets and in 1990 for pre-emergent control of annual weeds.

Planting dates were as soon as possible following harvest of the primary crop. Dates ranged from July 17 to August 12. Initial crops harvested as silage allowed an earlier second crop planting than crops harvested as grain. The late date in 1992 (Aug. 12) was the result of later-than-usual maturity of barley, harvested as grain.

Studies were designed to evaluate several alternatives, including turnips vs tyfon, rape, or radishes; turnips vs feedlot diets; and turnips vs sugar beet tops. In two studies (1994 and 1995), lambs were slaughtered directly after grazing in order to evaluate carcass characteristics, compared with drylot-fed lambs. Lambs were slaughtered at a commercial packing company. Warm carcass weights, quality and yield grades were determined. In 1994 and 1995 the effect of turnip and radish grazing on subsequent lamb performance in drylot was studied.

Animal and grazing management.

Individual full weights were taken at the start of trials, at 2-week intervals and when lambs were transferred from grazing to feedlot diets in 1994 and 1995. Lambs were initially allocated to treatments on an equal weight basis. Lambs had been weaned off ewes on pasture. Columbia-Rambouillet crossbred lambs were stocked at 35 to 50 lambs/ha in blocks of about 0.2 ha. Grazing animals received no supplemental feed, except in 1996, when a hay-supplemented group of lambs was included. Rotationally-grazed lambs were moved at approximately 2 weeks (10 to 20 days, dependent on amount of forage and size of lambs). Grazing periods varied from 26 days in 1992 to 84 days in 1995. Lambs were vaccinated for overeating (enterotoxemia) before grazing. All lambs were treated for internal parasites. Drylot comparisons were used in 1986, 1990, 1994, and 1995.

The feedlot diet consisted of 35% corn, 35% barley, 30% chopped alfalfa hay plus 0.36% mineral supplement (same as grazed) plus 1 oz. Bovatec®/ton. The amount of feed increased from 0.23 kg/lamb initially to 1.5 kg/lamb after 11 days. Water and a mineral supplement were provided free-choice to both drylot and grazing animals. In 1996, the hay group of lambs received 0.45 kg ground alfalfa hay/head/day.

Important dates are shown in Table 1. Second crop planting date, over the 7 years, varied from July 17 to August 12 . Grazing of second-crop brassicas was initiated as early as October 6 and as late as November 19. Lambs grazed until January 6 in 1987. On December 14, 1994, and on January 15, 1996 (1995 study), lambs were slaughtered at a commercial packing company. Warm carcass weights, yield grades, and fat depths were obtained. Dressing percentages were calculated as warm carcass weights divided by final pasture or feedlot weight.

Forage analyses.

Forage dry matter was determined with samples hand clipped from three random locations within each 0.2-ha plot. After grinding in a Wiley mill (1-mm screen), forage composition was determined according to A.O.A.C. (1975) procedures for all components, except for acid detergent fiber (ADF), neutral detergent fiber (NDF) and in vitro dry matter disappearance (IVDMD), which were determined according to the procedures of Goering and Van Soest (1970, ADF, NDF) and Tilley and Terry (1963, IVDMD). Forage yields were estimated from six 0.5 m2 samples of forage per pasture taken at the start of the grazing period.

Statistical analysis.

A randomized complete block design was used with all studies, except in 1992. Unreplicated blocks were sampled and grazed in 1992 due to poor overall growth of turnips and radishes. Data (except in 1992) were analyzed with procedures of SAS (1989). Treatment means were separated using LSD procedures when the effect of treatment was significant ($P<0.05$).

Results

Effect of planting date.

Planting date is probably the biggest factor in the productivity of turnips and other brassicas. Each day delay in planting results in a significant decline in dry matter accumulation. Average second crop planting date for the 14 plantings in Wyoming since 1986 was July 29 (July 17 to August 12). July plantings of turnips averaged 3900 and August plantings averaged 2500 kg dry matter/ha. Decline in production for each week delay in planting after July 20 averaged 700 kg/ha or about 25% of potential productivity per week. Thus, yield from an August 15 planting will likely be half that of a July 20 planting.

Turnips vs other brassica (tyfon, rape, radishes and beet tops) production.

Turnips were as productive as other brassicas, even though as much as half of the productivity in late fall was in the fleshy roots (Koch, 1995). Whereas perhaps 25% of turnip fleshy roots are aboveground, the bulk of roots are ungrazed, unless roots are mechanically removed before the ground freezes. Roots that are frozen solid and subsequently thaw soften and deteriorate rapidly. The grazing value of leafy growth, as long as it is not matted to the ground, will be preserved longer than that of roots.

In 1986 and 1987, turnip variety Green Globe was compared with tyfon. Shoot (top) growth was greater for tyfon; however, fleshy root growth was greater for Green Globe turnips (Table 2). Tyfon produces small fleshy roots, compared with turnips. In 1987 (Study 1), sugar beet tops provided a similar number of lamb grazing days, gain per animal and gain per hectare as turnips and tyfon (Table 3), even though sugar beet tops were lower in crude protein (CP) and IVDMD and higher in NDF (Table 4).

Turnips and radishes were compared in 1992, 1994 and 1995 (Table 2). In 1992, yields of both species were low due to low soil fertility. In 1994 and 1995, radishes produced about 1260 kg/ha more shoot or top growth than turnips; however, turnips produced as much fleshy root growth as tops (2.92 vs 2.56 tons/ha for roots and tops, respectively). Delayed grazing results in a translocation of dry matter from tops to roots, as shown in 1994 from October to November.

Tilled vs no-till seedbed.

In previous studies, turnips were more productive when planted into a tilled seedbed than when no-till planted (Koch, 1990). At Torrington (Wyoming) R&E Center, turnips planted July 29 into a tilled seedbed yielded nearly 5600 kg/ha of tops and fleshy roots, whereas turnips drilled into barley stubble produced nearly 4500 kg/ha. Most of the difference in production was in fleshy root growth. The 20% lower production with stubble planting is less than the average loss in production from a delay of one week in planting turnips. It may require a week, or more, to prepare a clean tilled seedbed, offsetting the advantage of clean tillage. A tilled seedbed is also more expensive and leaves no straw and generally no volunteer growth. For this reason, it may be desirable to supply high-fiber hay or other dry forage to animals grazing brassicas grown on a tilled seedbed.

Forage availability and utilization.

Five to 8 metric tons/ha of forage (dry matter) were available in all years except 1992, when production was poor due to low soil fertility (Table 2). One-half to more than 1 metric ton/ha of the total forage available was high-fiber regrowth of a previous crop and/or straw. In 1994, a typical year, between 85 and 90% of turnip and radish tops were consumed (Table 5). About half of turnip roots were utilized, even though roots were not removed from the ground. An estimated 1/3 of the roots of turnips grew above ground. Very few radish roots were consumed by lambs. More than 90% of regrowth (mostly oats) and more than half of the straw was consumed.

Brassica forage quality.

Over four different studies, turnip tops sampled in October averaged 13.1% (CP), but ranged from 11.5% in 1994 to 17.7% in 1991 (Table 4). Turnip roots averaged 10.0% and varied from 7.2 to 13.2% CP. By comparison, radish tops tested an average 11.9% CP (2 years) and sugar beet tops tested 8.8% CP (one year only). In 1992, a year when fertility was low, the CP of turnips was 7.2% (data not shown), clearly indicating an N deficiency. Over about 6 weeks (early October to mid-November), turnip tops and roots lost 3.4 and 1.1 percentage units of CP, respectively. In 1991, CP content of turnip tops declined from 17.7% on October 3 to 10.9% on January 6. Turnips were sampled just before being grazed. Crude protein content varied much more from study to study than other forage quality components. The relationship between brassica forage quality and soil nitrogen fertility and nitrogen fertilization was not studied.

The NDF content of turnip tops and roots averaged 23.8 and 20.9%, respectively, (Table 4) compared with an expected 40% NDF with alfalfa in late bud-early flower. Sugar beet tops were about 10 units higher (34.5% NDF) than turnip tops in 1987. There is an inverse relationship between NDF and animal intake of forage. The ADF content of turnip tops and roots averaged 19.8 and 17.2%, respectively. This compares with an expected ADF of high-quality alfalfa of 30% ADF. Sugar beet top ADF content in 1987 was 23.9%. There is an inverse relationship between ADF and digestibility. Turnips would be expected to be quickly digested in the rumen.

The IVDMD content of turnip tops and roots were high, averaging 85.7 and 86.4%. This is related to the low fiber content of tops and roots. Beet top IVDMD in 1987 was 80.4%. In 1991, ADF and NDF of turnip tops increased about four units each from October 3 to January 6 and IVDMD declined about seven units during the same period; however, forage quality was still relatively high on the latter date. In 1994 and 1995, radish tops sampled on the same dates were similar to turnip tops in all forage quality components, indicating that radishes should be a good substitute for turnips on land where the latter should not be grown.

In 1994, estimated availability of total forage was about 8 metric tons/ha of dry matter. Overall, about 2/3 of the total forage was consumed. Top growth of both turnips and radishes was more than 87% utilized. Lambs consumed very little radish roots and about half of turnip roots. Removal of roots from the ground would improve turnip root utilization. Regrowth of the previous crop (mostly oats) was more than 90% utilized, whereas dead straw stubble of the previous pea-oat crop was over half utilized.

Lamb performance on turnips.
Turnips were evaluated in seven lamb grazing trials (Table 3). One hundred ninety-one lambs grazed a total of 4690 days. Over all studies, average daily gain (ADG) of lambs was 0.183 kg. Greatest gain was in 1990 (0.25 kg/day) when lambs grazed turnips planted after plow down of alfalfa. The comparative gain of drylot lambs during the same 39-day grazing period was 0.23 kg/day. Least gain on turnips was in 1994 (0.13 kg/day). In 1994, lambs remained longer on paddocks relative to the amount of forage available than in other years, utilizing more than 88% of turnip tops (Table 3), compared with about 75% in previous years. Gain at the midpoint (35 days) was 0.16 kg/day in 1994. Average gain for lambs grazing turnips was 308 kg/ha.

In most years, turnips grow until early October. Fields planned for early-planted crops the next year (barley, beets) can be grazed first, so that fields can be fall tilled.

Turnips vs other forages.
Lamb gains/ha were similar for grazed turnips and tyfon in1986 and 1987; similar for turnips and sugar beet tops (1987); and similar for turnips and radishes in 1992, 1994 and 1995 (P>0.05) (Table 3).

Well-fertilized and irrigated turnips and other brassicas should carry an average of 50 lambs/ha for 30 days. Carrying capacity for 50 lambs declined from 37 days/ha with July seedings (average July 21 planting date) to 29 days/ha with August seedings (average August 6 planting date). Actual carrying capacity depends on amount of forage and size of lambs.

Grazing turnips vs drylot.
With periods of less than 1 month, liveweight gains were greater for lambs grazing turnips and other forages (data not shown) than for drylot-fed lambs. Lambs with previous grazing experience, as in these studies, needed no adjustment to turnips and other forages, even though they were more succulent, in most cases than previously grazed forages. Until they were on full feed, drylot lambs gained less per day than pastured lambs. Averaged over four years, lambs grazing turnips for 39 days gained 0.18 kg/day, and drylot lambs gained 0.20 kg/day (Table 3). After 35-40 days, rate of gain on turnips and other grazed forage decreased, whereas rate of gain in drylot increased.

Effect of previous crop.
Greatest lamb gains per day and per hectare were on turnips planted following plow-out of aged alfalfa stands (0.25 kg/day and 419 kg/ha in 1990 and 0.21 kg/day and 439 kg/ha in 1996). Part of the reason for the greater gains was the earlier planting of turnips and greater production of dry matter. Turnips were planted on July 23 and July 17 in 1990 and 1996, respectively. Although turnips were planted into a tilled seedbed in 1990 and 1996, in contrast to planting into stubble in other years, previous studies showed little difference in yield for turnips planted into tilled seedbeds and turnips seeded no-till into stubble.

Effect of fiber.
As previously mentioned, providing fiber in the form of hay to lambs grazing succulent pasture, such as turnips and other brassicas, may improve performance. In these studies, turnips and other fall-grazed forages were planted into stubble of the previous crop. Estimated average stubble was 1200 kg/ha. In 1996, turnips were planted into a clean-tilled seedbed. One group of lambs grazed turnips as the sole diet, while the other group of lambs grazed turnips and was fed 0.45 kg ground alfalfa hay/head daily. Both groups of lambs gained 0.21 kg/day (Table 3), indicating that additional fiber was not necessary for the 48-day duration of this study, contrary to the results of Lambert et al., 1987.

Effect of parasite treatments.
In 1990, two parasite treatments were compared. Half of each group of lambs (54) were treated with either Ivomec® or SafeGuard®. Average daily gains for Ivomec- and SafeGuard-treated lambs were 0.227 and 0.22 kg/day, respectively, and did not differ (P>0.05).

Effect of turnip grazing on later drylot gains.
Groups of lambs grazed either turnips or radishes for 10 weeks in 1994 and 12 weeks in 1995; other groups grazed turnips or radishes for 5 weeks (1994) and 6 weeks (1995) and were transferred to a drylot diet for the remaining 5 or 6 weeks. An additional group of lambs received a feedlot diet for the full 10 or 12 weeks (Table 1).

During the initial 5-week grazing period in 1994 and 6-week period in 1995, lambs that grazed radishes and turnips gained similarly (0.13 to 0.17 kg ADG) (data not shown). Lambs on a feedlot diet had the best ADG for 10 weeks (0.23 kg) and lambs grazing turnips and radishes continuously for 10 weeks in 1994 had the poorest ADG (0.12 to 0.13 kg). In 1995, lambs continuously grazing turnips or radishes for 12 weeks and lambs in the feedlot for 12 weeks performed similarly (0.15 to 0.17 kg/day). Lamb gains in the feedlot (0.15 kg/day) were lower than usually obtained. Also, lambs grazing turnips and radishes gained better in 1995 than in 1994, possibly because of larger grazing areas in 1995. Lambs transferred to the feedlot after grazing turnips or radishes for 10 weeks in 1994 or 12 weeks in 1995 performed similarly to lambs continuously in the feedlot (data not shown).

Effect on carcass characteristics.
Carcass weights were greater for feedlot lambs than for lambs grazing radishes and turnips for 10 weeks in 1994 (Table 6). There were no differences among carcass weights in 1995. Dressing percentage was greatest with lambs in the feedlot and least with lambs grazing turnips in 1994. In 1995, dressing percentage was greater than 50% for continuous feedlot lambs and less than 50% for lambs grazing continuously. Yield grade and fat depth of lambs in the feedlot were greater than for lambs that grazed turnips in 1994; however, there were no differences in 1995. Lambs grazing turnips and radishes, without a concentrate, produced acceptable market size and carcass grade but they required more time than feedlot lambs to reach similar weight.

The tendency for less fat, as with grazed lambs, is increasingly desired by consumers and the delay in reaching market weight, as with brassica grazing, might also be a benefit if as a result lambs are marketed off-peak season. Estimated cost of growing and grazing turnips and other brassicas is $220 to $250/ha, resulting in $0.72 to $0.79/kg of gain. Utilizing even a portion of the otherwise fallow acreage of irrigated small grains to grow and graze brassicas could result in significant value added to the lamb crop each year.

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Table 1. Agronomic and animal data for grazing studies conducted at the Powell Research and Extension Center, 1986-1995.

Year	1986	1987	1987	1990
Previous crop	Barley (silage)	Flatpea (silage)	Sugar beets	Alfalfa
Planting date	July 23	Aug 4	May 10	July 23
Varieties	Green Globe turnip; tyfon	Green Globe turnip; tyfon	Emerald rape; Stock beets	Green Globe turnip; Emerald rape
Weed control, l/ha	Roundup®, 1.75	Paraquat®, 1.17	Treflan®, 1.75	Treflan®, 1.75
Fertilizer, N-P-K, kg/ha	112-0-0	112-0-0	280-100-0	140-84-0
Tillage	Stubble seeded	Stubble seeded	Fall plowed	Plowed following first cutting of alfalfa
Irrigation	2x	4x	4x	3x
Treatment comparisons	Turnips; tyfon; drylot	Turnips; tyfon; sugar beet tops	Rape; stock beets	Rape, full season; rape, following alfalfa; turnip following alfalfa
Design[1]	RCB 3 groups of 10	RCB 3 groups of 8	RCB 3 groups of 10	RCB 3 groups of 9
Grazing period	Oct 24-Dec 1	Nov 4-Jan. 6	July 28-Sept 28	Nov 9-Dec 18

Year	1992	1994	1995	1996
Previous crop	Barley (grain)	Pea-oat (silage)	Pea-oat (silage)	Alfalfa (hay)
Planting date	Aug 12	July 20	Aug 02	July 17
Varieties	Green Globe turnip; Adagio radish	Purpletop turnip; Adagio radish	Purple top turnip; Adagio radish	Purpletop turnip
Weed control, l/ha	Poast® (1.75)+ crop oil conc. (2.4)	Roundup®, 1.75	Roundup®, 2.35	Roundup® + 2,4-D, 1.2 each
Fertilizer, N-P-K, kg/ha	112-0-0	67-0-0	84-56-0	112-0-0
Tillage	Stubble seeded	Stubble seeded	Stubble seeded	Plowed following first cutting of alfalfa
Irrigation	2x	3x	3x	4x
Treatments	Turnip; radish	Continuous radish and turnip grazing; radish and turnip grazing, followed by feedlot; continuous feedlot		Turnips; turnips + hay
Design[1]	Unreplicated	RCB 3 groups of 10	RCB 3 groups of 10	RCB 3 groups of 10
Grazing period	Nov 19-Dec 15	Oct 6-Dec 14	Oct 24-Jan 15	Oct 30-Dec 17

[1] Randomized complete block.

Table 2. Estimated availability of brassicas and other forages.

Seeded forage	Sampling date	Seeded species Shoots	 Roots	Previous crop regrowth[1]	Straw[2]	Total forage
				metric tons d.m./ha		
Turnip	Oct 1, 1986	3.88 a	1.80	0.49 a	0.67	6.84 a
Tyfon	Oct 1, 1986	4.29 a	-	0.56 a	0.67	5.52 b
Turnip	Nov 4, 1987	3.41 b	2.69	0.61 a	0.67	7.38 a
Tyfon	Nov 4, 1987	5.43 a	-	0.54 a	0.67	6.64 a
Turnip	Oct 23, 1992	1.14	0.67	0.47	0.45	2.73
Radish	Oct 23, 1992	1.77	-	0.18	0.45	2.40
Radish	Oct 6, 1994	4.74 a	1.35 b	0.92 b	0.90	7.91 a
Turnip	Oct 6, 1994	3.43 b	2.47 a	1.30 a	0.90	8.10 a
Radish	Nov 15, 1994	3.73 a	1.80 b	0.88 b	0.90	7.31 a
Turnip	Nov 15, 1994	1.84 b	4.27 a	1.32 a	0.67	8.10 a
Radish	Oct 18, 1995	2.99 a	1.12 b	0.74 a	1.35	6.20 a
Turnip	Oct 18, 1995	2.20 b	2.02 a	0.83 a	1.12	6.17 a

Means within columns and years with common letters do not differ, $P>0.05$. The 1992 study was unreplicated.

[1] Barley, flatpea, barley, and pea-oat regrowth or volunteer for 1987, 1992, 1994 and 1995, respectively.

[2] Dead stubble from the previous crop.

Table 3. Live weight gains of lambs grazing turnips and other forages.

Grazing trial	No. of lambs	No. of days	Initial weight	Final weight	Average gain per day	Average gain per ha	Lamb grazing days/ha
			kg	kg	kg	kg	
1986							
Turnips	30	38	34.7	41.4	0.18 a	389 a	2198
Tyfon	30	38	34.7	42.1	0.20 a	419 a	2198
Drylot	30	38	34.7	42.0	0.19 a	-	-
1987							
Study 1:							
Turnips	24	41	34.5	43.3	0.21 a	360 a	1680
Tyfon	24	41	34.9	43.3	0.20 a	335 a	1680
Sugarbeet tops	24	41	35.3	43.4	0.20 a	333 a	1680
Study 2:							
Rape, full-season	30	62	33.4	46.3	0.21 a	616 a	2954
Stock beets, full-season	30	48	33.4	39.4	0.13 b	301 b	2324
1990							
Rape, full-season	27	39	34.6	41.7	0.19 b	308 b	1680

Grazing trial	No. of lambs	No. of days	Initial weight	Final weight	Average gain per day	Average gain per ha	Lamb grazing days/ha
Rape, following alfalfa	27	39	32.9	42.9	0.26 a	370 a	1680
Turnips, following alfalfa	27	39	35.8	45.6	0.25 a	419 a	1680
Drylot	13	39	34.6	43.7	0.23 a	-	-
1992							
Turnip	20	26	39.6	43.2	0.14	87	622
Radish	20	26	38.0	42.6	0.18	110	622
1994							
Radish[1]	15/30	35/70	38.7	47.3	0.14 b	221 a	1588
Turnip[1]	15/30	35/70	38.8	47.5	0.13 b	206 a	1549
Drylot	30	70	39.0	54.9	0.23 a	-	-
1995							
Radish[2]	15/30	42/84	37.7	44.1	0.15 a	300 a	1974
Turnip[2]	15/30	42/84	37.5	43.6	0.14 a	321 a	1074
Drylot	30	84	37.4	43.9	0.15 a	-	-
1996							
Turnip	35	48	36.1	46.3	0.21 a	439 a	2075

					Average gain		Lamb
Grazing trial	No. of lambs	No. of days	Initial weight	Final weight	per day	per ha	grazing days/ha
Turnip with hay	35	48	36.6	46.9	0.21 a	445 a	2075

[1] 30 lambs for 35 days; 15 lambs for 70 days.

[2] 30 lambs for 42 days; 15 lambs for 84 days.

Means within years and studies with the same letter are not significantly different (P>0.05). The 1992 study was unreplicated.

Table 4. Forage nutritive value of turnips and other forages.

Study	Sampling		Component			
year	date	Seeded species	CP	ADF	NDF	IVDMD
			%, c.m. basis			
1987	Oct 14	Turnip tops	11.0 ab	25.1 a	24.0 b	89.7 a
		Tyfon tops	9.3 bc	23.2 a	23.3 b	87.6 a
		Beet tops	8.8 c	23.9 a	34.5 a	80.4 b
1991	Oct 3	Turnip tops	17.7 a	20.9 b	22.7 c	90.4 a
	Nov 26	Turnip tops	15.5 b	23.6 a	25.1 b	86.6 ab
	Jan 6	Turnip tops	10.9 cd	24.6 a	26.9 a	83.4 b
	Oct 3	Turnip roots	13.2 c	23.7 a	24.9 b	85.7 b
	Nov 26	Turnip roots	11.1 cd	24.0 a	25.4 ab	82.8 b
1994	Oct 6	Radish tops	12.7 a	18.5 a	24.9 ab	80.0 d
		Turnip tops	11.5 a	17.1 ab	23.0 ab	81.2 cd
		Turnip roots	7.2 b	12.7 c	17.8 c	88.0 a
	Nov 15	Radish tops	8.3 b	18.0 ab	25.7 a	83.4 bcd
		Turnip tops	7.0 b	16.6 b	22.7 b	84.2 bc
		Turnip roots	7.1 b	13.1 c	18.1 c	86.5 ab
1995	Oct 18	Radish tops	11.0 ab	18.8 a	26.3 a	85.8 a
		Turnip tops	12.1 a	15.5 b	22.3 b	85.9 a
		Turnip roots	9.6 b	12.4 c	18.3 c	89.1 a

CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; IVDMD = in vitro dry matter disappearance.

Means within a column and year followed by the same letter are not significantly different.

Table 5. Estimated utilization of available forages[1].

Year	Seeded species	Seeded species Tops	Seeded species Roots[2]	Regrowth	Straw	Total
		Availability, kg/ha				
1994	Turnip	2082	1981	747	1217	6027
	Radish	2972	1167	702	1145	5986
		Utilization, kg/ha				
1994	Turnip	1838	1052	681	684	4255
	Radish	2585	50	646	670	3951
		Utilization, %				
1994	Turnip	88.3	53.1	91.2	56.2	70.6
	Radish	87.0	4.3	92.0	58.5	66.0

There were no significant differences ($P>0.05$) between turnip and radish means.

[1] Weeds (<390 kg/ha) were not included.

[2] Fleshy roots only.

Table 6. Carcass characteristics of turnip-grazed lambs in comparison to radish-grazed and drylot-fed lambs.

Year	Species/feed	Dressing percentage	Carcass weight	Yield grade	Fat depth
			kg		cm
1994	Radish, 10 weeks	48.1 b	22.7 b	1.8 ab	0.13 ab
	Turnip, 10 weeks	46.5 b	21.8 b	1.5 b	0.10 b
	Drylot, 10 weeks	50.0 a	26.7 a	2.2 a	0.18 a
1995	Radish, 12 weeks	48.8 b	24.2 a	1.5 a	0.10 a
	Turnip, 12 weeks	48.8 b	24.6 a	1.7 a	0.13 a
	Drylot, 12 weeks	50.1 a	25.3 a	1.6 a	0.13 a

Means within years and studies with the same letter are not significantly different ($P>0.05$).

Effects of Prenatal Shearing of Ewes on Birth Weight and Neonatal Survivability of Lambs

S.J. Falck[1], G.E. Carstens[1,2] and D.F. Waldron[3]

Summary

A three-year study was conducted with a flock of mixed-aged Rambouillet ewes to determine the effect of late-gestation shearing on lamb birth weights (N = 480) and survival rates during the neonatal period in typical West Texas conditions. Ewes were randomly assigned, within sire family and year of birth, to one of two shearing treatments, prenatal shorn or unshorn. The ewes remained on the same treatment for all 3 years. The prenatal shorn ewes were shorn in early January, 2 to 54 d prior to lambing (mean = 20 d). The unshorn ewes were shorn after lambs were an average of 96 d old. Lamb survival rates were analyzed using a model that included fixed effects of shearing, year, sex of lamb, type of birth, age of dam, significant interactions, and linear and quadratic effects of birth weight and ambient minimum temperature on the day of birth. Lamb survival rates were not affected by age of dam, but were lower ($P < .02$) on day 3 for triplet compared to twin and single lambs (74.3, 88.0 and 89.2 ± 5%, respectively). A significant interaction between sex of lamb and shear treatment ($P < .05$) was found for lamb survival. Male lambs from shorn ewes had 12% lower ($P < .01$) survival rates at one day of age than male lambs born to unshorn ewes, whereas, survival rates of female lambs was not affected by prenatal shear treatment. Lamb birth weight ranged from 1.6 to 7 kg and was not affected by shear treatment ($P > .5$). Lamb survival rates increased quadratically as both birth weight ($P < .05$) increased and as minimum temperature on day of birth ($P < .01$) increased. Predicted lamb survival rates at 3 days of age for 3, 4, 5, and 6 kg birth weight lambs were 81.7, 91.0, 95.0 and 94.0 ± 4%, respectively. Predicted lamb survival rates at 3 days of age for minimum temperatures at lambing of -7, -1 and 4° C were 72.1, 88.8 and 93.5 ± 5%, respectively. The results of the present study demonstrate that prenatal shearing of Rambouillet ewes 20 d prior to lambing in typical West Texas conditions did not increase birth weights or improve survival rates of neonatal lambs.

Key words: birth weight, lambs, shearing, survivability

Introduction

Lamb deaths represent a considerable economic loss to the sheep industry each year. A 1996 USDA report estimated that 9.4% of lambs born alive died prior to weaning. In Michigan flocks, Rook (1989) reported mortality rates of 15 to 20%, and found that the majority of these deaths occurred within the first three days of life.

Simpson (1995) found that weather related causes were responsible for 40.5% of the lamb deaths, with only predator losses accounting for a greater proportion of lamb deaths. Weather losses include deaths from lightning, drowning, and chilling. Other post-mortem studies suggest that 30% of all neonatal deaths may be the result of hypothermia, starvation, or the combination of the two (McCutcheon et al., 1981). Hypothermia and starvation share physiological mechanisms and each condition may contribute to the other. Lambs in a cold environment must increase heat production to avoid hypothermia. This increased heat production depletes body reserves and can lead to starvation unless the lamb receives adequate energy from nursing. As lambs become hypothermic their ability to suckle is impaired. Failure to suckle, whether from mismothering, central nervous system injury due to dystocia, or discomfort will result in starvation, thereby contributing to hypothermia as lambs have less energy to utilize for heat production. This phenomenon has been called the starvation-exposure syndrome (McCutcheon et al., 1981).

In a study conducted in Nebraska, Azzam et al. (1993) examined the effects of environmental conditions on neonatal calf mortality rates. They reported that mortality rates of non-dystocia calves born in a dry environment increased from less than 4% at 30° C to over 18% when the ambient temperature was -20° C. Precipitation amount on the day of calving also negatively affected calf mortality rates, particularly at lower temperatures. Azzam et al. (1993) also found that calves with low birth weights (< 1.5 SD below the mean) had much higher mortality rates than heavier calves. Low birth weight lambs are also much more susceptible to death during the neonatal period than heavier lambs. Alexander and McCance (1958) reported that the rectal temperatures of lambs that died within 72 h of birth were significantly

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lower at 6 h of age than the temperatures of lambs that survived.

Management practices that are able to reduce the incidence of low birth weights of lambs will likely increase lamb survival rates. Rutter et al. (1971) demonstrated that shearing pregnant ewes 7 weeks prior to parturition increased lamb birth weights by 16% compared with unshorn ewes. Mortality rates also decreased from 35.8% in lambs born to unshorn ewes to 18.5% in lambs born to shorn ewes. Thompson et al. (1982) found that lambs born to shorn ewes and exposed to cold temperatures (1 to 6° C) for 5 weeks prior to lambing were 27% heavier than lambs born to unshorn ewes and exposed to warmer ambient temperatures (15° C).

A number of studies conducted outside of the United States have examined the effects of prenatal shearing on lamb survival rates. The objective of this experiment was to determine if shearing pregnant ewes during late gestation would increase birth weight and improve lamb survival in a West Texas Rambouillet flock.

Materials and Methods

A three-year study was conducted with a flock of mixed-aged Rambouillet ewes. Prior to mating in the first year of the study, ewes were randomly assigned, within sire family, and year of birth to one of two shearing treatments. The treatments consisted of shearing prior to lambing (prenatal shorn ewes) and shearing after lambing (unshorn ewes). The ewes in the unshorn group were tagged (sheared around udder and between rear legs) on the same day as the prenatal shearing group was shorn. The ewes in the prenatal shorn treatment were shorn in January each year an average of 20.1 ± 12.6 d prior to lambing, whereas, the unshorn ewes were not shorn until April, 96.2 ± 15.1 d after lambing. As young ewes were added to the flock each year they were assigned to a shearing treatment prior to mating. Once assigned to a shearing treatment, ewes were kept on the same treatment in subsequent years so that a 12-month fleece was produced. There were a total of 276 parturitions over the three-year period resulting in 480 lambs. The average body weight of the ewes at time of mating was 60.2 ± .6 kg.

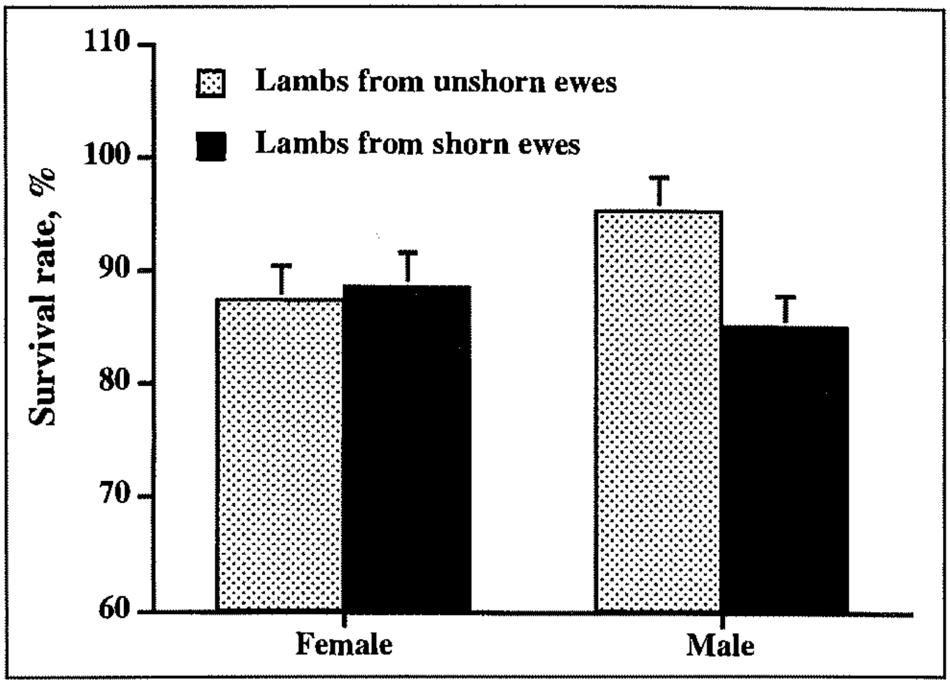

Figure 1. The effect of prenatal shearing on day-1 survival rates of female and male lambs. The prenatal shearing x sex of lamb interaction was significant ($P < .05$).

Upon shearing of the prenatal shorn ewes in January, both groups were housed in a common pen (45 x 90 m) with access to a three-sided shed. While housed in this pen, ewes were fed a diet consisting of 30% sorghum grain, 40% peanut hulls, 16.5% cottonseed meal, 8% molasses, 3% salt, 1% calcium carbonate, 1% urea, and 0.5% ammonium chloride. Ewes and lambs remained in this pen until lambs were 7 to 14 days of age, at which point they were returned to pasture.

Data collected at lambing included lamb birth weight, sex, type of birth (single, twin, or triplet), and age of ewe. Minimum and maximum temperatures on the day of birth were also recorded. Lamb survival was observed for up to 7 days of age. Data were analyzed using general linear model procedures in SAS (1996) to examine factors affecting birth weights. Variables in the model were shearing treatment, year, sex of lamb, type of birth, and age of dam. The age of dam was categorized as 2-yr-olds, 3- to 5-yr-olds or 6- to 7-yr olds. All interactions were examined in initial models and remained in the final model if $P < 0.2$, but there were no significant interactions in this model.

Survival rate on day 1 was coded as 0 if a lamb died at birth or during the first day of life or 1 if the lamb survived through the first day of life. Lamb survival rates through days 3 and 7 were likewise coded. This model included shearing treatment, year, sex of lamb, type of birth, and age of dam. The interaction of shearing treatment x sex of lamb had a $P < .20$ so it was also utilized in the model. In addition, linear and quadratic effects of day-of-birth minimum temperature and birth weight were included in the model.

Results and Discussion

The average litter size was not affected by shearing treatment (1.69 and 1.74, for unshorn and shorn, respectively). Age of dam affected litter size. The 2-yr-old ewes had smaller litters ($P < .01$) than did the 3 to 5-yr-old or 6 to 7-yr-old ewes (1.53, 1.81, and 1.79, respectively).

Type of birth significantly affected the birth weight of lambs (Table 1). Single lambs were 22.5% heavier than twin lambs ($P < .001$), and twin lambs were 17.8% heavier than triplet lambs ($P < .001$). Survival rates for triplet lambs were lower ($P < .05$) on days 1, 3, and 7 compared to single and twin lambs. Yapi et al. (1992) found a positive correlation between litter size and lamb mortality, which is probably due to heavier birth weights (McCutcheon et al.,

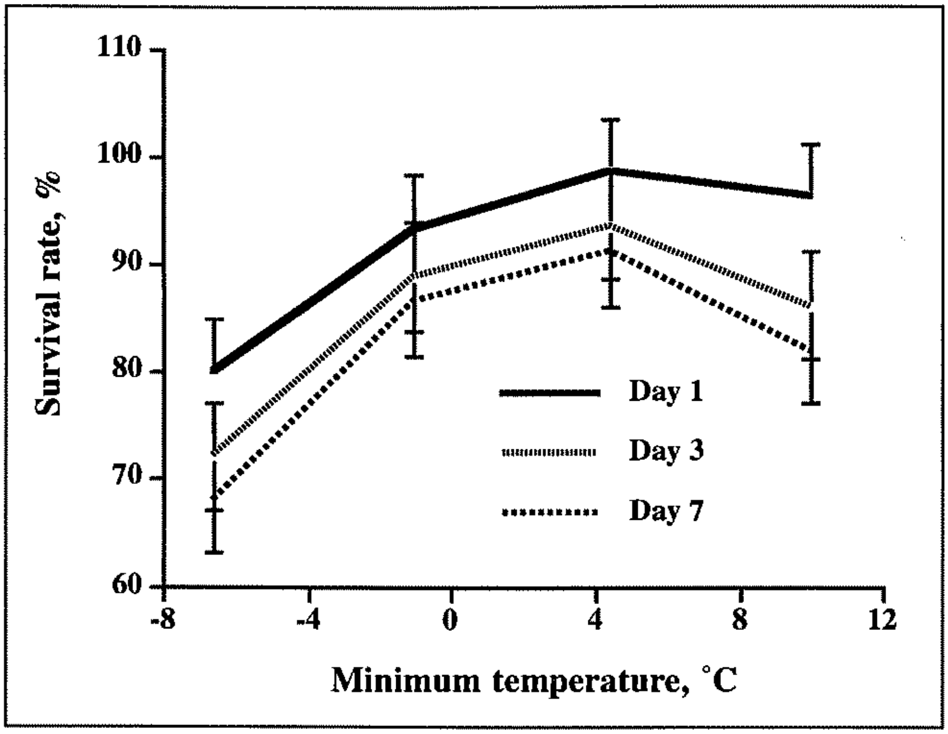

Figure 2. The effect of minimum temperature on the day of lambing on survival rates of lambs at 1, 3 and 7 days of age.

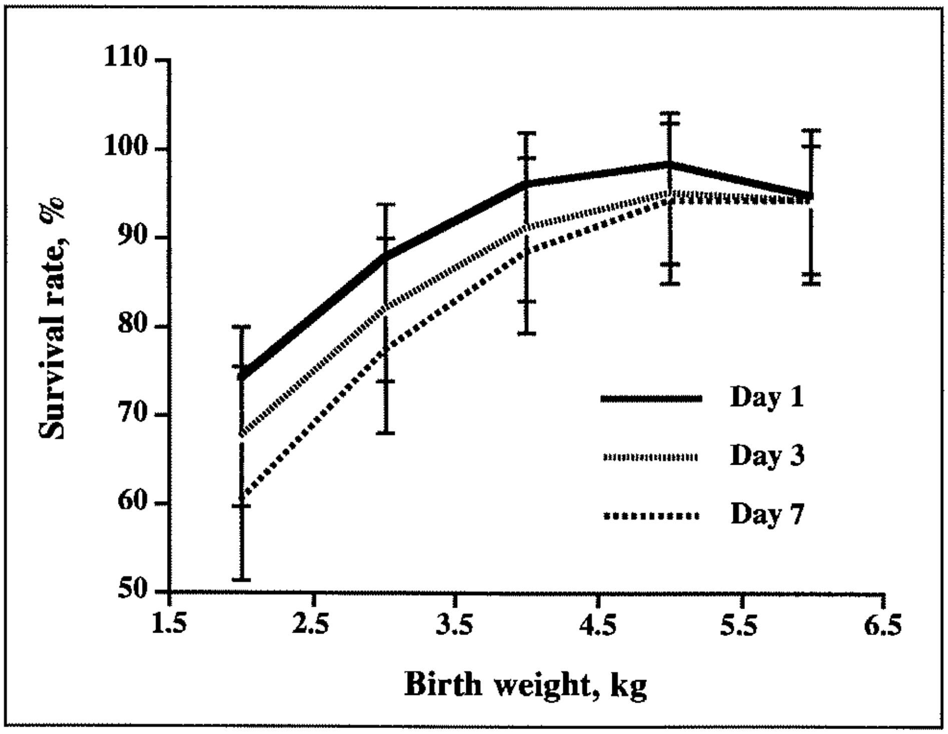

Figure 3. The effect of birth weight on lamb survival rates.

1983) and increased cold resistance (Stott and Slee, 1987) of single lambs compared to twin and triplet lambs. Despite finding that twin lambs were lighter than single lambs, no differences in lamb survivability between single and twin lambs were found in this study.

Minimum temperature on the day of lambing had a significant ($P < .01$) quadratic effect on survival rates for day 1, day 3, and day 7 (Figure 2). The optimum minimum temperature range was from 4 to 6° C. As temperatures fell below 4° C there was a decline in lamb survival rates. Compared to survivability at 4° C, survival rates declined 5% when temperatures decreased to -1° C and 23% when temperatures decreased to -6° C.

Lamb birth weight had a significant quadratic effect on lamb survival rates on day 1 ($P < 0.01$) and also tended to affect survival rates on day 3 ($P = .06$) and day 7 ($P < .10$). The effect of lamb birth weight on survival rate is illustrated in Figure 3. There was a 9% reduction in day-1 survival rates when birth weights decreased from 4 to 3 kg, and a 30% reduction when birth weights decreased from 4 to 2 kg. Similar effects were noted for survival rates on days 3 and 7. At heavier birth weights, survival rates declined slightly, reflecting possible complications from dystocia. Gama et al. (1991) found that birth weight was the best predictor of lamb mortality rates.

Age of dam had a significant effect on lamb birth weights (Table 2). Lambs from the 6 to 7-yr-old ewes were 4.7% heavier than lambs from 3 to 5-yr-old ewes and 14.1% heavier than lambs from 2-yr-old ewes. Age of dam was not a significant factor affecting survival on days 1, 3, or 7. This corresponds with Hanrahan (1986) who found no effect of ewe age on lamb survivability when adjusted for litter size.

Regardless of prenatal shear treatment, the majority of lamb deaths for 7 d mortality rates occurred within the first day of life. Deaths within the first day of life accounted for 61.8 and 53.4% of the 7 d mortality rates of prenatal shorn and unshorn treatments, respectively.

Lamb birth weight was not affected by prenatal shear treatment (Table 2). There was a significant interaction between prenatal shear treatment and sex of lamb for survival rates on days 1 ($P < .05$), 3 ($P < .01$), and 7 ($P < .01$). Prenatal shearing did not affect day 1 survival rates of female lambs, however, male lambs born to shorn ewes had lower ($P < .01$) survival rates than male lambs born to unshorn ewes (Figure 1). This was also the case for day 3 and 7 survival rates. The possibility was considered that prenatal shearing increased birth weights of male but not female lambs, thereby increasing the incidence of dystocia in male lambs. This was not likely the case, however, since the interaction between prenatal shear treatment and sex of lamb for birth weight was not significant (P > .25). Moreover, previous studies have not reported significant interactions between sex of lamb and prenatal shear treatment for lamb birth weights or survival rates. The finding that male lambs born to shorn ewes had lower survival rates than male lambs born to unshorn ewes is contrary to results from previous studies (Table 3). Further inspection of the records provides insight into the significance of the sex of lamb and prenatal shear treatment. The mean survival rate for the 480 lambs was 88.5 %. The survival rates for female lambs were 87.6% and 86.8% for shorn and unshorn ewes, respectively. The survival rates for male lambs were 82.4% and 96.1% for shorn and unshorn ewes, respectively. There were 5 male lambs in the unshorn group that died. Therefore, it appears that the significance of the interaction was due to an unusually high survival rate for male lambs born to unshorn ewes. In those studies that have reported beneficial effects of prenatal shearing on lamb survivability it was also found that prenatal shearing increased birth weights. Therefore, the lack of a positive prenatal shearing effect on lamb survival in the present study is not surprising given that birth weight was also not affected.

One possible explanation as to why prenatal shear treatment did not increase birth weight or improve survivability of lambs in this study, is that the time interval from shearing to lambing may not have been long enough. Only 5 of the 17 studies reviewed in Table 3 reported no effect of prenatal shearing on lamb birth weight. In these five studies, the time interval from prenatal shearing to lambing was only 21 to 36 d, whereas, in the studies that reported an increase in birth weight due to prenatal shearing , the length of time from shearing to lambing was typically greater than 40 d. Two studies specifically examined the effects of length of time from shearing to lambing on birth weights (Black & Chestnutt, 1990; Morris & McCutcheon, 1997). In these two studies, the smallest increases in birth weight due to prenatal shearing occurred when the time interval from shearing to lambing was less than 40 d (Table 3). In support of this observation, Shelton et al. (1981) found that the percent lamb crop marked at weaning was significantly higher in lambs born to ewes that were shorn three to four months prior to lambing (111%) compared to lambs born to ewes shorn approximately one month prior to lambing (91%) or lambs born to ewes shorn one to two months after lambing (96%). The time interval from shearing to lambing was investigated in the present data set. A linear covariate for the time interval between shearing and lambing, nesred within shearing treatment, was included in the model for lamb survival in order to investigate the significance of the time interval from shearing to lambing. Results showed that there was no significant difference between the estimated regression coefficients for the two treatments. Because of the management practices employed and the time of year of the shearing date, the time interval between shearing and lambing was related to other

Table 1. Effects of sex of lamb and type of birth on lamb birth weights and survival rates.

Factor	Birth Weight[a]	Survival Rate[b] Day 1	Survival Rate[b] Day 3	Survival Rate[b] Day 7
Sex of Lamb				
Female (n=250)	3.46	88.1	83.1	82.1
Male (n=230)	3.74	90.2	84.5	80.6
SE	.05	2.2	2.7	2.9
P-Value	.001	.39[c]	.65[c]	.66[c]
Type of Birth				
Singles (n=93)	4.30	94.6	89.2	87.5
Twins (n=324)	3.51	93.5	88.0	83.6
Triplets (n=63)	2.98	79.3	74.3	72.9
SE	.08	3.8	4.7	5.1
P-Value	.001	.01	.02	.09

[a] Birth weight of lambs, kg.
[b] Lamb survival rates: percentage of lambs alive after the 1st, 3rd or 7th day of age.
[c] Sex of lamb x shear treatment was significant for lamb survival rates (see Figure 1 and text).

Table 2. Effects of prenatal shearing treatment and age of dam on lamb birth weight and survival rates.

Factor	Birth Weight[a]	Survival Rate[b] Day 1	Survival Rate[b] Day 3	Survival Rate[b] Day 7
Shear Treatment				
Prenatal Shorn (n=231)	3.58	86.9	81.3	78.8
Unshorn (n=249)	3.61	91.4	86.4	83.9
SE	.05	2.1	2.6	2.9
P-Value	.50	.06	.09	.11
Age of Dam				
2-yr-olds (n=102)	3.34	86.3	83.5	79.2
3 to 5-yr-olds (n=299)	3.64	88.8	84.1	83.1
6 to 7-yr-olds (n=79)	3.81	92.4	83.9	81.8
SE	.07	3.1	3.9	4.2
P-Value	.001	.32	.99	.67

[a] Birth weight of lambs, kg.
[b] Lamb survival rates: percentage of lambs alive after the 1st, 3rd or 7th day of age.

Table 3. Influence of prenatal shearing of ewes on lamb birth weights and survival rates.

Reference	Experimental Conditions	Prenatal Temperature	Prenatal Treatment Days	Birth Weight	Survival Rate	Other
Rutter et al. (1971)	shorn vs unshorn	Not reported	105	↑ 16%	↑ (81.5 vs 64.2%)	
Rutter et al. (1972)	shorn vs unshorn	Not reported	105	↑ 21%	↑ (91 vs 78%); nonsignificant	
Austin & Young (1977)	shorn vs unshorn	0.5 to 14° C	70	↑ 14%	↑ (98 vs 93%); nonsignificant	↑ ewe intake
Maund (1980)	shorn vs unshorn	Not reported	70	↑ 7.5% twins ↑ 22.5% triplets	↑ for twins & triplets	↑ ewe intake
Symonds et al. (1986)	shorn vs unshorn	11.9° C	56	↑ 16%	Not reported	↑ ewe glucose levels
Vipond et al. (1987)	shorn vs unshorn	Not reported	40 to 66 3-year study	↑ 15% (average)	↑ (94 vs 88%); nonsignificant	↑ ewe intake ↑ gestation length
Black & Chestnutt (1990)	shorn vs unshorn	Not reported	28, 42, 63 or 84	↑ 5%--28 d ↑ 22%--42 d ↑ 15%--63 & 84 d	Not reported	↑ gestation length ↑ ewe intake ↑ ewe plasma glucose
Fernandez et al. (1991)	shorn vs unshorn	Not reported	25 to 30	No effect	No effect	
Boer (1994)	shorn vs unshorn	Not reported	56	↑ 14%	↑ (91.4 vs 82.4%)	
Cloete et al. (1994)	shorn vs unshorn	7 to 19° C	14--YR 1 28--YR 2	↑ 3.9%--YR 1 No effect--YR 2	↑ (73 vs 67%)--YR 1 no effect--YR 2	↑ lamb growth to 8 weeks; ewes on pasture
Dabiri et al. (1994)	shorn vs unshorn	Not reported	21 to 28	No effect	Not reported	ewes on pasture
Cueto et al. (1995)	shorn vs unshorn	Not reported	30	↑ 5%	Not reported	
Dabiri et al. (1995)	shorn vs unshorn	Not reported	36	No effect	No effect	
Cueto et al. (1996)	shorn vs unshorn	Not reported	35	↑ 8%	Not reported	
Dabiri et al. (1996)	shorn vs unshorn	Not reported	32	No effect	Not reported	
Husain et al. (1997)	shorn vs unshorn	8° C	35	↑ 14%	Not reported	↓ ewe rectal temperature
Morris & McCutcheon (1997)	shorn vs unshorn	4 to 12° C	20, 50 or 80	↑ 7% --20 d ↑ 9%--50 d ↑ 16% --80 d	Not reported	Shearing affected birth weight of twin, but not single lambs

Table 4. Effects of prenatal shearing and (or) temperature exposure of ewes on lamb birth weights and survival rates.

Reference	Experimental Conditions	Prenatal Temperature	Prenatal Treatment Days	Birth Weight	Survival Rate	Other
Slee & Samson (1982)	cold + shorn vs warm + unshorn	2 to 8° C (shorn) Thermoneutral (unshorn)	42	↑ .7 kg--Study 1 ↑ .4 kg--Study 2	Not reported	↑ gestation length
Thompson et al. (1982)	cold + shorn vs warm + unshorn	1 to 6° C (shorn) 15° C (unshorn)	35	↑ 27% singles ↑ 9% twins	Not reported	↑ plasma glucose in lambs and ewes
Stott & Slee (1985)	cold + shorn vs warm + unshorn	6° C (shorn) 26° C (unshorn)	14	no effect	Not reported	↑ norepinephrine-induced metabolic response
Shelton & Huston (1968)	24-h warm; 12-h warm vs control	32° C (warm) 24° C (control)	50 to 75	↓ 40%--24-h warm ↓ 20%--12-h warm	55%--24-h warm 80%--12-h warm 100%--control	
Brown et al. (1977)	warm--housed vs pastured	28° to 38° C (warm) Pasture--Not reported	50	↓ 30%	↓ (66 vs 96%)	↑ weak lambs
Bell et al. (1989)	warm vs control	40° C (warm) 20° C (control)	70	↓ 17%	Not reported	

factors. The simple correlation between the time interval between shearing and lambing and minimum temperature on the day of birth was .29. This positive correlation shows that ewes with longer intervals also lambed on warmer days, as it was getting closer to spring. Because ewes were kept in the pen and fed between shearing and lambing, the time interval is also a measure of days on feed. Indeed, the correlation between the time interval and birthweight was .21. The inclusion of the time interval between shearing and lambing did not result in substantial differences in the results of the analyses without the time interval.

A second reason for a lack of a prenatal shearing effect may be that the ambient temperatures during late gestation were too mild. The 3-year average minimum temperature on the day of lambing in this study was 2.4 ± 4.5° C (range of -8.3 to 15.0° C), and the average maximum temperature on day of lambing was 18.1 ± 6.5° C (range of

-5.0 to 29.4° C). Surprisingly, few authors have reported the ambient temperature conditions that existed during their studies (Table 3). The studies that did report ambient temperatures were not extremely cold compared to the temperatures reported in the current study. Collectively, the results of studies presented in Table 4 clearly demonstrate that prenatal cold exposure enhances and prenatal heat exposure suppresses lamb birth weights, thereby potentially impacting lamb survival rates.

Despite the fact that prenatal shearing treatment did not increase lamb survivability in this study, the majority of prenatal shearing experiments have shown beneficial responses (Tables 3 and 4). There are a number of possible mechanisms whereby prenatal shearing may improve lamb survival rates. Prenatal shearing has been shown to affect ewe behavior at lambing. In ewes not housed during lambing, Lynch and Alexander (1976) observed that prenatal shearing increased the likelihood that ewes lambed in sheltered areas, thereby improving the chances of lamb survival especially during inclement weather. Another possible benefit from prenatal shearing could be increased colostrum consumption by lambs due to less wool around the udders.

Several studies have reported an increase in dry matter intake of ewes that were shorn prior to lambing (Austin and Young, 1977; Vipond et al., 1987; Symonds et al., 1992; Black and Chestnutt, 1990; Dabiri et al., 1996). This increase in intake was thought to be a factor in increasing lamb birth weights by increasing the total supply of nutrients available to the developing fetus. However, because cold exposure increases rate of passage and decreases digestibility, differences in metabolizable energy intake between shorn and unshorn ewes have been shown to be minimal (Symonds et al., 1986). In one trial, prenatal shorn and unshorn ewes were fed equal amounts of dry matter and the shorn ewes still had heavier lambs (Thompson et al., 1982).

Cold exposure may alter the way nutrients are partitioned in the ewe. Exposure to cold environmental temperatures has been shown to increase plasma glucose concentrations in ewes (Symonds et al., 1992; Clarke et al., 1997) as well as in fetuses (Thompson et al., 1982). Infusion of glucose into fetuses during the last 4 wk of pregnancy has been shown to increase fetal weights as well as the proportional mass of brown adipose tissue compared with saline-infused fetuses (Stevens et al., 1990).

Shearing pregnant ewes during late gestation may also be beneficial to lamb survival by reducing the thermal heat load of the ewe. Shelton and Huston (1968) examined the effects of heat stress during late gestation. Control ewes were housed at 24° C, whereas, warm-treated ewes were exposed to 32° C for 12 (partial) or 24 (full) h per day. The partial heat treatment lowered birth weights by 16% and increased lamb mortality rates to 20%. The full heat treatment resulted in a 40% reduction in birth weights and increased lamb mortality rates to 45% (Table 4).

In addition to increasing birth weight, prenatal shearing has also been shown to enhance brown fat metabolism in newborn lambs. Brown fat is present in newborn lambs and functions to produce heat through nonshivering thermogenic mechanisms to help prevent hypothermia (Carstens, 1994). Stott and Slee (1985) conducted a study where ewes were exposed to either warm (26° C, full fleece) or cold (6° C, shorn) treatments 14 d prior to lambing. Brown fat metabolism, measured as an increase in oxygen consumption in response to a norephinephrine challenge, was found to be 2.8 times thermoneutral metabolism in lambs from cold-exposed ewes, but only 1.7 times thermoneutral metabolism in lambs from warm-exposed ewes. Likewise, Symonds et al. (1992) found that lambs from cold-exposed ewes had 40% greater brown fat thermogenic activity than control lambs.

The factors that influence lamb birth weight and survival rate responses to prenatal shearing cannot be clearly delineated from the present study and those studies reviewed in Tables 3 and 4. Moreover, it is likely that numerous factors (i.e., prenatal nutrition of the ewe, weather patterns) interact with prenatal shearing of ewes to influence overall lamb survival rates. The review of these studies does suggest, however, that shearing of pregnant ewes at least 40 to 60 d prior to lambing may improve lamb survival rates during the neonatal period.

Conclusions

Results from this study indicate that prenatal shearing of ewes an average of 20 d prior to lambing did not increase birth weights or improve neonatal survival rates of lambs managed in typical West Texas conditions. It is apparent from reviewing other studies, that the effects of prenatal shearing on lamb survivability are influenced by the degree of cold exposure of the ewe during late gestation and the length of time between shearing and lambing. Therefore, the lack of a prenatal shearing effect on lamb survival rates found in this study may have been due to the time interval from shearing to lambing being too short. Collectively, these studies suggest that implementation of the management practice of shearing ewes 60 to 90 d prior to lambing may improve lamb survivability during the neonatal period.

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Scrapie in Sheep: A Transmissible Spongiform Encephalopathy

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Introduction

Scrapie is a transmissible, fatal, degenerative disorder of the central nervous system that affects sheep and goats. It belongs to a family of neurodegenerative diseases in mammals known as transmissible spongiform encephalopathies (TSEs), which includes bovine spongiform encephalopathy (BSE) in cattle, Creutzfeldt-Jakob Disease (CJD) in humans, and chronic wasting disease in deer and elk (Johnson and Gibbs, 1998). The focus of this review is on scrapie, which affects most sheep-producing countries in the world.

Symptoms

Scrapie is an insidious, fatal disease characterized by a long incubation period and neurodegeneration. After primary infection with scrapie has occurred, an incubation stage of at least one year typically precedes the development of overt physical symptoms. Clinical signs of scrapie in sheep (Dickinson, 1976) begin with mildly impaired social behavior, in which affected animals become nervous, confused, or anxious and separate themselves from the flock. Physical manifestation of the disease usually involves intense itching caused by local irritation of the skin. Scrapie acquired its name because, during this stage of the disease, affected sheep rub themselves against fence posts, buildings, and feeders and bite at their legs, belly, or rump in an attempt to relieve the itching, thereby scraping off their wool and causing skin abrasions.

As the disease progresses, locomotor incoordination becomes apparent in affected animals. Ataxia, especially of the hind limbs, is often accompanied by muscular tremors; consequently, scrapie-infected animals walk with a characteristic swaying of the hindquarters and a high-stepping gait of the forelimbs. Motor incapacitation could be accompanied by visual impairment (Clark, 1980), causing animals to run into fixed objects, stumble, and fall. Changes in fleece pigmentation (Laplanche et al., 1999) and facial hair color (Capucchio et al., 2001) are sometimes observed in scrapie-infected sheep, and these are probably caused by altered metabolism. Although affected animals typically have a normal appetite, weight loss and emaciation occur because prehension, chewing, and swallowing become impaired. Overt clinical signs usually last for one to three months before death (Clark, 1980).

The clinical presentation of scrapie varies widely among breeds of sheep and individual animals, particularly with respect to the development of intense scratching and locomotor incoordination. While Suffolk sheep typically show signs of both itching and motor incapacitation (Dickinson et al., 1965), only one of these symptoms typically dominates the clinical course in some other breeds of sheep. In Icelandic sheep, scrapie presents as ataxia and trembling with little itching (Pálsson and Sigurdsson, 1958). In contrast, the hill sheep of northern India exhibit severe itching and persistent rubbing without an extended period of locomotor incoordination (Zlotnik and Katiyar, 1961).

Response to scrapie infection also varies among individual animals of the same breed. Clark (1980) reported that only 31% of affected Rambouillet animals in the USDA Scrapie Field Trial at Mission, TX exhibited itching, while the remaining cases progressed directly to the stages of ataxia and trembling. In Norway, where 94% of scrapie cases involve the Rygja breed, approximately half of the infected sheep exhibit itching, while the other animals primarily show symptoms of incoordination (Ulvund, 1996). Furthermore, not all scrapie-infected sheep display clinical signs before death. Clark and Moar (1992) reported that 16% of the scrapie-positive animals examined on the Shetland Islands between 1985 and 1991 were found dead without exhibiting prior clinical symptoms. Thus, the physical manifestation of scrapie in sheep is widely variable, but death is inevitable for all infected animals.

Prevalence

The exact incidence of prevalence is difficult to ascertain because of inconsistent postmortem diagnosis and the lack of validated preclinical diagnostic tests. Furthermore, producers are reluctant to report suspect cases in order to protect their reputation and livelihood. Hoinville et al. (2000) estimate that only 13% of British farmers who suspect that they own scrapie-infected animals have reported them to the Ministry of Agriculture, Fisheries, and Food (MAFF), even though notification of

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suspect cases has been compulsory within the European Union since 1993 (Schreuder et al., 1993). Additionally, scrapie cases could be among deaths caused by unidentified illness. In a Scottish study (Clark, 1991), postmortem histopathological examinations of sheep that had been found dead without previously showing signs of disease revealed that 21% were infected with scrapie. All of these factors should be taken into account when considering scrapie prevalence statistics.

The first case of scrapie was reported in 1732 in England (McGowan, 1922). In the subsequent decades, scrapie endemically affected flocks in several countries due to intercontinental movement of affected sheep. In 1947, scrapie was first reported in the United States in animals imported from Canada that originated in the United Kingdom. Since this time, over 1,000 flocks have been infected with scrapie in the United States (APHIS, 2001a), and the number of reported scrapie cases is steadily increasing (Wineland et al., 1998). During the first half of 2001, 69 confirmed cases of scrapie were reported in the United States (APHIS, 2001b).

Today, the worldwide incidence of scrapie remains obscure, but it appears to be more prevalent in the northern hemisphere than in the southern hemisphere (Laplanche et al., 1999). Following the introduction and subsequent eradication of scrapie in Australia and New Zealand during 1952 (Brash, 1952; Bull and Murnane, 1958), extensive protective measures were implemented in these countries to prevent the importation of scrapie (MacDiarmid, 1996). Australia and New Zealand are now widely recognized as scrapie-free. In contrast, European countries have a relatively high incidence of scrapie-infected flocks. In Great Britain, the country with which scrapie is most commonly associated, 128 positive cases were reported during the first half of 2001 (DEFRA, 2001). In a recent survey (Hoinville et al., 2000), 14.9% of British sheep producers owning more than 30 breeding ewes reported that scrapie had probably affected their flock, and the prevalence of infected sheep in this survey was consistent with abattoir data from another study (Simmons et al., 2000). In the Netherlands, it has been estimated that 3.8 to 8.4% of flocks are infected with scrapie (Schreuder et al., 1993). Although the Scandinavian countries of Denmark, Finland, and Sweden are at low risk for scrapie (Laplanche et al., 1999), there was recently a surge in the number of scrapie cases in Norway (Ulvund, 1996). Therefore, scrapie appears to be concentrated in particular geographic regions; whether this is due to the actual prevalence of scrapie or the absence of reporting in some areas is unknown. It is also important to note that the incidence of scrapie might be influenced by breed specificity or genetic predisposition (see below).

Economic Significance

In the United States, the American Sheep Industry Association estimates that scrapie costs the industry between $20 and $25 million annually (NIAA, 2001). This financial loss is due to decreased productivity of scrapie-infected flocks, lost income from potential exports, and increased disposal costs for offal. Annual mortalities in scrapie-infected flocks typically range from 3 to 5%, but in some cases annual mortalities can be greater than 10 or 20% (Detwiler, 1992). In scrapie-affected flocks, the number of infected animals increases and the age of scrapie onset decreases after several years, making these flocks economically unviable. The presence of scrapie in the US also prevents the exportation of breeding stock, semen, and embryos to many other countries.

The disposal of scrapie-infected carcasses is also of concern because the inclusion of TSE-infected protein in feedstuffs is probably one mode of horizontal scrapie transmission. Because the scrapie agent is extremely resistant to sterilization processes, including high temperatures, ultraviolet light, and suspension in formalin (Outram, 1976), rendering procedures that inactivate the scrapie agent are being investigated (Taylor et al., 1995, 1997, 1998, 1999; Schreuder et al., 1998a).

The scrapie disease has also economically impacted the scrapie-free countries of Australia and New Zealand. Most importantly, there has been damage to genetic improvement schemes where scrapie avoidance has limited the choice of potential breeding stock. Very few new bloodlines have been imported into Australia and New Zealand in the last 40 years (MacDiarmid, 1996).

In addition, the introduction of scrapie into Australia or New Zealand would severely impact biopharmaceutical manufacturers, a major component of the Australasian economy (MacDiarmid, 1996). The use of postmortem tissues derived from sheep and cattle for the production of biopharmaceuticals, including vaccines, has led to the generation of TSEs in some recipients. In Scotland, a scrapie infection occurred in 1937 after sheep were innoculated with a contaminated vaccine against louping-ill, which had been prepared in a 0.35% formalin suspension of ovine brain, spinal cord, and spleen tissues (Gordon, 1946). More recently, administration of a commercial vaccine against *Mycoplasma agalactiae*, which was prepared with ovine brain and mammary gland homogenates, was identified as the culprit for the sudden outbreak of scrapie in Italy in 1997 and 1998 (Agrimi et al., 1999; Caramelli et al., 2001).

Etiology of Scrapie

The current model for scrapie pathogenesis involves the interaction between a transmissible agent and the genetic makeup of the host. A novel proteinaceous infectious particle, called the prion protein (Pruisner, 1982), is thought to be the sole transmissible agent of scrapie (Pruisner et al., 1998). The natural transmission of prion proteins probably occurs by multiple pathogenic mechanisms, but the physical manifestation of the disease is also influenced by the host genetic makeup. The gene encoding prion protein contains several polymorphisms that are associated with scrapie susceptibility in sheep. Thus, an awareness of the interaction between the infectious prion agent and the host prion genotype appears to be critical for understanding scrapie etiology.

Infection with Prions

The only consistent characteristic of scrapie, as well as all TSEs, is the presence of an abnormal, aggregated form of a sialoglycoprotein called prion protein (PrP), which is tethered to neuronal and lymphocytic surfaces by a glycosylphospharidylinositol (GPI) anchor. Upon scrapie infection, the normal cellular conformer (PrP^C), which consists of 42% *a*-helix and 3% ß-sheet, is posttranslationally converted into an abnormal scrapie isoform (PrP^{SC}), which consists of 30% α-helix and 43% ß-sheet (Pan et al., 1993). This alteration in tertiary structure involves a templating process in which PrP^{SC} acts as a catalyst in the conversion of endogenous PrP^{C} into PrP^{SC} (Pruisner et al., 1990). Molecular chaperones (DebBurman et al., 1997) or partially unfolded PrP intermediates (Morillas et al., 2001) might aid in PrP^{SC} formation.

The mechanism by which PrP^{SC} subsequently induces pathological alterations in nervous tissue remains obscure. Immediately following exposure to the infectious agent, the conversion of PrP^{C} to PrP^{SC} occurs in gut-associated lymphoid tissues and in the spleen (Jeffrey et al., 2000), where PrP^{SC} incubates for several months before spreading to the central nervous system (Jeffrey et al., 2001). The exact mode of neuroinvasion by which PrP^{SC} translocates to the brain has not been elucidated, but a great deal of attention has focused on the implication of follicular dendritic cells and B-lymphocytes in PrP^{SC} transmission to the central nervous system (Klein et al., 1997; Brown et al., 1999a). However, recent evidence downplays the necessity of these factors in scrapie neuroinvasion (Shlomchik et al., 2001); dendritic cells from PrP^{SC}-infected splenic tissue can migrate to the central nervous system in the absence of additional lymphoid components (Aucouturier et al., 2001). Van Keulen et al. (1999) suggested that PrP^{SC} simply diffuses from gut-associated lymphoid tissues to the central nervous system by way of the enteric nervous system, and PrP^{SC} has been detected in enteric and autonomic ganglia of the gastrointestinal tract early in the incubation period (McBride et al., 2001). This hypothesis that neuroinvasion of the scrapie agent occurs directly within PrP^{SC}-containing tissues is supported by the observation that noradrenergic nerve endings lie close to PrP^{SC}-accumulating cells in the spleen (Bencsik et al., 2001).

Aggregation of PrP^{SC} molecules occurs upon PrP^{SC} invasion of the central nervous system, leading to the formation of prion rods, or scrapie-associated fibrils (SAF), in the brain (Rubenstein et al., 1987). Microglial cell activation occurs in response to abnormal PrP^{SC} deposition in the central nervous system (Williams et al., 1997; Giese et al., 1998). Subsequently, the intracellular free calcium concentration increases in microglial cells (Herms et al., 1997), and tyrosine kinase signal transduction cascades are activated (Combs et al., 1999). The secretion of reactive oxygen species (Brown et al., 1996) and proinflammatory cytokines (Peyrin et al., 1999) by microglia seems to be critical for disease pathogenesis. Reactive oxygen species such as the superoxide anion are essential for the mediation of PrP^{SC}-induced neurotoxicity (Brown et al., 1996). Nerve cell death occurs by apoptosis (Giese et al., 1995; Lucassen et al., 1995), resulting in vacuolar formations that are characteristic of scrapie-positive animals. Astroglial cell proliferation, another attribute of scrapie-infected brain tissue, is induced by cytokines interleukin-1 and interleukin-6, which are also released from PrP^{SC}-activated microglia (Hafiz and Brown, 2000).

The normal physiological function of PrP^{C} is poorly understood, but experimental alteration of the gene for PrP^{C} in mice has provided insight into the normal cellular role of prion proteins. Mice lacking PrP^{C} generally exhibit normal behavior and development (Büeler et al., 1992), although there are reports of increased locomotor activity (Roesler et al., 1999) and greater susceptibility to seizures (Walz et al., 1999). Evidence exists that PrP^{C} may be involved in nucleic acid metabolism (Gabus et al., 2001), protection against neuronal apoptosis (Bounhar et al., 2001), resistance to oxidative stress via copper binding (Brown et al., 1999b, 2001; Klamt et al., 2001), signal transduction in neurons (Mouillet-Richard et al., 2000), mediation of neuritogenesis through laminin binding (Graner et al., 2000), T-cell activation (Cashman et al., 1990), regulation of intracellular free calcium levels (Whatley et al., 1995), and promotion of sleep continuity (Tobler et al., 1997).

Although the role of PrP^{C} in normal cellular physiology is ambiguous, its involvement in scrapie is well documented. Mice lacking PrP^{C} are resistant to scrapie infection (Büeler et al., 1993), and the presence of PrP^{C} in the host is necessary for scrapie infection to occur (Brandner et al., 1996). However, unresolved issues regarding the role of prions in scrapie remain. How did PrP^{SC} originally adopt its deviant structure, which is required for infectivity? Are there other players involved in scrapie infection? These questions are the basis for ongoing discussions about infectious agents in the scrapie disease.

Genetic Influence

Scrapie susceptibility is influenced by the genetic makeup of infected sheep. The ovine prion protein gene (*PRNP*), which contains three exons and is over 20 Kb long (Westaway et al., 1994), is known to affect scrapie susceptibility in sheep. Exon 3 of the ovine *PRNP* gene contains the entire protein-coding sequence for PrP as well as a downstream 3'-untranslated region. Polymorphic variants in the protein-coding region of the *PRNP* gene, particularly at codons 136, 154, and 171, are associated with the incidence of scrapie in several breeds of sheep. Amino acid substitutions at these positions facilitate the conversion of PrP^{C} to PrP^{SC} in vitro (Bossers et al., 2000). In addition, polymorphisms in the 3'-untranslated region of ovine *PRNP*, such as an *Eco*RI restriction fragment length polymorphism (Hunter et al., 1991), have been associated with modified protein synthesis and disease progression (Goldmann et al., 1999).

In many breeds, including the Bleu du Maine, Cheviot, Flemish, Herdwick, Île-de-France, Romanov, Rygja, Scottish Halfbred, Shetland, Swaledale, Swifter, and Texel, the *PRNP* allele encoding valine at codon 136 (V$_{136}$) is associated with an extremely high risk of scrapie (Maciulis et al., 1992; Laplanche et al., 1993; Goldmann et al., 1994; Hunter et al., 1993, 1994, 1996, 1997a; Belt et al., 1995; Clouscard et al., 1995; Bossers et al., 1996; Tranulis et al., 1999). In scrapie-affected flocks of these breeds, infected animals typically carry V$_{136}$ on least one *PRNP* allele. In a study of Scottish Cheviot sheep (Hunter et al., 1996), none of the scrapie-positive animals was homozygous for the wild-type codon (AA$_{136}$); however, 77% of infected sheep were VV$_{136}$ and 23% were VA$_{136}$. Codon 136 also affects scrapie incubation time; sheep with the genotype VV$_{136}$ have a shorter incubation time than VA$_{136}$ animals (Goldmann et al., 1994; Hunter et al., 1996; Elsen et al., 1998).

The V$_{136}$ codon is very rare in British, Irish, Japanese, and US Suffolk sheep (Hunter et al., 1994, 1997b; Ikeda et al., 1995; O'Rourke et al., 1996; O'Doherty et al., 2000) as well as in Lacuanes (Clouscard et al., 1995), Poll Dorsets (Hunter et al., 1994), Soays (Hunter et al., 1997a), and Southdowns (Tyler et al., 1999). In these breeds, scrapie susceptibility is typically determined by PRNP codon 171. Three polymorphisms at codon 171 [glutamine (Q_{171}), arginine (R_{171}) and histidine (H_{171})] have been identified (Goldmann et al., 1990; Laplanche et al., 1993; Belt et al., 1995; O'Rourke et al., 1996). In studies of scrapie-positive Cheviot, Lacaune, Poll Dorset, Romanov, Soay, Southdown, and Suffolk sheep (Westaway et al., 1994; Clouscard et al., 1995; Ikeda et al., 1995; Hunter et al., 1997a, 1997b; Elsen et al., 1998; Tyler et al., 1999), infected animals were homozygous for glutamine at codon 171 (QQ_{171}). Sheep homozygous for arginine (RR_{171}) or heterozygous (QR_{171}) at *PRNP* codon 171 did not develop scrapie from either natural or experimental challenge in several studies (Laplanche et al., 1993; Goldmann et al., 1994; Westaway et al., 1994; O'Rourke et al., 1996, 1997; Hunter et al., 1997a; Elsen et al., 1998). These analyses suggest a relationship between the *PRNP* QQ_{171} genotype and scrapie susceptibility in Suffolk sheep. However, this association is not absolute, as there are several reported cases of QR_{171} animals with scrapie (Hunter et al., 1997b; Junghans et al., 1998; Tranulis et al., 1999), and a scrapie-positive Suffolk sheep with the RR_{171} genotype was found in Japan (Ikeda et al., 1995).

The H_{171} mutation has been identified in the Belclare, Corriedale, Galway, Mayo Blackface, Suffolk, and Texel breeds (Belt et al., 1995; Ikeda et al., 1995; O'Rourke et al., 1996; Hunter et al., 1997a; O'Doherty et al., 2001). While the H_{171} mutation appears to be associated with a high incidence of scrapie in the Corriedale breed (Ikeda et al., 1995), H_{171} in Texels confers neither resistance nor susceptibility to scrapie (Belt et al., 1995), and all Suffolk animals carrying the H_{171} mutation have been scrapie-free (O'Rourke et al., 1996; Hunter et al., 1997a).

The *PRNP* allele encoding arginine at codon 154 (R_{154}) is very frequent in sheep, but a histidine at codon 154 (H_{154}) has also been identified in the Belclare, Donegal Blackface, Galway, Herdwick, Icelandic, Mayo Blackface, Poll Dorset, Romanov, Rygja, Scottish Halfbred, Shetland, Suffolk, Swaledale, Texel, and Wicklow Cheviot breeds (Laplanche et al., 1993; Belt et al., 1995; Ikeda et al., 1995; Hunter et al., 1997a; Elsen et al., 1998, 1999; Thorgeirsdottir et al., 1999; Tranulis et al., 1999; O'Doherty et al., 2001). Although R_{154} is not associated with scrapie susceptibility or resistance, the presence of H_{154} confers scrapie resistance by overriding the Q_{171} mutation in some cases (Laplanche et al., 1993; Elsen et al., 1998, 1999; Thorgeirsdottir et al., 1999). In a study of Herdwick, Poll Dorset, Scottish Halfbred, Shetland, Swaledale sheep, the H_{154} mutation was identified only in scrapie-free animals (Hunter et al., 1997a). However, scrapie-positive animals with the genotype HH_{154} have been identified in Norway (Tranulis et al., 1999) and France (Elsen et al., 1998).

Recently, genotypes at all three *PRNP* codons have been taken into consideration when examining genetic predisposition to scrapie. The presence of a scrapie-susceptible genotype at any of the three codons renders an animal susceptible to scrapie. Therefore, the most resistant genotype is $AA_{136}RR_{154}RR_{171}$ (Belt et al., 1995; Bossers et al., 1996; Hunter et al., 1997a; Elsen et al., 1998, 1999; Thorgeirsdottir et al., 1999). Only one scrapie-positive animal with the genotype $AA_{136}RR_{154}RR_{171}$ has been identified (Ikeda et al., 1995). In addition, carriers of the $A_{136}H_{154}Q_{171}$ allele appear to be nearly as resistant to scrapie as $A_{136}R_{154}R_{171}$ carriers (Hunter et al., 1997a; Elsen et al., 1998, 1999; Thorgeirsdottir et al., 1999). The most susceptible genotype is $VV_{136}RR_{154}QQ_{171}$ (Bossers et al., 1996; Hunter et al., 1997a; Elsen et al., 1998, 1999; Thorgeirsdottir et al., 1999). However, it should be noted that while certain genotypes are susceptible to scrapie, the actual incidence of scrapie is dependent on other risk factors as well, such as exposure to the agent and dose of infection.

A PRNP-related gene called *PRND* (Moore et al., 1999), which encodes for the doppel protein (Dpl), has recently been identified. The topological structure of Dpl is very similar to that of PrP^C; it is an *a*-helical, GPI-anchored glycoprotein that is attached to the extracellular surface of cell membranes (Silverman et al., 2000; Mo et al., 2001). However, studies thus far have not identified a role for Dpl in scrapie; disease development and PrP^{SC} formation appear to occur normally in the absence of Dpl (Behrens et al., 2001). Dpl is upregulated in the central nervous system of PrP-deficient mice during Purkinje cell death and ataxia (Moore et al., 1999), which can be reversed upon introduction of PrP^C (Nishida et al., 1999). These apparent antagonistic roles of PrP^C and Dpl are supported by a recent observation that Dpl intensifies oxidative damage (Wong et al., 2001), which is in contrast to the normal cellular role of PrP^C as an antioxidant (Brown et al., 1999b, 2001; Klamt et al., 2001). Although Dpl has not been implicated in TSE development, the close relationship of Dpl and PrP^C justifies further investigation of Dpl in these diseases. To date, six polymorphic variants in the human *PRND* gene have been reported and are not associated with CJD susceptibility (Mead er al., 2000; Peoc'h et al., 2000). The ovine *PRND* sequence was recently described (Tranulis et al., 2001), and this sequence will serve as a tool for investigating the role of Dpl in scrapie development in sheep.

There is evidence that natural scrapie in Île-de-France sheep is influenced by the MHC (*OLA*) locus (Millot et al., 1985, 1988); however, scrapie was not associated with any of the OLA-linked markers tested in a study of Cheviot sheep (Hunter et al., 1996). In mice, MHC expression increases in neurons and astrocytes following scrapie infection (Duguid and Trzepacz, 1993). Differential expression of other genes in neural tissues following scrapie infection in mice has also been documented (Kenward et al., 1994; Lazarini et al., 1994; Doh-ura et al., 1995; Dandoy-Dron et al., 1998; Kim et al., 1999; Riemer et al., 2000). In addition, Miele et al. (2001) reported that the expression of the erythroid differentiation-related factor (*EDRF*) gene in the spleen decreases as scrapie progresses, which is the first report of differential gene expression in extraneural tissues. While the expression of these genes is altered during scrapie infection, there is no clear evidence that they are directly involved in disease manifestation.

Natural Transmission

In addition to the transfer of scrapie-susceptible or scrapie-resistant prion alleles to offspring, parental transmission of the infective scrapie agent PrP^{SC} to progeny is an important means of disease propagation within a flock. Although there is no evidence for paternal transmission through semen (Wrathall, 1997), maternal transmission is thought to be one of the strongest contributors to scrapie dissemination (Pálsson, 1979). Progeny from scrapie-infected ewes are more likely to become clinically infected than unrelated offspring from scrapie-free dams (Dickinson et al., 1974; Hourrigan et al., 1979). However, it is difficult to determine whether this familial pattern of scrapie infectivity is due to genetic susceptibility, genuine maternal transmission in utero, or post-partum lateral transmission from ewe to lamb.

Although embryo transfer studies have primarily investigated the feasibility of salvaging valuable genetic material from infected animals, these studies have also provided insight into the maternal transmission of scrapie during gestation. Two groups have transferred embryos from scrapie-positive donor ewes to scrapie-free recipients to determine whether embryos harbor the infectious agent. Foster et al. (1992, 1996) have consistently found that scrapie develops in embryos from infected donor ewes; 23% of embryo transfer progeny in the earlier study and 50% of offspring from the later study subsequently developed scrapie. In contrast, Foote et al. (1993) successfully transferred 67 embryos from a scrapie-infected flock to scrapie-free recipients without scrapie transmission. However, this study has been criticized (Detwiler et al., 1996) because only 30 to 61% of donor ewes were diagnosed with scrapie, and only 9.5% of animals in the positive control group were infected. In a more recent study by the same group (Wang et al., 2001), 52 embryo-transfer progeny from scrapie-positive donors were successfully transferred to scrapie-free recipients without scrapie transmission.

These two groups also disagree on whether maternal transmission occurs through placental or fetal membranes in utero; both groups have also transferred embryos from scrapie-negative donors to scrapie-positive ewes. While Foster et al. (1996) found that 75% of these embryo-transfer progeny subsequently developed scrapie, all 25 offspring in the Foote et al. (1993) study remained scrapie-free during the 60-month investigation. The infectious PrP^{SC} protein has been detected in placental membranes, including the caruncular endometrium and cotyledonary chorioallantois, from scrapie-positive ewes (Pattison et al., 1972, 1974; Race et al., 1998; Tuo et al., 2001); however, PrP^{SC} has not been found in fetal tissues and fluids (Tuo et al., 2001). Therefore, fetal exposure to PrP^{SC} in utero is probably not a primary mode of transmission because the fetus and the PrP^{SC}-positive tissues are physically separated by PrP^{SC}-negative amniotic fluids.

Although maternal transmission of PrP^{SC} does not appear to occur in utero, it is widely accepted that scrapie transmission occurs during the perinatal period. The longer that lambs remain in contact with their infected mothers after parturition, the more likely they are to develop scrapie (Hourrigan et al., 1979). Because the scrapie agent has not been identified in colostrum or mammary glands of scrapie-positive ewes (Hadlow et al., 1982), it is unlikely that transmission occurs through the milk. However, the expulsion of infected placental membranes and fluids during parturition may expose newborn lambs to the infectious scrapie agent PrP^{SC}. Given the relative stability of PrP^{SC} in the natural environment, the accumulation of PrP^{SC} in lambing barns over time would provide unexposed ewes and lambs a chance to come in contact with the infectious material. This model of transmission is supported by the observation that unrelated lambs housed in the same mothering pen as scrapie-infected ewes show an increased probability of developing the disease (Detwiler, 1992). Furthermore, approximately 89% of scrapie-infected animals are between the ages of 1.5 and 4.5 years (Dickinson et al., 1964); this fits the hypothesis that scrapie infection occurs primarily during lambing, followed by an incubation period of at least 18 months before clinical manifestation and death.

While recent evidence indicates that natural transmission occurs via parturition, the possibility that scrapie is transmitted by other mechanisms cannot be ruled out. Scrapie appears to be transmitted horizontally among sheep (Brotherston et al., 1968; Dickinson et al., 1974); however, the precise mode of horizontal transmission by which PrP^{SC} is disseminated through a flock is not well understood. In preclinically scrapie-infected animals, the infectious agent is first detected in lymphoid tissues draining the digestive tract, including the retropharyngeal and mesenteric-portal lymph nodes (Hadlow et al., 1982), the tonsils (Schreuder et al., 1998b), and the ileal Peyer's patches (Heggebo et al., 2000). These results indicate that the ailmentary tract is a major route of entry for the scrapie agent.

Ingestion of the infectious agent could take place on scrapie-contaminated pastures, but exposure though shared bedding, water, feed, and pen surfaces or direct contact between flockmates during confinement are more likely to occur (Pálsson et al., 1979). Even though the primary mode of horizontal transmission is unknown, each of these routes is plausible because PrP^{SC} is relatively resistant to degradation, as demonstrated by Brown and Gadjusek (1991).

Tissues of scrapie-infected animals harboring the infectious agent PrP^{SC} are likely to be the primary sources of infectivity. Although PrP^{SC} is found in high concentrations in nervous tissues such as the brain (Race et al., 1998), the central nervous system is not exposed to the exterior where transmission could occur. Instead, excretions of PrP^{SC} in saliva, nasal discharge, and feces are more likely to be vehicles of transmission for the scrapie agent; additionally, skin scarification has been suggested as a possible PrP^{SC} source in sheep (Taylor et al., 1996). Salivary glands of scrapie-infected sheep do not contain PrP^{SC} (Herrmann et al., 2000), but small amounts of an infectious agent have been found in nasal mucosa, which was probably derived from the tonsils and retropharyngeal lymph nodes (Hadlow et al., 1982). The presence of the scrapie agent in the proximal colon (Hadlow et al., 1982) and the rectal nervous tissue (van Keulen et al., 1999) indicates that PrP^{SC} could be sloughed from intestinal wall into the feces; however, the scrapie agent has not been detected in fecal matter (Hourrigan et al., 1979).

Sheep with scrapie-resistant genotypes could harbor subclinical infections and transmit the PrP^{SC} agent to animals with scrapie-susceptible genotypes. Although Hill et al. (2000) recently demonstrated that the accumulation of a hamster PrP^{SC} strain in the brains of mice could occur without the development of clinical signs during a normal lifespan, no such cases have been reported in sheep. Clearly, an understanding of the interaction between the infectious PrP^{SC} agent and the host genotype is important.

Control and Regulation of Scrapie

The lack of a validated live-animal diagnostic test for scrapie, combined with the long incubation period and variable expression of clinical signs in affected sheep, has made it difficult to employ regulatory measures to control this disease. The development of sensitive and reliable diagnostic tools will contribute greatly to the control and regulation of scrapie.

Diagnostic Techniques

Traditionally, scrapie diagnosis has involved the identification of clinical symptoms followed by confirmation using postmortem examination techniques (Fraser, 1976). The primary method of postmortem confirmation has been through histopathological examination of brain sections for neuronal degeneration, spongiform vacuolation, and astroglial cell proliferation. Additionally, the presence of SAF in brain tissue can be used to diagnose scrapie-positive animals (Merz et al., 1981). Because these neurological changes occur during advanced stages of the disease, it is not possible to diagnose preclinically infected animals using histological techniques. Other drawbacks to histopathology include the variable severity of neuronal vacuolation exhibited by different breeds of sheep, the natural autolysis of brain tissue within a few hours after death, and the presence of neurological changes in apparently normal sheep (Fraser, 1976).

The discovery that prion proteins are essential for scrapie manifestation (Pruisner et al., 1990) has led to the development of detection systems capable of identifying the PrP^{SC} molecule in tissues from scrapie-infected animals. Immunohistochemistry (IHC) on paraffin-embedded brain sections, which involves antibody staining of PrP^{SC}, is useful for verifying the presence of scrapie in questionable cases (Miller et al., 1993). Furthermore, IHC has been successfully used in the preclinical diagnosis of scrapie-positive animals that were erroneously diagnosed as scrapie-negative using histopathological techniques (Hamir et al., 2001; Kim et al., 2001; Ryder et al., 2001). However, IHC on brain tissue is a postmortem diagnostic technique; this test is not useful for determining the prevalence of scrapie in a population or for establishing policies to control the disease in live animals.

Recent efforts have focused on developing efficient PrP^{SC}-detection systems for accessible tissues from living sheep. The identification of PrP^{SC} in extraneural tissues of scrapie-infected sheep has provided several potential sources of PrP^{SC}-infected tissues. Although most studies have focused on testing lymphoreticular tissues for the presence of PrP^{SC} (Ikegami et al., 1991; van Keulen et al., 1996), blood from infected animals has been used in capillary immunoelectrophoresis assays (Schmerr et al., 1999). Tonsillar biopsy followed by IHC detection of PrP^{SC} (Schreuder et al., 1998b) initially showed potential as a preclinical diagnostic test; however, tonsil collection requires the administration of a general anaesthetic. The IHC detection of PrP^{SC} in the third eyelid, or nictitating membrane, of infected animals (O'Rourke et al., 1998) currently shows the most promise in preclinical scrapie diagnosis. The third eyelid is more accessible than the tonsils, and only a local anaesthetic is required for tissue collection. In a preliminary screening of preclinically infected sheep (O'Rourke et al., 2000), the results of the third-eyelid test were consistent with the scrapie status for 41 of 42 clinically suspect cases with confirmed scrapie and 174 of 175 scrapie-negative sheep. This test is useful for animals 14 months of age or older, assuming that the infection was acquired at birth (O'Rourke, 2001). The third-eyelid test is currently the focus of large-scale validation studies for use as a preclinical diagnostic tool that could be used in the control and regulation of scrapie worldwide.

Regulatory Measures

The United States Department of Agriculture (USDA) began regulating scrapie in 1952, after the US Secretary of Agriculture declared a state of emergency because of a scrapie outbreak in a flock in California (Detwiler et al., 1996). Despite ongoing efforts to eliminate scrapie from US flocks, the disease has continued to spread through the US sheep industry. In 1992, the USDA's Animal and Plant Health Inspection Service (APHIS) established the current scrapie eradication program, the Voluntary Scrapie Flock Certification Program. Producers enrolled in the certification program are required to officially identify all animals older than one year of age, maintain complete records on every animal, and report suspect animals to health officials. Because scrapie has a long incubation period, participating flocks must be monitored for five years before being certified as scrapie-free. As of July 2, 2001, the program had only 781 participating flocks (APHIS, 2001b), of which 55 were certified scrapie-free; however, there are an estimated 66,000 sheep operations nationwide (NASS, 2001). Because the Voluntary Scrapie Flock Certification Program is not mandatory for all sheep producers, scrapie has continued to spread through US sheep flocks.

In an attempt to eliminate scrapie from the US by 2010, APHIS implemented the National Scrapie Eradication Program on November 19, 2001. All flocks that are not enrolled in the Voluntary Scrapie Flock Certification Program are required to participate in the new plan. The federal government allocated $10 million in the 2001 budget for the program, and the entire project will require an estimated $100 million (USDA, 2000). These funds will be used for animal identification, slaughter surveillance, and the validation of a live animal test for scrapie (USDA, 2001). Detailed and up-to-date information on this federal program is available online (www.animalagriculture.org/scrapie).

Under the National Scrapie Eradication Program, the primary responsibility of producers will be to use permanent ear tags or tattoos to identify all breeding sheep over 18 months of age, scrapie-exposed animals, and show sheep. In addition, a Certificate of Veterinary Inspection must accompany all breeding animals that enter into interstate commerce. The new program will also incorporate a slaughter surveillance plan, developed by APHIS's Centers for Epidemiology and Animal Health, which calls for the testing of 11,300 sheep at 25 plants in 14 states for scrapie using IHC of the brain stem. The data collected from this abattoir investigation will be useful in determining the prevalence of scrapie in the US. Eventually, scrapie-positive animals will be traced to their flock of origin, and owners of infected flocks will be required to prepare a scrapie eradication plan for that flock. Another aspect of the National Scrapie Eradication Program is the validation of the third-eyelid test. Because this test will confirm whether or not living animals are infected with scrapie, it will be useful for identifying and removing only infected animals from the flock.

In the European Union (EU), scrapie has been a notifiable disease since 1993 (Schreuder et al., 1993). Further surveillance requirements were put forth in a 2001 EU Commission Regulation (EU, 2001). These requirements included the implementation of a compulsory slaughter scheme for all suspect animals and confirmatory diagnosis by histopathological examination or IHC detection. All EU-member countries were required to implement annual monitoring programs and provide compensation to owners for lost animals. Strict regulations on the import and export of live animals, embryos, ova, and semen were also described in the decision, and the feeding of all mammalian-derived protein to ruminants was prohibited.

In addition to these policies, the MAFF in England and agricultural administrations in Scotland and Wales are currently developing a National Scrapie Plan for Great Britain. During the first phase of the program, animals with genetic resistance to scrapie will be selectively bred. The Scrapie Information Group in Great Britain has developed a five-class scoring system (R1 to R5), that relates to the risk of scrapie infection in animals and their first generation progeny (Dawson et al., 1998). Scores correspond to specific genotypes; for example, the R1 classification corresponds to the $AA_{136}RR_{154}RR_{171}$ genotype for low scrapie susceptibility while the R5 category corresponds to the highly susceptible genotypes $VV_{136}RR_{154}QQ_{171}$, $AV_{136}RR_{154}QQ_{171}$, and $AV_{136}RR_{154}QH_{171}$. The Scrapie Information Group advises that animals with scores of R4 or R5 not be used for breeding.

Although Australia and New Zealand are widely recognized as being scrapie-free, these countries are taking measures to ensure that TSEs are not introduced into their herds or flocks (Turner, 1997). In 1996, the World Health Organization (WHO) advised that countries with no cases of TSE prohibit the feeding of meat and bone meal to livestock; subsequently, the Agriculture and Resource Management Council of Australia and New Zealand imposed a ban on feeding ruminant-derived protein. In 1997, the Australian Monitoring and Surveillance Program for TSEs was established, following the recommendation of the Office of International Epizooties (OIE). Under this program, veterinarians conduct field investigations and histopathological brain inspections to determine whether animals exhibiting signs of nervous disease are infected with TSE. The Australian Monitoring and Surveillance Program was structured so that there is a 90% probability of identifying a 1% incidence of TSE among nervous conditions affecting Australian sheep and cattle. It is important that Australia and New Zealand participate in these quality assurance programs to prove that they remain scrapie-free.

Conclusion

Clearly, controlling scrapie is vital to the future success of sheep operations. Because the complete biological mechanism of scrapie pathogenesis has not been elucidated, efforts at developing therapeutic drugs for treatment of clinical signs of the disease have been hindered. The identification of prion proteins and their crucial role in TSEs has led to the development of genetic tests for scrapie susceptibility and resistance. Given the currently available data, genetic selection will play a crucial role in the eradication of scrapie in the US. Therefore, breeding programs should incorporate criteria such as PRNP-resistant genotypes in animal selection. While genetic selection may be helpful in controlling and eliminating clinical disease within flocks at the present time, the future validation of reliable live-animal diagnostic tests will expedite the eradication of scrapie worldwide.

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Effect of Colostrum Intake on Serum Hormone Concentrations and Immunoglobulin G Absorption in Neonatal Lambs[1]

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Summary

Colostrum contains nutrients, immunglobulins, hormones, and growth promoting substances, such as insulin-like growth factor–I (IGF-1). An experiment was conducted to study the effects of feeding three amounts of colostrum on immunoglobulin G (IgG), and hormone concentrations during the first 18 hours of life. Fifteen Rambouillet x Merino lambs were assigned to three treatments. Pooled colostrum was fed at 10 mL/kg of body weight (BW), 20 mL/kg BW, or 30 mL/kg BW every 3 hours for 15 hours. Blood samples were obtained from lambs immediately after birth and every 3 hours through hour 18. Concentrations of growth hormone (GH), prolactin (PRL), triiodothyronine (T3) and thyroxine (T4) did not differ ($P > .10$) among treatments. Serum IgG, IGF-1 and insulin (INS) increased linearly ($P < .03$) as colostrum intake increased. A quadratic effect ($P = .06$) was detected for concentrations of GH as colostrum amounts increased. Feeding increasing amounts of colostrum following birth influenced serum IgG, INS, IGF-1 and GH concentrations, thereby, influencing both passive immunity and endocrine status in lambs. Feeding 10 mL/kg produce no health- related mortality at either a week of age or at weaning. Ten mL/kg of BW of colostrum every 3 hours for 15 hours may provide sufficient nutrition, growth-promoting factors and IgG to lambs at high risk.

Key Words: lamb, hormone, immunoglobulins, colostrum

Introduction

Colostrum contains nutrients and immunoglobulins, and growth-promoting products in higher quantities than milk from later in lactation (Koldovsky, 1989; Campana and Baumrucker, 1995). Bovine and ovine colostrum is especially rich in IGF-1, INS, PRL, GH, T4 and T3 (Ronge and Blum, 1988; Grosvenor er al., 1992; Campana and Baumrucker, 1995; Mazzone, 1997). Components of colostrum support development and function of the gastrointestinal (GI) tract, establish passive immunity and influence metabolic and endocrine systems and neonatal nutritional status (Koldovsky, 1989; Simmen et al., 1990; Burrin et al., 1995; Mazzone, 1997; Rauprich et al., 2000).

Colostrum intake by neonatal lambs is often insufficient and can cause hypothermia as the lambs' body energy reserves become depleted (Mellor, 1988). Amount of colostrum consumed has also been shown to greatly affect metabolic and endocrine traits in neonatal calves (Hammon and Blum, 1998, 1999). The actual amount of colostrum that should be fed to newborn lambs to ensure survival by avoiding hypothermia and maintaining adequate serum IgG concentrations is not known. Likewise, whether feeding different amounts of colostrum the first day of life affects endocrine profiles and immunoglobulin absorption and growth performance has not been addressed in lambs. The objective of this study was to determine if feeding three amounts of colostrum influences serum IgG, endocrine traits and growth performance in lambs.

Material and Methods

Animal Selection and Management

Fifteen newborn lambs (Rambouillet x Merino; average BW = 5.5 ± 3 kg; mean ± SE, eight males and six females) were selected from nine multiparous ewes. Six ewes produced twins and three ewes produced single offspring. Dams were monitored 24 hours a day during the lambing period. At parturition, lambs were muzzled with JorVet Muzzles (size 13.34 cm or 15.24 cm, Jorgenson Laboratories, Inc., Loveland, CO) to prevent suckling and remained with their dams in individual pens (1.2 m x 1.5 m) except during treatment and blood sample collection. Lambs were weighed, sexed, and ear-tagged within 30 minutes following birth. Lambs were also weighed at weaning (90 ± 2 days; mean ± SD) and weights were adjusted for day of age, sex, age of dam and type of rearing. The protocol for this experiment was approved by the Animal Care Committee of the University of Nevada according to guidelines provided by the

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Consortium (1988).

Treatments and Blood Collection

At birth, lambs (five lambs/treatment) were randomly allotted to treatment with twin lambs produced by a single dam designated to separate treatments. Lambs were tube-fed either 10 mL/kg (three males/two females), 20 mL/kg (two males/three females), or 30 mL/kg of BW (three males/two females) of pooled colostrum 30 minutes after birth. Feedings continued every 3 hours for a period of 15 hours. The 30 mL/kg of BW of colostrum was selected to fulfill the normal amount required for newborn lambs based on previous literature recommendations (Bobb, 1997). The 20 mL/kg and 10 mL/kg of BW treatments were selected to represent one-third and two-thirds below the normal requirements, respectively. Blood samples (5 mL) were obtained via jugular venipuncture from lambs immediately after birth, and then at hours 1, 2, and 3, and every 3 hours thereafter, through hour 18. Blood collection occurred just before lambs were fed.

Blood samples were stored at 4∞C for 24 hours and centrifuged at 2500 x g at 4∞C for 15 minutes. Serum was separated and stored at -20∞ C for later analysis of IgG and hormone concentrations.

Colostrum Pool Collection

Lambs were fed from a pool of colostrum, which was obtained by collecting colostrum at 0, 6, 12, and 18 hours after parturition from 17 ewes. Ewes used for collection of pooled colostrum were vaccinated approximately 4 weeks before parturition with Covexin 8 (Clostridium chauvoei, C. septicum, C. haemolyticum, C. nouvyi, C. tetani, C. perfringens Type C and D, and Bacterium toxoid, Schering-Plough, Omaha, NE). Colostrum was collected using an Alfa Laval Sheep Milker (Alfa Laval Agri Inc., Kansas City, MO). All Alfa Laval Sheep Milker fittings and parts were sterilized between milkings. Before each milking, ewes' teats were cleaned with a diluted Nolvasan solution (Fort Dodge Laboratories, Inc., Fort Dodge, IA). Ewes were given an injection of 20 international units (IU) of oxytocin (AmTech Group, Inc., St. Joseph, MO) intramuscularly (IM) 1 minute before milking. Colostrum was collected in a sterile container, weighed, and frozen in 1.5 liter plastic bottles. Once enough colostrum had been collected, all bottles were thawed using a water bath (37∞ C) and the colostrum was mixed in a large sterile container. Aliquots of the pooled colostrum were measured into 1.5 liter plastic bottles for individual lambs. Colostrum aliquots were then refrozen and thawed when needed at 37∞ C (water bath) at the time of the recipient lamb's birth and through the 18-hour feeding period.

Colostrum pool samples were collected from eight selected lambs' feed aliquots from feeding times 0, 6, and 12 hours. Because the same colostrum was used in all treatments, stratification by treatment group was not necessary. Colostrum pool samples were stored at -20∞ C for analysis of IgG and hormone concentrations.

Laboratory Analyses of Serum and Colostrum

Lamb serum and colostrum pool samples were analyzed for concentrations of IgG, PRL, INS, IGF-1, T3, and T4. Serum PRL was determined using RIA techniques described by Spoon and Hallford (1989), with the revision that colostrum samples were brought to a 1:20 dilution using a .1 M phosphate buffered saline plus .1% gelatin solution. The interassay and intrassay CV were 15% (n = 5) and 9.0% (n = 5), respectively, for serum and the intraassay CV was 3.0 % (n = 2) for colostrum. Serum and colostrum INS concentrations were determined by RIA techniques discussed by Sanson and Hallford (1984). Colostrum samples for the INS RIA were defatted by diluting 1:2 with .1M phosphate buffered saline plus 1% bovine serum albumin (PBS + 1% BSA), centrifuging for 10 minutes at 1500 rpm at 4∞C, and removing the resultant fat layer from the top of each sample. Defatted samples were further diluted 1:20 with PBS + 1% BSA for RIA analysis. Serum INS inter- and intraassay CV were 14.9% (n = 7) and 11.1% (n = 11), respectively. The INS intraassay CV was 7.6% (n = 2) for colostrum. Serum and colostrum IGF-1 concentrations were determined by RIA techniques developed by Berrie et al. (1995). Serum IGF-1 between assay CV was 13.7% (n = 7) and within assay CV was 7.7% (n = 7). Colostrum IGF–1 within intraassay CV was 15.5% (n = 4). T3 and T4 were analyzed using a commercially available solid phase RIA kit (Coat-A-Count, Diagnostic Products Corporation, Los Angeles, CA). Colostrum samples were diluted with analytical grade water to a dilution of 1:3 for both the T3 and T4 RIA's. Inter- and intraassay CV were 10.5% (n = 5) and 12.5% (n = 5) for serum T3 and 7.7% (n = 5) and 6.8% (n = 5) for serum T4. The intraassay CV for colostrum T3 and T4 were 1.9% (n = 3) and 2.9% (n = 2), respectively. Serum and colostrum IgG concentrations were determined by RIA (Richards et al., 1999). Inter- and intrassay CV were 5.4% (n = 8) and 13.3% (n = 7) for serum IgG. Area under the curve for serum IgG was determined by a microcomputer program that employed the algorithm reported by Lunstra et al. (1989). GH was examined in serum sample only. Serum GH concentrations were determined by RIA techniques developed by Hoefler and Hallford (1987) with an intraassay CV of 17.0% (n = 8).

Statistical Analyses

Lamb body weights at birth, 18 hours after birth and at weaning were analyzed with a one-way analysis of variance (ANOVA) using GLM procedures of SAS (SAS, 1996). Serum and colostrum hormone concentrations were analyzed using a split-plot ANOVA with treatment in the main plot and time of sampling in the subplot. The effect of treatment was tested using animal within treatment as the error term. When a significant treatment by time interaction was noted, further analysis with a one-way ANOVA was performed using the SAS GLM procedures (SAS, 1996). Linear and quadratic contrasts were used when a significant F-test ($P < .10$) was noted for treatment.

Results

Hormones and IgG in Colostrum

No time of sampling effect ($P > .10$) for concentrations of IgG, IGF-I, INS, PRL, T3, or T4 was detected. Mean colostrum concentrations for IgG, IGF-1, and INS were 31.6 ± 1mg/mL, 124.2 ± 6.1 ng/mL, and 125.3 ± ng/mL, respectively. Prolactin, T3, and T4 concentrations for pooled colostrum were 1114.3 ± 62.4 ng/mL, 9.2 ± .6 ng/mL, and 11.2 ± .9 ng/mL, respectively. These results confirm that the pooled colostrum fed to lambs was homogenous in IgG and hormone concentrations.

Hormones in Lamb Serum

No treatment x time of sampling interactions (P > .47) were observed for serum concentrations of GH, IGF-I, PRL, T3, or T4. Concentrations of PRL, T3, and T4 did not differ (P > .20) among treatments (Table 1). In contrast, a quadratic effect (P = .06) was detected for concentrations of GH, whereas, a linear increase (P = .01) was observed for concentrations of IGF-I as colostrum intake increased. No time of sampling effect (P > .33) was detected for either T3 or IGF-1. However, a time of sampling effect (P < .002) across treatments was observed for PRL, T4 and GH (Figure 1). Serum PRL concentrations were greater (P < .05) at hours 0 through 4 than for samples collected following that period. Serum T4 concentrations were greater (P < .05) at hours 0, 1, 2 and 3 versus hours 6 through 18. Serum GH concentrations decreased (P < .05) from hour 0 and were lowest at hours 1 through 6. GH increased (P < .05) at hours 9 and 12, after which a decline (P = .04) was noted at hour 18.

Table 1. Serum hormone concentration (ng/mL) in lambs fed three amounts of colostrum, including growth hormone (GH), insulin-like growth factor-I (IGF-I), prolactin (PRL), triiodothyronine (T_3), and thyroxine (T_4).

	Colostrum, mL/kg body weight[a]					
Hormone	10	20	30	SE	F test[b]	Contrast[c]
GH	7.6	9.7	5.0	.6	.08	Q = .06
IGF-I	145.7	193.6	227.7	8.0	.04	L = .01
PRL	58.5	100.7	75.8	20.0	.41	
T_3	3.6	4.3	3.5	.1	.19	
T_4	96.3	102.2	99.0	2.6	.85	

[a] Treatment: 10 mL/kg, 20 mL/kg, or 30 mL/kg of body weight of pooled colostrum tub fed every 3 hours from hour 0 through 18, n=5 in each group.

[b] F test P values.

[c] Contrast: quadratic = Q; linear = L.

[a] Treatment: 10 mL/kg, 20 mL/kg, or 30 mL/kg of body weight of pooled colostrum tub fed every 3 hours from hour 0 through 18, n=5 in each group.

[b] F test P values.

[c] Contrast: quadratic = Q; linear = L.

A treatment x time of sampling interaction was detected (P = .08) for serum INS (Figure 2). Serum INS did not differ (P > .75) among treatments at hour 0 or 1. However, at hour 2, a linear increase (linear, P = .05) in serum insulin was observed as colostrum intake increased. Insulin concentrations exhibited a linear increase (P < .01) with increased colostrum intake at hours 6, 9, 12, and 15.

Because no detectable levels of IgG were observed in hour 0 samples, and only a few lambs had detectable values at hour 1, data at these times were not included in the data set. A treatment x time of sampling interaction (P = .002) was detected for serum IgG, therefore, treatment effects were examined within sampling time (Figure 3). Serum IgG concentrations exhibited a linear increase (P < .03) with increased colostrum intake at hours 6, 9, 12, 15, and 18. Area under the serum IgG curve differed (linear, P < .01) with total IgG concentrations of 89.0, 179.2, and 264.5 mg/mL for lambs receiving 10, 20, and 30 mL/kg of BW, respectively. These values reflect the available IgG in the systemic circulation of lambs during the 18-hour period.

Lamb Body Weight

Lamb weights immediately following parturition were 5.5 ± .3 kg for all treatments (P = .99). Eighteen hours after parturition, lamb weights did not differ (P = .56) among treatments and were 5.4, 5.5, and 5.8 ± .2 kg for lambs receiving colostrum at 10, 20, and 30 mL/kg of BW, respectively. No lamb mortalities occurred during the first week following birth. Ninety-day adjusted weaning weights were 33.3 kg (SE=2.1 kg) for each treatment (P = .99). One lamb that received the 10 mL/kg of BW was killed by a predator before reaching 90 days of age.

Discussion

Hormones in Lamb Serum

Mazzone (1997) reported similar serum T3 and T4 concentrations to those presented in this study. Thyroid hormones were not influenced by feeding. Similarly, Kühne et al. (2000) reported feeding different amounts of colostrum failed to exert an effect on either T3 or T4 concentrations in calves.

No treatment differences were detected for serum PRL, but a time of sampling response was observed. In general, PRL decreased following birth for the 18-hour period. Rauprich et al. (2000) reported a decrease in PRL for the first 4 hours following the first feeding after birth in calves with an increase 24 hours after feeding. In our study, PRL increased at hour 18 compared with the four previous samplings.

Plasma GH concentrations in newborn calves were reported to be minimally influenced by colostrum feeding (Baumrucker and Blum, 1994; Hammond and Blum, 1997). In contrast, GH concentration was influenced by differing amounts of colostrum in lambs in our study. Plasma GH has been associated with nutrient status with feed restriction increasing GH concentrations in growing cattle (Breier and Sauerwein, 1995). Additionally, Rauprich et al. (2000) reported GH was reduced in newborn calves fed high amounts of nutrients. In our study, GH concentrations were the least for the 30 mL/kg of BW treatment, which would be expected, however, the 20 mL/kg of BW treatment was the greatest, whereas, the 10 mL/kg of BW treatment was intermediate. Sampling time across treatment groups also influenced GH concentrations. Serum GH decreased 1 hour after birth and remained similar through hour 6, after which, GH increased through hour 15. Therefore, GH concentrations are not only influenced by amount of colostrum fed, but by time of sampling in lambs the first 18 hours of life.

Concentrations of serum IGF-1 were similar to those noted by Mazzone (1997). The linear increase of IGF-1 with increased colostrum intake may indicate both increased uptake by the neonatal gut, as well as increased production by the neonatal liver. Campbell and Baumrucker (1989) reported that one source of IGF-1 in the neonate may be from absorption of IGF-1 in the small intestine. Although it is unknown if lambs have the ability to absorb colostral IGF-1, Hammon and Blum (1997) reported that IGF-1 is barely

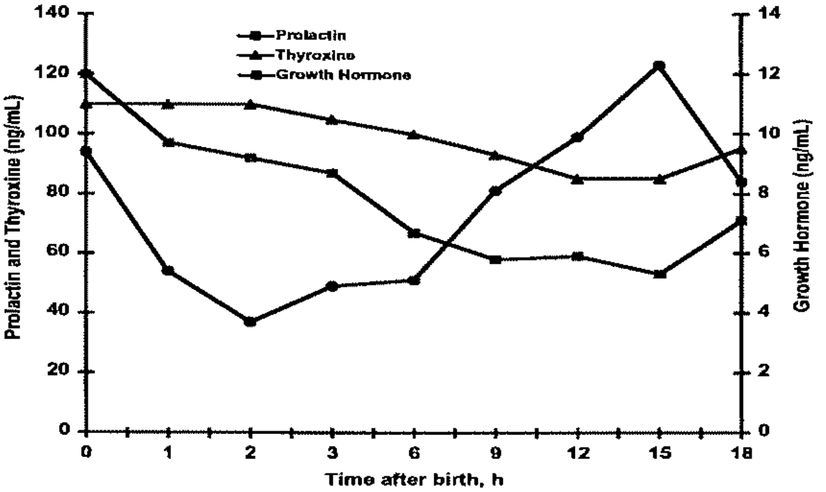

Figure 1. Serum prolactin (PRL), thyroxine (T_4) and growth hormone in lambs across the three treatments from birth through hour 18 (treatment x time of sampling; P > .47; time of sampling effect; P < .002).

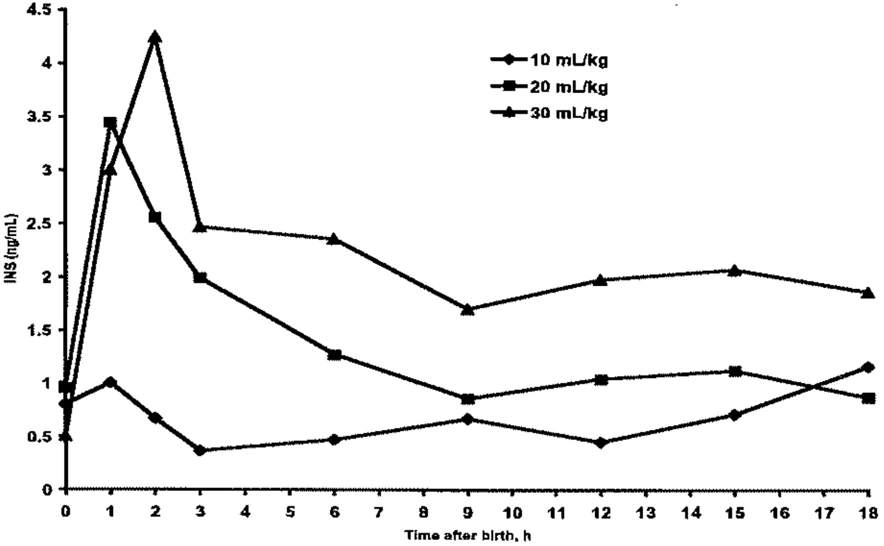

Figure 2. Serum insulin (INS) in lambs receiving 10 mL/kg, 20 mL/kg, and 30 mL/kg of body weight of colostrum from birth through hour 18. A treatment x time of sampling interaction was detected (P = .08). The pooled SE was .51 ng/mL.

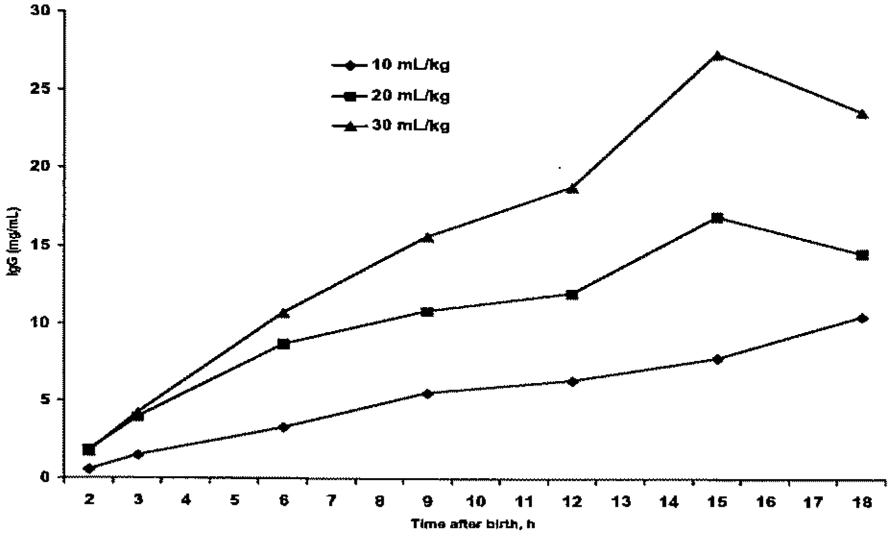

Figure 3. Serum immunoglobulin G (IgG) in lambs receiving 10 mL/kg, 20 mL/kg, and 30 mL/kg of body weight of colostrum every 3 hours from birth through hour 18. A treatment x time of sampling was detected (P = .002). The pooled SE was 1.03 ng/mL.

absorbed, if at all, in newborn calves. Prolonged colostrum feeding (six times instead of one) has been shown to cause greater IGF-1 concentrations in neonatal calves (Hammon and Blum, 1997). Neonates with a high plane of nutrition are also capable of producing more IGF-1 in the liver (Chestnutt and Wylie, 1995). As colostrum intake increased, the liver may have increased production of IGF-1.

Serum IgG concentrations in our study are similar to those reported by others (Klobasa et al., 1992; Mazzone et al., 1999). In calves between hours 0 and 24, IgG concentrations were greatest when fed larger amounts of colostrum sooner after birth (Stott et al., 1979b). Stott et al. (1979a) also found that age of calves at the first feeding had an inverse effect on the rate of IgG absorption. Lambs absorb IgG in the intestine up until the time of gut closure. The linear increase in serum IgG concentrations may reflect the cumulative effect of absorption of immunoglobulins after each consecutive feeding. This is in agreement with the theory that passive immunity of neonatal lambs is improved by multiple feedings of colostrum (Halliday, 1978). The increase in serum IgG concentrations is probably not evident until hour 6 some time is required after ingestion for nutrients to pass through the gastrointestinal tract and to be absorbed by the small intestine. Klobasa et al. (1992) noted greater serum IgG concentrations when lambs were fed at 4 to 6 hour intervals compared to 1 to 2 hour intervals between feedings.

A rise in serum INS followed the first feeding in all treatments in our study, however, a linear increase was observed as the amount of colostrum increased. Porter and Bassett (1979) reported INS increased 60 to 120 minutes after suckling in lambs 1 day old and older. The linear insulin rise associated with increased amounts of colostrum was likely the consequence of greater postprandial hyperglycemia with increased colostrum intake. Although there appears to be only one INS surge shown in Figure 2, blood samples were collected hourly only during the first 3 hours; subsequent INS surges might not have occurred due to the frequency of sampling after hour 3. In general, a linear increase in INS was noted at most sampling times as colostrum intake increased. Factors such as feeding density, and energy and protein intake have been reported to modify insulin secretion (Guilloteau et al., 1997; Kühne et al., 2000).

Implications

Feeding increasing amounts of colostrum following birth influenced serum IgG, INS, IGF-1 and GH concentrations, thereby, influencing both passive immunity and endocrine status. Feeding between 20 and 30 mL/kg of BW of colostrum every 3 hours appeared to be beneficial to newborn lambs, resulting in high levels of serum IgG. Because no lamb mortality resulted from health problems during the first week of life and at weaning, even a minimal amount of colostrum (10 mL/kg of BW fed every 3 hours) seemed to provide an adequate source of nutrition, growth-promoting substances and IgG for neonatal survival the first week of life and through weaning.

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Adipose Tissue Lipogenic Enzyme Activity, Serum IGF-I, and IGF-Binding Proteins in the Callipyge Lamb

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Abstract

The purpose of this study was to determine if reduced adipose tissue accretion in callipyge lambs during growth was related to activities of lipogenic enzymes and serum concentrations of insulin, insulin-like growth factor-I (IGF-I), and IGF-binding proteins. Normal lambs were homozygous normal (clpg/clpg), and callipyge lambs were heterozygotes (CLPG/clpg). Lambs were slaughtered at 25, 41, 57, or 73 kg (target live weight gtoups), with five normal and five callipyge lambs in each weight group. Subcutaneous, intermuscular, and perirenal adipose tissue samples were dissected as soon as possible after slaughter from the 41, 57, and 73 kg groups. Tissue homogenates were prepared for assay of fatty acid synthase, acyl-CoA synthetase, glycerophosphate acyltransferase, and lipoprotein lipase activities. Most numeric values for enzyme activities were higher for the normal lambs in each adipose tissue depot. Callipyge lambs had lower (P = 0.05) glycerophosphate acyltransferase activity in subcutaneous adipose tissue at 41 kg. In intermuscular adipose tissue, each enzyme activity was lower ($P \le 0.05$) at 41 kg for callipyge lambs. In perirenal adipose tissue, fatty acid synthase and glycerophosphate acyltransferase activities were lower (P = 0.02) for callipyge lambs at 41 kg, and acyl-CoA synthetase was lower (P = 0.02) for callipyge lambs at 73 kg.. Serum concentrations of insulin were not affected by genotype ($P > 0.20$). Serum insulin in nonfasted callipyge lambs was not affected by body weight, but increased with weight in non-fasted normal lambs (P = 0.03). Two-day fasted lambs had decreased serum insulin in both genotypes, which increased (P = 0.03) similarly with body weight for both genotypes. Serum IGF-I was greater (P = 0.09) in normal lambs at 73 kg, whereas IGF-I in 2-d fasted callipyge lambs was greater (P = 0.03) than normal lambs. No genotype effects were observed for the relative proportions of the IGF-binding proteins. We conclude that callipyge lambs had lower lipogenic enzyme activities in adipose tissue than normal lambs, but these changes were not related to serum concentrations of insulin or IGF-I.

Key words: lambs; callipyge; lipogenesis; insulin

Introduction

The callipyge phenotype is an inheritable neomutation, and the result of a single dominant autosomal gene (Cockett et al., 1994; Cockett et al., 1996). Although growth rates of callipyge lambs were similar to normal lambs (Jackson et al., 1997a; Freking et al., 1998), callipyge lambs were more muscular, especially in the hind quarters, and lower in fat depth than normal lambs (Jackson et al., 1997b; 1997c; Freking et al., 1998). Biochemical characterization of the callipyge lamb has been limited to muscle, with the calpain/calpastatin system the most thoroughly studied (Koohmaraie et al., 1995). Collagen and collagen crosslinking also have been reported (Field et al., 1996). To date no data on adipose tissue biochemistry have been reported for the callipyge lamb. The reduced fat deposition previously reported for callipyge lambs suggests that lipid accretion was down regulated; however, the mechanism remains unknown. We hypothesize that adipose tissue lipogenic enzyme activity is lower in callipyge than in normal lambs. The purpose of the present study was to determine if lipogenic enzyme activity in ovine adipose tissue is influenced by the callipyge genotype, and to determine if changes are related to insulin, insulin-like growth factor-I (IGF-I), and IGF-binding proteins in serum.

Materials and Methods

Animals.

A serial slaughter of 40 wether lambs weighing from 18.2 to 74.3 kg was conducted. Lambs were the offspring from hererozygous callipygous Dorset/Columbia rams (CLPG/clpg) mated to normal Columbia ewes (clpg/clpg). Because the callipyge phenotype cannot be distinguished accurately before 10 wk of age, lambs under 25 kg were genotyped with microsatellites flanking the CLPG locus (Cockett et al., 1994; Cockett et al., 1996). Lambs over 25 kg were phenotyped for the heavy muscling characteristic of the callipyge expression or for normal muscling.

Lambs were reared with their dams under

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confinement until reaching slaughter weight or weaned at about 90 d postpartum. Ewes and lambs were fed chopped alfalfa hay ad libitum, and the ewes were supplemented daily with 0.5 kg of whole barley. Lambs had ad libitum access to a commercial lamb creep feed until about 90 d of age. After weaning, lambs were adjusted to a diet of 60% whole barley and 40% pelleted alfalfa offered for ad libitum consumption. Lambs were randomly preassigned to a slaughter weight group. Appropriate guidelines for humane lamb slaughter were implemented.

Tissue sampling.
Adipose tissue was only sampled from lambs slaughtered at target live weights of 41, 57, and 73 kg because the subcutaneous depot of 25-kg lambs could not provide a sufficient tissue sample. Subcutaneous, intermuscular, and perirenal adipose tissue samples were obtained immediately after stunning, exsanguinating, and removing the pelt. Subcutaneous adipose tissue was dissected adjacent the 12th rib, and intermuscular adipose tissue was sampled from around the prescapular lymph node (beneath the trapezius muscle). Tissue samples were wrapped in aluminum foil, and placed in liquid nitrogen. Samples were stored at -70° C until analyzed (within 12 wk).

Ten d before slaughter, jugular venous blood samples were obtained from each lamb of the 25, 41, 57, and 73-kg target live weight groups. Lambs were then fasted for 48 h, after which a second jugular venous blood sample was obtained. Lambs were then provided ad libitum access to their diet until slaughter. Serum was harvested for analysis of insulin, IGF-I, and IGF-binding proteins.

Adipose tissue and serum assays.
Activities of fatty acid synthase, acyl-CoA synthetase, glycerophosphate acyltransferase, and lipoprotein lipase were determined in tissue homogenates. Fatty acid synthase activity was determined by quantifying the rate of oxidation of NADPH (Vernon, 1976; Vernon and Taylor, 1986). Acyl-CoA synthetase activity was quantified by determining the rate of palmitate conversion to palmitoyl-CoA (Shimamura et al., 1992). Glycerophosphate acyltransferase activity was determined by measuring the rate of incorporation of palmitoyl-CoA into total glycerolipids (Rule et al., 1988a). Total lipoprotein lipase activity was determined according to Andersen et al. (1996). All data were expressed per mg of homogenate protein, as assayed using the biuret procedure. Tissue freezing in liquid N did not affect glycerolipid biosynthesis activity in swine adipose tissue (Rule et al., 1988b). By using protease inhibitor for preparation of lipoprotein lipase activity measurements, activity in frozen preparations was not inhibited (Rule et al., 1996). Fatty acid synthase activity was nor lost by tissue freezing in preliminary experiments.

Serum concentrations of IGF-I were determined in duplicate as described previously (Echternkamp et al., 1990; Funston et al., 1995a; Clapper et al., 1998). Relative amounts of IGF-binding proteins in serum were analyzed by one-dimensional SDS-PAGE (Laemmli, 1970) and ligand blotting (Hossenloop et al., 1986; Howard and Ford, 1992) as described previously (Funston et al., 1995a; Clapper et al., 1998). Identities of IGF-binding proteins-2, -4, and –5 in serum were previously confirmed by immunoprecipitation (Clapper et al., 1998; Funston et al., 1996a,b). On the basis of the similarity in molecular masses of IGF-binding proteins identified in cattle (Funston et al., 1995; Roberts and Funston, 1993), the IGF-binding protein detected as a 40/44 kDa doublet was presumed to be IGF-binding protein-3. Band density of each IGF-binding protein was divided by the band density of the respective IGF-binding protein present in a standard ovine serum sample placed on each gel. These data, expressed as percentages of standard band densities for each IGF-binding protein, were compared to determine effects of treatment and genotype on each IGF-binding protein.

Statistical analysis.
Data for lipogenic enzymes were analyzed by three-way ANOVA to determine effects of genotype, body weight group, and tissue depot. Genotype effects across body weight groups and tissues depots were observed; therefore, genotype and body weight group effects within adipose depot were reported. Serum hormones and IGF-binding protein data were analyzed by repeated measures to ascertain the effects of feed restriction, and by two-way ANOVA to determine effects of genotype and body weight group. Statistical Analysis System (SAS, Version 5 Edition; 1985) was used for statistical computations. Effect of genotype was considered significant at $P < 0.10$; however, actual P values were noted for the readers' interpretation.

Results and Discussion

Live weights at slaughter were slightly lower than the target weights because of shrink caused by the overnight stand without feed before slaughter. Actual live weights (mean ± SEM) for the 25, 41, 57, and 73-kg groups, respectively, were as follows: 22.1 ± 0.6 , 37.7 ± 0.8, 52.5 ± 0.9, and 70.4 ± 2.3 for the callipyge lambs, and 18.7 ± 0.5, 35.6 ±0 .9, 53.8 ± 1.2, and 67.9 ± 1.1 for the normal lambs. The mean age within target weight groups were similar for normal and callipyge lambs (25-kg: 100 vs. 103 d; 41-kg: 148 vs. 147 d; 57-kg: 163 vs. 160 d; 73-kg: 246 vs. 244 d, respectively). Expression of the callipyge gene did not affect growth rate when normal and callipyge lambs were fed similar diets (Snowder et al., 1994; Jackson et al., 1997b).

Lipogenic enzyme activities.
Across body weight group and adipose tissue depot, genotype effects were observed for fatty acid synthase ($P = 0.02$), acyl-CoA synthetase ($P = 0.02$), glycerophosphate acyltransferase ($P = 0.009$), and lipoprotein lipase ($P = 0.10$), with callipyge lambs having the lower activity for each enzyme. Across genotype and adipose tissue depot, body weight group effects ($P \leq 0.03$) were observed for each enzyme. Fatty acid synthase and acyl-CoA synthetase activities were lowest at 41 kg, intermediate at 57 kg, and highest at 73 kg. Glycerophosphate acyltransferase and lipoprotein lipase activities were highest at 57 kg, and lowest and 41 and 73 kg; these enzyme activities were similar at the latter two body weights. Across genotype and body weight group, adipose tissue depot effects were observed for each enzyme ($P < 0.001$) except for glycerophosphate acyltransferase ($P = 0.23$). Fatty acid synthase and acyl-CoA synthetase activities were highest in perirenal adipose tissue, but were similar for subcutaneous and intermuscular adipose tissue, and lipoprotein lipase activity was lowest in subcutaneous adipose tissue, but similar for perirenal and intermuscular adipose tissues. No genotype x adipose tissue depot interactions were observed (P =

0.13 to 0.89). No genotype x body weight group x adipose tissue depot interactions were observed (P = 0.08 to 0.64). A genotype x body weight group interaction was observed for glycerophosphate acyltransferase (P < 0.001), but not for the other enzyme activities (P = 0.21 to 0. 90).

Lipogenic enzyme activities in callipyge and normal lambs for the three adipose tissue depots are presented in Tables 1-3. Except for acyl-CoA syntherase at 41 kg and glycerophosphate acyltransferase at 57 kg, numeric values for subcutaneous adipose tissue lipogenic enzyme activities (Table 1) were higher in normal lambs than in callipyge lambs. Fatty acid synthase activity in subcutaneous adipose tissue tended to be greater in normal lambs with the greatest difference expressed at 73 kg (P = 0.12). Glycerophosphate acyltransferase activity in subcutaneous adipose tissue was greater for normal lambs at 41 kg (P = 0.05), but tended to be greater for normal lambs at 73 kg (P = 0.11). In contrast, glycerophosphate acyltransferase activity in subcutaneous adipose tissue of 57 kg callipyge lambs tended to be greater (P = 0.08) than that in the normal lambs. Lipoprotein lipase activity in subcutaneous adipose tissue tended to be greater in normal lambs (P values ranged from 0.12 to 0.54). Overall, lipogenic enzyme activities of fatty acid synthase, acyl-CoA synthetase, and lipoprotein lipase in subcutaneous adipose tissue increased with increasing weight with higher values generally observed in normal lambs compared to callipyge lambs. Glycerophosphate acyltransferase activity in callipyge lambs was similar at 57 and 73 kg (P > 0.05), but in normal lambs, this enzyme activity increased by nearly 60% (P < 0.05) between 57 and 73 kg.

Similar to subcutaneous adipose tissue, numeric values for enzyme activities in intermuscular adipose tissue were generally greater in normal than in callipyge lambs, except for fatty acid synthase at 73 kg, which tended to be greater (P = 0.09) in callipyge than in normal lambs (Table 2). For each enzyme in intermuscular adipose tissue, normal lambs had greater activity (P = 0.05 to 0.001) than callipyge lambs at 41 kg. Except for fatty acid synthase activity at 73 kg, no genotypic differences (P ≥ 0.24) in enzyme activities were observed at 57 and 73 kg.

Table 1. Lipogenic enzyme activity[a] in subcutaneous adipose tissue of callipyge and normal lambs from 41 to 73 kg

Enzyme	Weight group, kg	Genotype Callipyge	Normal	SE[b]	*P*-value[b]
Fatty acid synthase	41	17.8^d	27.7^d	8.0	0.41
	57	78.0^c	87.6^c	15.0	0.66
	73	81.3^c	130.2^c	19.9	0.12
Acyl-CoA synthetase	41	46.5^d	41.2^e	3.6	0.34
	57	59.6^d	67.4^d	5.4	0.34
	73	103.5^c	115.0^c	11.0	0.50
Glycerophosphate acyltransferase	41	33.3^d	47.4^d	4.3	0.05
	57	64.2^c	47.2^d	5.8	0.08
	73	55.9^c	75.4^c	7.5	0.11
Lipoprotein lipase	41	31.0^d	39.1^d	4.0	0.16
	57	56.1^c	64.0^c	9.0	0.54
	73	61.0^c	81.1^c	8.1	0.12

[a] Units of enzyme activity were as follows: Fatty acid synthase, nMol NADPH oxidized • 15 min^{-1} • mg of homogenate protein^{-1}; acyl-CoA synthetase, nMol palmitate converted to palmitoyl-CoA • 10 min^{-1} • mg of homogenate protein^{-1}; glycerophosphate acyltransferase, nMol glycerol-3 phosphate converted to glycerolipid • 10 min^{-1} • mg homogenate protein^{-1}; lipoprotein lipase, nEquivalents of fatty acid released • 10 min^{-1} • mg of homogenate protein^{-1}.

[b] Standard error (SE) and probability (P) values were determined by ANOVA for comparison of genotype within a body weight group. N=5 per genotype within each weight group.

[c,d,e] Within a column, for each enzyme, genotypic means without a common superscript letter differ within weight groups (P < 0.05).

Table 2. Lipogenic enzyme activity[a] in intermuscular adipose tissue of callipyge and normal lambs from 41 to 73 kg

Enzyme	Weight group, kg	Genotype Callipyge	Normal	SE[b]	*P*-value[b]
Fatty acid synthase	41	33.4^d	64.7^e	2.7	0.001
	57	93.9^c	107.2^c	8.1	0.28
	73	108.4^c	86.4^d	8.0	0 .09
Acyl-CoA synthetase	41	27.4^e	41.4^d	4.4	0.05
	57	58.2^d	61.3^d	5.7	0 .71
	73	83.7^c	117.4^c	18.3	0.24
Glycerophosphate acyltransferase	41	36.0^d	59.4^c	2.5	0 .001
	57	60.0^c	63.6^c	5.8	0 .66
	73	43.5^d	40.9^d	5.1	0 .73
Lipoprotein lipase	41	53.0^d	89.1^c	7.9	0.02
	57	89.2^c	79.9^{cd}	9.9	0 .54
	73	76.1^{cd}	61.9^d	9.1	0 .33

[a] Units of enzyme activity were as follows: Fatty acid synthase, nMol NADPH oxidized • 15 min^{-1} • mg of homogenate protein^{-1}; acyl-CoA synthetase, nMol palmitate converted to palmitoyl-CoA • 10 min^{-1} • mg of homogenate protein^{-1}; glycerophosphate acyltransferase, nMol glycerol^{-3} phosphate converted to glycerolipid • 10 min^{-1} • mg homogenate protein^{-1}; lipoprotein lipase, nEquivalents of fatty acid released • 10 min^{-1} • mg of homogenate protein^{-1}.

[b] Standard error (SE) and probability (P) values were determined by ANOVA for comparison of genotype within a body weight group. N=5 per genotype within each weight group.

[c,d,e] Within a column, for each enzyme, genotypic means without a common superscript letter differ within weight groups (P < 0.05).

Table 3. Lipogenic enzyme activity[a] in perirenal adipose tissue of callipyge and normal lambs from 41 to 73 kg

Enzyme	Weight group, kg	Genotype			
		Callipyge	Normal	SE[b]	*P*-value[b]
Fatty acid synthase	41	56.1^{e}	84.1^{d}	6.8	0.02
	57	124.5^{d}	147.8^{c}	9.7	0.13
	73	157.9^{c}	180.7^{c}	16.1	0.34
Acyl-CoA synthetase	41	50.5^{e}	64.2^{e}	6.8	0.19
	57	79.4^{d}	118.2^{d}	12.4	0.06
	73	119.2^{c}	152.3^{c}	8.2	0.02
Glycerophosphate acyltransferase	41	38.1^{d}	62.8^{cd}	6.0	0.02
	57	79.7^{c}	67.9^{c}	6.0	0.20
	73	36.2^{d}	42.4^{d}	6.5	0.52
Lipoprotein lipase	41	79.0	93.9^{cd}	13.0	0.44
	57	87.0	102.2^{c}	10.1	0.33
	73	75.9	66.1^{d}	8.9	0.47

[a] Units of enzyme activity were as follows: Fatty acid synthase, nMol NADPH oxidized • 15 $\min^{-1}$ • mg of homogenate protein^{-1}; acyl-CoA synthetase, nMol palmitate converted to palmitoyl-CoA • 10 $\min^{-1}$ • mg of homogenate protein^{-1}; glycerophosphate acyltransferase, nMol glycerol^{-3} phosphate converted to glycerolipid • 10 $\min^{-1}$ • mg homogenate protein^{-1}; lipoprotein lipase, nEquivalents of fatty acid released • $\min^{-1}$ • 10 mg of homogenate protein^{-1}.

[b] Standard error (SE) and probability (P) values were determined by ANOVA for comparison of genotype within a body weight group. N=5 per genotype within each weight group.

[c,d,e] Within a column, for each enzyme, genotypic means without a common superscript letter differ within weight ($P < 0.05$).

In perirenal adipose tissue, fatty acid synthase activity was greater ($P = 0.02$) in normal lambs at 41 kg, and tended ($P = 0.13$) to be greater in normal lambs at 57 kg (Table 3). Acyl-CoA synthetase activity in perirenal adipose tissue was greater in normal lambs at 57 ($P = 0.06$) and at 73 kg ($P = 0.02$). Glycerophosphate acyltransferase activity was greater ($P = 0.02$) in normal lambs at 41 kg, but did not differ at 57 and 73 kg. Lipoprotein lipase activity in perirenal adipose tissue did not differ between normal and callipyge lambs. Across weight groups, activities of fatty acid synthase and acyl-CoA synthetase increased ($P < 0.05$) with increasing weight in perirenal adipose tissue. Across adipose tissue depots, lipogenic enzyme activity was greater in perirenal adipose tissue compared to subcutaneous (Table 1) and intermuscular adipose tissues (Table 2).

Expressing lipogenic enzyme activity on a protein basis accounts for potential differences in adipose tissue cellularity because as adipocytes decrease in volume, the protein concentration should increase, as well as the number of adipocytes per gram of tissue. Adipose tissue homogenate protein concentration across weight group was not affected by genotype for either subcutaneous ($P = 0.85$) or perirenal ($P = 0.15$) adipose tissues. For perirenal adipose tissue across genotypes, protein concentration was greatest ($P < 0.001$) for the 41 kg lambs (7.78 mg/ g tissue), whereas, protein concentration for the 57 kg lambs (4.10 mg/g tissue) tended ($P = 0.16$) to be greater than for the 73 kg lambs (2.80 mg/ g tissue). In subcutaneous adipose tissue across genotype, protein concentration for the 41 kg lambs (9.88 mg/ g tissue) was greatest ($P = 0.003$), intermediate for the 57 kg lambs (5.98 mg/ g tissue), and lowest ($P = 0.05$) for the 73 kg lambs (3.58 mg/ g tissue). In the intermuscular adipose tissne depot, an interaction ($P = 0.008$) between genotype and weight group was observed. The 41 kg lambs had greater ($P < 0.001$) protein concentration (8.20 mg/ g tissue) than either the 57 kg lambs (4.32 mg/ g tissue) or the 73 kg lambs (3.55 mg/ g tissue), both of which were similar ($P = 0.42$). The 41 kg callipyge lambs had over twofold the protein concentration (11.08 mg/ g tissue) of the other genotype and weight groups, all of which had similar ($P \geq 0.42$) protein concentration in the intermuscular depot (3.50 to 5.32 mg/ g tissue). For each genotype and tissue depot, the effect of weight group suggests that as animal weight increased protein concentration decreased, which also would be expected for adipocyte number per g of tissue. Expressing data on a tissue weight basis (data not shown) altered few of the genotype comparisons, with the major exception being the 41 kg callipyge lambs in the intermuscular depot where on a tissue weight basis genotype effects were diminished. Thus, expressing the data on a protein basis proved to be an acceptable comparison of normal and callipyge lamb lipogenic enzyme activity.

Our data indicate a general depression in lipogenic enzyme activity across adipose tissue depots and at various body weights of callipyge compared with normal lambs. Callipyge lambs used in the present study were leaner over the growth curve than the normal lambs (Snowder et al., 1998). Thus, lower fat deposition during growth in callipyge lambs can be attributed, in part, to lower lipogenic enzyme activities than in normal lambs. However, the mechanism by which lipogenic enzyme activities were decreased cannot be discerned from the present study. Genetic predisposition to lower rates of lipid accretion may partially characterize callipyge lambs because models of genetic obesity, such as porcine obesity, have greater lipogenesis in adipose tissue at various times during postnatal growth (Mersmann, 1986). Moreover, adipose tissue of Meishan pigs (an obese model) had greater activities of lipogenic enzymes, especially during periods of greatest fat deposition (Mourot et al., 1996). In Zucker obese rats, lipogenic enzyme activity in adipose tissue was greater than in lean rats even during periods of feed restriction (Cleary et al., 1987). Based on these examples, lower lipogenic enzyme activities in callipyge adipose tissue may have been the result of genetic down-regulation of lipogenesis compared with their normal counterparts.

Alternatively, the depressed enzyme activities observed in callipyge adipose tissue may have occurred through increased cellular utilization of substrate supply by muscle, leaving adipose tissue in a state of reduced substrate availability. Pothoven and Beitz (1975) clearly demonstrated a reduction in lipogenesis and lipogenic enzyme activity in adipose tissue of fasted cattle. In response to fasting, endocrine and metabolite changes occur rapidly in cattle (Rule et al., 1985), as well as in sheep as illustrated in the present study with insulin (Table 4). Feed restriction, as opposed to fasting, also reduces activities of lipoprotein lipase and glycerophosphate acyltransferase in adipose tissue of growing lambs (Andersen et al., 1996). In the present study, the most pronounced differences in enzyme activities occurred at the lighter weights, suggesting that at 41 kg, the muscular hypertrophy occurring in the callipyge lambs may have resulted in the greatest competition with adipose tissue for lipogenic substrates.

Table 4. **Insulin and insulin-like growth factor-I (IGF-I) concentrations in non-fasted and fasted callipyge and normal lambs from 25 to 73 kg**

	Genotype[a]			
	Callipyge		Normal	
Weight group, kg	Non-fasted	Fasted	Non-fasted	Fasted
Insulin, µIU/mL				
25	10.9	$5.6^{c,x}$	10.9^{d}	$6.9^{c,x}$
41	13.8	$7.8^{c,x}$	$12.0^{c,d}$	$6.8^{c,x}$
57	13.6	11.2^{b}	$15.0^{b,c}$	$10.3^{a,y}$
73	14.1	$11.7^{b,y}$	16.7^{b}	12.1^{a}
SE	1.1	0 .8	1.3	1.1
IGF-I, ng/mL				
25	41.8^{d}	25.8^{d}	38.3^{d}	$20.2^{c,y}$
41	125.3^{b}	$81.6^{c,y}$	$119.7^{b,c}$	$69.5^{b,y}$
57	$92.2^{b,c}$	$104.4^{b,c}$	84.9^{c}	86.0^{b}
73	$75.2^{c,d}$	117.5^{b}	132.6^{b}	$76.3^{b,y}$
SE	13.4	8.4	13.8	10.3

[a] No effect of genotype ($P > 0.2$) was observed for non-fasted or fasted serum insulin concentrations. For IGF-I, genotype effects were observed only for the 73 kg lambs, in which IGF-I was greater for normal lambs ($P < 0.09$), but fasted values were lower for normal lambs ($P = 0.03$) than for the callipyge lambs.

[b,c,d] Within a column, means without a common superscript letter differ within weight groups ($P < 0.03$ for insulin, and $P < 0.01$ for IGF-I).

[x] Within a column depicting common genotypic means (either callipyge or normal), non-fasted values were different from fasted values ($P < 0.01$).

[y] Within a column depicting common genotypic means (either callipyge or normal), non-fasted values were different from fasted values ($P < 0.05$).

Serum concentrations of insulin, IGF-I, and IGF-binding proteins.

No genotypic effect on non-fasted or fasted serum concentrations of insulin (Table 4) were observed at any of the body weights studied ($P > 0.20$). For both callipyge and normal lambs, fasted insulin values were lower than the non-fasted values ($P < 0.05$). For the non-fasted callipyge lambs, serum insulin concentrations were not affected by body weight group ($P = 0.19$); however, fasted insulin concentrations were greater ($P < 0.01$) for the 57 and 73 kg callipyge lambs than for the 25 and 41 kg callipyge lambs. In normal lambs, serum insulin concentrations increased with body weight for both non-fasted values ($P = 0.03$) and fasted values ($P = 0.01$). Serum insulin concentrations in non-fasted callipyge and normal lambs also were not different in a previous study (Whisnant et al., 1998).

Genotype effects on IGF-I concentrations were observed only for the 73-kg lambs (Table 4). For non-fasted lambs, callipyge had lower IGF-I values ($P = 0.09$) than normal lambs. After fasting, however, IGF-I concentrations in callipyge lambs were greater ($P = 0.03$) than in normal lambs. For both genotypes, fed IGF-I concentrations increased ($P < 0.01$) with development from 25 to 41 kg and did not change thereafter for callipyge, but continued to increase ($P < 0.01$) for normal lambs. For fasted lambs, IGF-I concentrations tended to continually increase for the callipyge lambs, but for the normal lambs, fasted IGF-I reached a plateau by 41 kg of live weight. Similar observations were reported for callipyge compared with normal lambs in the fed state (Hossner et al., 1995; Whisnant et al., 1998).

Six IGF-binding proteins were detected in serum. On the basis of immunoprecipitation in previous studies (Roberts and Funston, 1993; Funston et al., 1995a,b; Funston et al., 1996; Clapper et al., 1998; Snyder et al., 1999), these proteins were identified as a 29 kDa IGF-binding protein (presumably IGF-binding protein-1; Gallaher et al., 1992), IGF-binding protein-2 (34 kDa), IGF-binding protein-3 (40 and 44 kDa), and IGF-binding protein-4 (24 and 28 kDa). Standardized band densities for each IGF-binding protein were expressed as a percentage of the respective IGF-binding protein in a standard ovine serum sample in Table 5. No genotypic effect was observed for IGF-binding proteins for either non-fasted or fasted lambs ($P > 0.20$). This result contrasts that reported by Hossner et al. (1995) wherein feed restriction reduced IGF-I binding to IGF-binding protein-4 by 55% in normal lambs, but not in callipyge lambs.

Fasting resulted in reductions ($P < 0.01$) in the proportions of IGF-binding proteins-4, and the 29 kDa binding protein; whereas, fasting resulted in increased proportions of the 40 and 44 kDa IGF-binding protein-3. No effect of fasting was observed for IGF-binding protein-2. In serum of non-fasted lambs, proportions of the 24 and 28 kDa IGF-binding proteins increased ($P < 0.05$)

Table 5. Standardized IGF-binding protein percentages in non-fasted lambs and after 48 hours of fasting, from 25 to 73 kg

Condition	Weight group, kg	IGF Binding Proteins[a] BP-4 24 kDa	BP-4 28 kDa	BP-3 40 kDa	BP-3 44 kDa	BP-2	BP 29 kDa
Non-fasted	25	20.7^{d}	26.9^{d}	35.0^{c}	3.8	4.4	9.3
	41	27.8^{c}	38.0^{c}	17.4^{d}	3.3	5.2	8.4
	57	27.4^{c}	33.0^{cd}	20.0^{d}	4.9	6.2	8.5
	73	29.1^{c}	34.8^{c}	21.3^{d}	3.1	4.4	7.3
	SE	2.4	2.6	4.6	0 .7	0 .6	1.0
Fasted	25	8.4^{e}	9.3^{d}	58.0^{c}	13.0^{c}	5.6	5.6
	41	16.7^{d}	20.7^{c}	43.1^{d}	7.9^{d}	5.4	6.2
	57	19.7^{de}	23.4^{c}	36.8^{d}	7.2^{d}	5.7	7.2
	73	23.9^{c}	27.1^{c}	31.6^{d}	6.3^{d}	4.9	6.2
	SE	2.2	2.7	4.5	1.1	0.4	0.5

[a] Pixel density for each IGF-binding protein/pixel density for the respective IGF-binding protein in a standard ovine sereum sample x 100.

[b] Fed was different from fasted ($P < 0.01$) for each BP except for BP-2 ($P = 0.31$).

[c,d,e] Within a condition, columns with weight group means with different superscript letters differ ($P < 0.05$ for non-fasted lambs and $P < 0.01$ for fasted lambs).

from 25 to 41 kg of live weight, whereas the proportion of the 40 kDa binding protein-3 decreased ($P < 0.05$). Similar types of responses ($P < 0.01$) to growth occurred for the IGF-binding proteins after fasting, except that the proportion of the 44 kDa binding protein-3 decreased from 25 to 41 kg of live weight ($P < 0.01$).

The major changes in proportions of the IGF-binding proteins occurred from 25 to 41 kg of body weight. IGF-I concentrations also changed to the greatest extent between 25 and 41 kg of body weight. Because components of the IGF-I system may change independently of changes in the circulation, it remains possible that IGF-I and IGF-binding proteins in discrete tissues could differ among callipyge and normal lambs and thereby influence growth and fat accretion in a paracrine or autocrine fashion (McGuire et al.,1992; Jones and Clemmons, 1995; Snyder et al., 1999).

The relationships between insulin, IGF-I, and IGF-binding proteins with lipogenic enzymes were not readily apparent in the present study. Little, if any, effect of genotype occurred for the serum hormones measured, whereas callipyge adipose tissue had lower lipogenic enzyme activities. .

In conclusion, lipogenic enzyme activities in adipose tissue of callipyge lambs were generally lower than normal lambs. This observation may partially explain the reduced fat deposition common to callipyge lambs during growth, but the mechanism of the lower enzyme activities remains unclear. Little effect of genotype on serum insulin, IGF-I, and IGF-binding proteins was observed; however, responsiveness of adipose tissue or muscle to these hormones is not known. Further research on growth factor effectiveness and IGF-binding proteins in muscle is needed to determine how these elements affect the growth differential between callipyge and normal lambs.

Implications

The callipyge lamb offers consumers a leaner, more muscular alternative to common lamb. Moreover, the callipyge lamb may also represent a model for a genetically lean animal. The lower lipogenic enzyme activities partially explain the lean qualities of the callipyge lamb; however, further research is necessary to elucidate the mechanism for the enzymatic changes, as well as the role growth factors play in expression of the callipyge phenotype.

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Technical Note

Genetic Control of Color in Dorper Sheep and Their Crosses

D. R. Notter[*,1] and D. P. Sponenberg[†]

South African Dorper sheep were imported into the U.S. during the 1990's, and have generated considerable interest within the American sheep industry. The typical South African Dorper is a white animal with a black head, although both entirely white animals and white animals with red heads also occur. The Dorper breed was derived from crosses between the Dorset and the Blackhead Persian, beginning in the 1940's (Milne, 2000), and the Dorper color pattern is essentially the same as that of its Blackhead Persian parent. The typical Dorper coat is composed predominantly of hair fibers, although many animals possess a detectable proportion of wool fibers and some have a distinctively wooly coat (Cloete et al., 2000). Shedding of wool fibers, when they are present, is common, and shearing is not practiced in commercial flocks.

Many of the lambs produced by crossing blackheaded Dorper rams to ewes of American wool breeds are spotted or, in some cases, almost entirely black. In contrast, offspring of whiteheaded Dorper rams are normally white. As a result, some breeders have developed a preference for the white Dorper, while others prefer blackheaded animals. In all cases, the fleeces of crosses between Dorpers and wool breeds are a mixture of wool and hair fibers and have little, if any, value.

The inheritance of color in Dorpers and their crosses is complex, but relatively well understood (Sponenberg, 1997). The genes controlling color in Dorpers are distinct from those that control color in most American wool breeds, leading to novel combinations of genes influencing color in crossbred animals.

In American wool breeds, color is controlled predominantly by the Agouti (or A) gene. The predominant allele at this locus is A^{Wt} which is a dominant allele producing white fleeces in most wool breeds. The A^{Wt} allele is also associated with red or tan color in hair sheep and in a few wool breeds such as the Tunis. Several other alleles can be found at the Agouti locus (Adalsteinsson, 1970; Sponenberg, 1997), but most are rare in U.S. wool breeds. The most common alternative form of the gene is A^a, which is completely recessive and permits expression of colored wool. Animals of genotype A^aA^a are generally black, although the final expression of color can be influenced by other genes. The other, rarer Agouti alleles are intermediate to A^{Wt} and A^a in degree of dominance and produce various color patterns including badgerface (or blackbelly) and black-and-tan.

Most of the colored sheep that occasionally appear in U.S. wool breeds are homozygous for A^a at the *Agouti* locus. Most such animals are black or, occasionally, brown. Brown color is controlled the *Brown* (or *B*) gene. The dominant and most common allele at the *B* locus is B^+, which produces black wool. A rare alternative, recessive allele, B^b, produces a brown fleece which is sometimes known as a "moorit" fleece. Most black sheep that appear in U.S. wool breeds are of genotypes $A^aA^aB^+B^+$ or $A^aA^aB^+B^b$. The common observation that black coats in young lambs often fade to gray or that brown coats often fade to ivory results from the action of more poorly understood genetic modifiers.

In contrast, color in Dorpers is controlled predominantly by two different genes: the *Extension* gene and the *Pigmented head gene*. The dominant allele at the Extension locus (E^D) produces black fibers, whereas the alternative recessive allele (E^+) permits wool color to be defined by other genes. Most blackheaded Dorpers are E^DE^D or E^DE^+. These animals are not solid black because the effect of E^D is modified by the associated *Pigmented head* (or *Ph*) gene. In Dorpers, animals commonly carry the *Persian* allele (Ph^P) at the *E* locus. Two copies of Ph^P produce the classic Dorper color pattern. The typical blackheaded Dorper is thus $E^DE^DPh^PPh^P$. To fully understand Dorper color, especially in crosses, requires a change in viewpoint: the typical Dorper is not a white sheep with a black head. Instead, it is a black sheep whose body is covered with a large white spot resulting from the Ph^PPh^P genotype.

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Crosses between the Dorper and U.S. wool breeds may thus carry both dominant white (A^{Wt}) at the *Agouti* locus and dominant black (E^D) at the *Extension* locus. When this happens, the animal will be black because E^D takes precedence over A^{Wt}. Dominant black is also present in a few wool breeds. Black Welsh Mountain, Karakul, and Jacob sheep all express dominant black. Crosses between homozygous E^DE^D animals of these breeds and white wool breeds produce only black offspring.

The typical Dorper ram is $E^DE^DPh^PPh^P$ (black with a white body). The Agouti alleles that are present in Dorpers are not really known because E^D and Ph^P commonly mask their expression. The typical white ewe of a U.S. wool breed is $A^{Wt}A^{Wt}E^+E^+Ph^+Ph^+$ (a white ewe carrying recessive, and therefore unexpressed, alleles at the *Extension* and *Pigmented head* loci). *Brown* generally can be ignored because B^b is rare and in crossbreds will usually be masked by either A^{Wt} or E^D. A cross between these two types of animals (Figure 1) produces lambs that are $A^{Wt}A^?E^DE^+Ph^PPh^+$ where $A^?$ indicates that the Agouti allele obtained from the Dorper is usually not known. These lambs are commonly black with spots. Spotting occurs because animals that have only one copy of Ph^P exhibit spotting instead of a uniform white body color. The Ph^PPh^+ animal thus has an intermediate level of spotting between that of Ph^PPh^P and Ph^+Ph^+, and most crossbreds are black animals with spots.

Some exceptions to this classic pattern of color inheritance in Dorper crosses occur. All Dorpers do not have black heads, some Dorper crossbreds are solid black, and a few Dorper crossbreds out of blackheaded rams are solid white.

Whiteheaded Dorpers are homozygous for the recessive E^+ allele at the *Extension* locus and therefore do not express black color. In South Africa, these sheep arose from selection among foundation crosses between Dorset and Blackhead Persian or from use of other white South African hair breeds such as the Van Rooy (Campher et al., 1998) in development of the Dorper (Milne, 2000). Crossbred offspring of white Dorper rams should normally be of genotype $A^{Wt}A^?E^+E^+Ph^PPh^+$, and are expected to be white.

Many purebred Dorpers in the U.S. have been graded up by repeated matings of purebred Dorper rams to crossbred ewes. These animals carry residual amounts of genetic material from the ewe breeds used to make the initial crosses and may also occasionally carry color alleles from these animals. Production of solid white crossbred offspring from a blackheaded ram can occur if the Dorper ram carries only one copy of E^D. Such a ram ($E^DE^+Ph^PPh^P$) would have a typical Dorper color pattern, but one half of his crossbred offspring (Figure 2) are expected to receive the E^+ allele and, in crosses with wool breeds, would be white ($A^{Wt}A^?E^+E^+Ph^PPh^+$); the other half are expected to be spotted ($A^{Wt}A^?E^DE^+Ph^PPh^+$). Heterozygous E^DE^+ rams can result from grading up in U.S. flocks or from the presence of white Dorper ancestors in the animal's pedigree. Recent molecular characterization of the *Extension* gene (Vage et al., 1999) may allow development of a DNA test to identify carriers of E^+.

Solid black crossbred animals can occur if Dorper males carry only one copy of the *Persian* allele at the *Pigmented head* locus ($E^DE^DPh^PPh^+$). Such a ram would himself be spotted, a common occurrence in the early generations of a grading-up program. In matings with white wool ewes (Figure 3), half the progeny are expected to be $A^{Wt}A^?E^DE^+Ph^PPh^+$ (spotted) and half are expected to be $A^{Wt}A^?E^DE^+Ph^+Ph^+$ (black).

Finally, spotted Dorper animals may carry only one copy of both E^D and Ph^P (Figure 4). This situation would not be surprising in commercial Dorper rams produced in upgrading programs. Matings of such animals to white wool ewes would produce the full array of color patterns with expected frequencies of 50% white, 25% spotted, and 25% black.

These general rules should allow color to be predicted with reasonable accuracy in Dorpers and their crosses. Some exceptions may occur as a result of unanticipated interactions between the *Agouti* alleles of wool breeds and the *Extension* and *Pigmented Head* alleles of the Dorper, but should be few in number. Frequencies of the various *Agouti* alleles in Dorpers are not well known (because they are normally covered up by E^D) but may result in unexpected color patterns in some Dorper crosses. The extent of spotting in Ph^PPh^+ individuals is likewise variable, ranging from predominantly black to predominantly white.

There are a few other genes that may occasionally be expressed in crossbreds. A separate *Spotting* gene exists in some U.S. breeds (Sponenberg, 1997). A recessive allele at this locus (S^S) is responsible for spotting in Jacob sheep and is present in some wool breeds. In some cases, sheep that carry this gene have wool in the black areas that is longer and coarser than that in the surrounding white areas, producing a unique, sculpted fleece. A difference in rate of wool growth between black and white areas has been observed in a few Dorper crosses (D. R. Notter, ***unpublished***). It is not known if this pattern of fiber growth occasionally accompanies spotting associated with Ph^PPh^+ or results from the action of other spotting genes.

Prediction of color is more difficult when Dorpers are mated to ewes of hair sheep breeds. In the U.S., crossing of Dorper rams on Katahdin ewes is widespread, and the Dorper is becoming popular in the Caribbean and Latin America as a terminal sire for use on local hair sheep breeds. The greater complexity in predicting color when Dorpers are crossed with other hair breeds has two sources. First, many hair sheep of genotype $A^{Wt}A^{Wt}$ or $A^{Wt}A^a$ are tan, red, or brown rather than white (Sponenberg, 1997). The A^{Wt} allele is thus expressed differently in hair breeds and can result in a range of colors from pure white to dark red or brown. The factors controlling expression of A^{Wt} in hair breeds are not well understood, but relate to the observation that color intensity is generally greater in coarser primary follicles and in hair than in finer secondary follicles. Differential expression of A^{Wt} accounts for the occasional redheaded Dorper. Crosses between Dorpers and Katahdins may express a range of colors including solid black, solid white, solid red or tan, and black-and-white spotting.

Caribbean and Latin American hair breeds are also more likely to carry alleles at the *A* locus that result in color patterns (such as blackbelly). Interactions of these alleles with alleles at the *E* and *Ph* loci of the Dorper can result in a wide range of color patterns. The *A* alleles that produce color patterns are generally recessive to A^{Wt}, resulting in unanticipated color patterns in crosses.

Development of a white Dorper flock should be relatively easy, once the E^+ allele has been introduced through crossing with white wool sheep or use of white Dorpers. E^D is dominant, so whenever it is present, it will be expressed and can be removed by culling animals that show color. This cannot be done in the first generation after using a pure blackheaded Dorper ram (E^DE^D) because all offspring will be black, but white individuals will appear in future generations involving matings with white Dorpers or between crossbred rams and ewes.

Fixation of the typical Dorper color pattern in flocks developed by grading up from ewes of wool breeds will initially be challenging. Spotted animals will be common due to segregation of Ph^P alleles and white animals will occur when parents are E^DE^+. But with some attention to color, the frequency of occurrence of white individuals in a blackheaded flock eventually need not be meaningfully higher than the frequency of occurrence of colored animals in flocks of white wool breeds.

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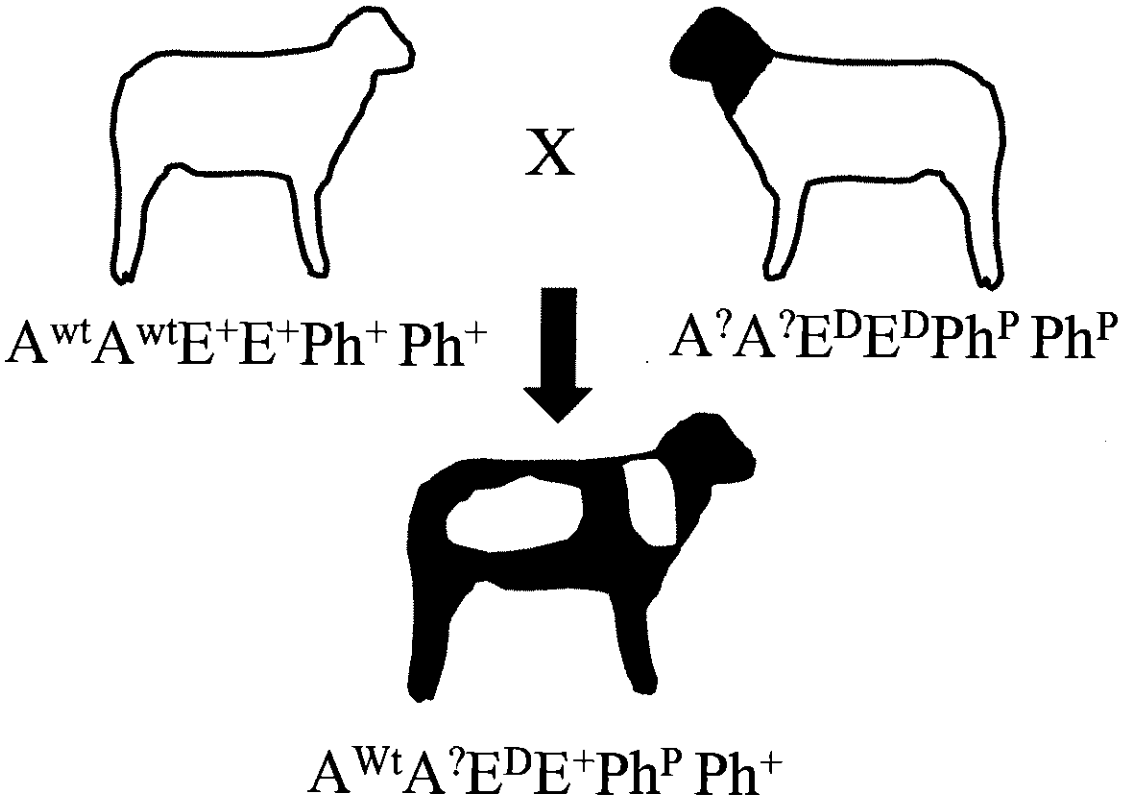

Fig. 1

Figure 1. Crosses between blackheaded Dorpers homozygous for both E^D and Ph^P and typical ewes of white wool breeds (genotype $A^{Wt}A^{Wt}E^+E^+Ph^+Ph^+$) produce spotted offspring that are heterozygous at the *E* and *Ph* genes. $A^?A^?$ indicares that the genotype of the Dorper at the *Agouti* locus is commonly not known.

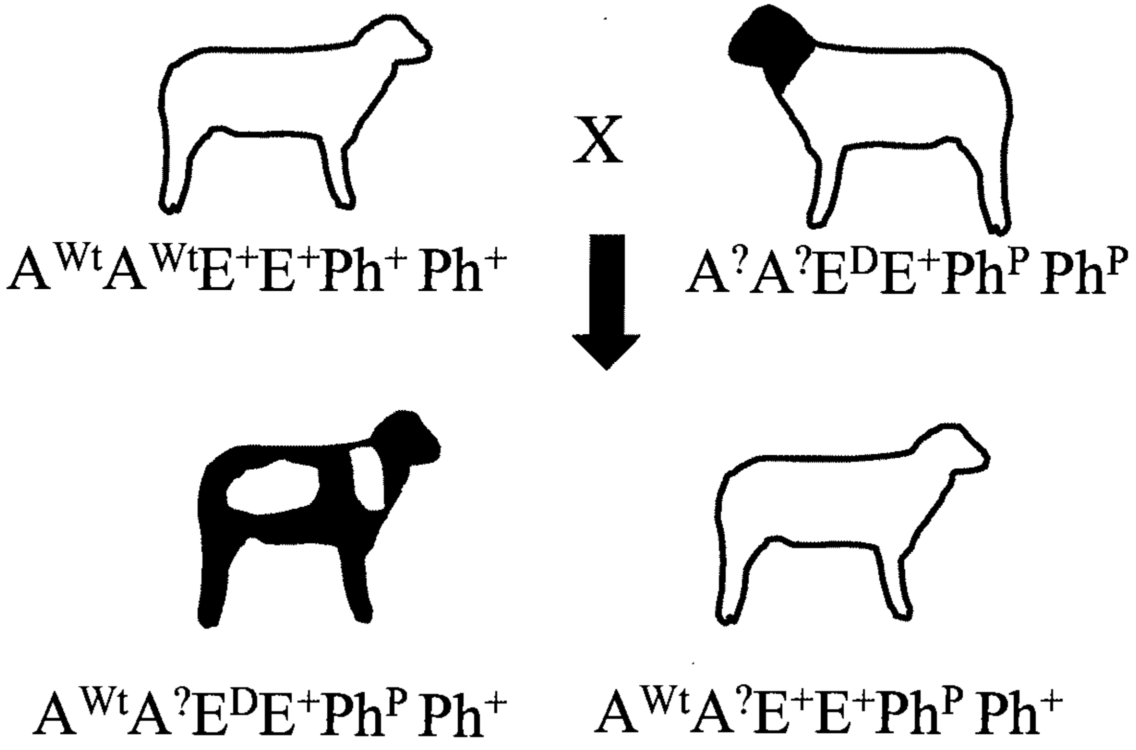

Fig. 2

Figure 2. When ewes of white wool breeds are mated to blackheaded Dorper rams that are heterozygous at the *E* locus, 50% of the resulting lambs are expected to be white and 50% are expected to be spotted.

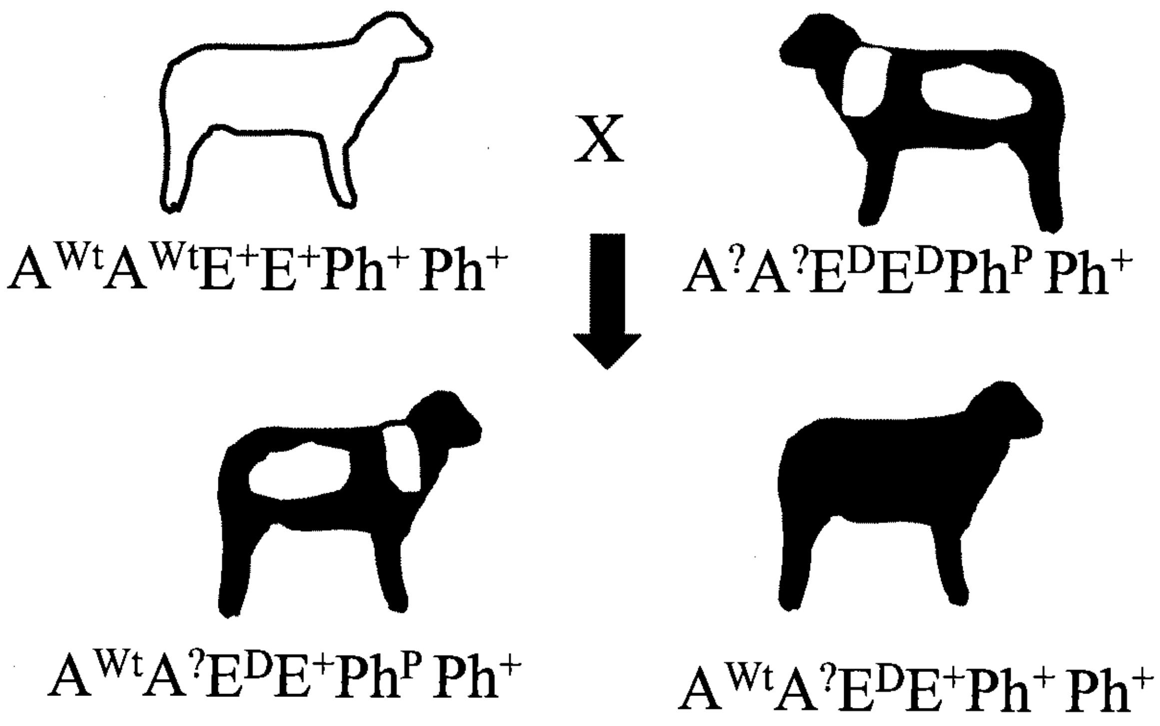

Fig. 3

Figure 3. When ewes of white wool breeds are mated to spotted Dorper rams ($Ph^{P}Ph^{+}$) that are also homozygous for E^{D}, 50% of the resulting lambs are expected to be black and 50% are expected to be spotted.

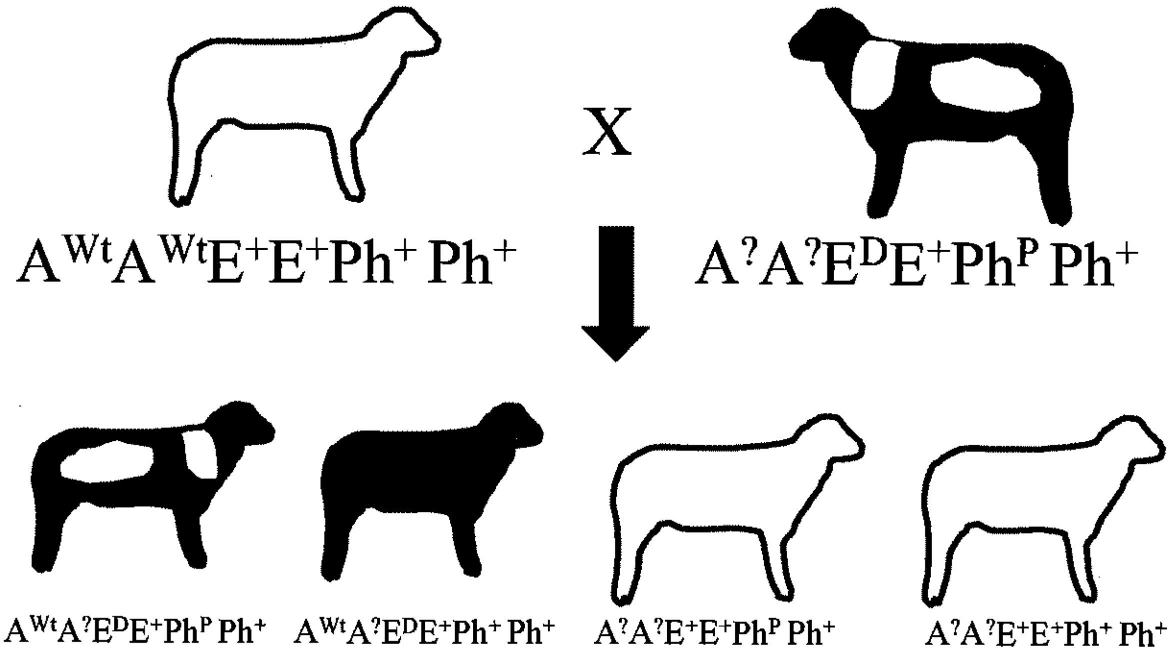

Fig. 4

Figure 4. When ewes of white wool breeds are mated to spotted Dorper rams that are heterozygous at both the *E* and *Ph* loci, the resulting lambs are expected to be 50% white, 25% black, and 25% spotted.

Research Note

Influence of Supplement Form on Ewe Performance and Reproduction

N. Taylor[*], P. G. Hatfield[*][1], B. F. Sowell[*], and G. S. Lewis[†]

Supplementing ewes grazing dormant rangeland pastures with protein is a common practice in the Northern Great Plains. Supplement form can impact individual animal intake and performance. Ducker et al. (1981) reported that 19 % of 2,931 grazing ewes failed to consume any supplements when offered supplement in block form. Taylor et al. (2000) reported that only 2 % of ewes given pellets were non-consumers, while 35 % of those offered blocks were non-consumers. Bowman and Sowell (1997) summarized a number of ewe studies and reported that the mean coefficient of variations in supplement intake by ewes that were hand-fed pelleted supplements were significantly less than those reported for block-fed ewes. However, few studies have examined how these two-supplement forms affect ewe performance when fed under commercial conditions. The objective of this study was to compare how supplement form (pellets or cooked molasses block) influenced ewe body weight, body condition, wool characteristics, and lambing percentage.

Range ewes (n = 698, 2 to 6 years of age) were used in a 30-day supplementation study during mid-gestation to evaluate the influence of type of supplement on ewe body weight, body condition, wool characteristics, and lambing percentage. In February, ewes were allocated randomly to supplement treatments. Supplement treatments were 1) ad libitum access to a 80 % CP cooked molasses block (n = 3 50) and 2) daily feeding of a 25 % CP urea/wheat mid pelleted supplement at the rate of 114 g•ewe-1•day-1 (n = 348; Table 1). Ewes were fed a basal diet of barley straw (0. 9, 76, and 54 % CP, NDF, and ADF, respectively).

Ewes were weighed and body condition scored at the beginning and end of the supplementation period. Ewes were penned overnight without feed or water before each weighing. Body condition was based on a scale of I to 5 with a score of I designating an emaciated ewe and 5 designating an obese ewe. After the study, ewes were combined into one group, supplemented with the pelleted supplement until April, when ewes grazed native range without supplemental feed. Ewes were shorn approximately 30 days after the end of the supplementation study. Fleece weights were recorded at shearing. In addition, wool yield and fiber diameter were determined.

Body weight, body condition, and wool characteristics were analyzed using the General Linear Model procedures of SAS (1993) with ewe as the experimental unit. The model included supplement treatment with ewe age and lambing date as covariables. Lambing percentage was analyzed using Chisquare (SAS, 1993).

Based on disappearance of the block supplement, average CP intake for block-supplemented ewes was approximately 28 g CP•ewe-1•day-1. This was similar to CP intake by pellet-supplemented ewes (i.e., 114 g pellet•ewe-1•day-1 x 25 % CP = 28.5 g CP•ewe-1 •day-1). lock supplemented ewes lost body weight while pellet supplemented ewes gained body weight (P = 0.001, Table 2). There was no effect (P = 0.28) of supplement form on body condition score (Table 2) or on grease fleece weight (P = 0.69), clean wool fiber percentage (P = .91), or fiber diameter (Table 3). Finally, there was no effect (P = 0.61) of supplement form on lambing percentage (Table 2).

Body weight loss by ewes in the block treatment could possibly be explained by variation in individual intake as noted by Taylor et al. (2000) in which 35 % of the block-supplemented ewes consumed little or no supplement. Inadequate protein in the diet can lead to reduced forage intake and consequently decreased performance. We speculate that ewes consuming the pelleted supplement gained weight than ewes consuming the block supplement due to a more consistent CP intake. Although blocks and other

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forms of urea based supplements that allow ad libitum access and consumption are perceived to enhance ruminal digestion of fiber via a more constant infusion of urea than limit fed urea based pelleted supplements, Ribhani et al. (1993) concluded that digestion and microbial net synthesis by sheep is not enhanced by continuous N release in the rumen. Although block supplemented ewe had ad libitum access to supplement, pellet supplemented ewes, although limit fed, may have had better fiber digestion because of more uniform intake.

The lack of supplement form effect on body condition score, wool characteristics, or lambing percentage is consistent with results reported by Soder et al. (1995). Thomas and Kott (1995) demonstrated that forage conditions are usually the major factors that influence ewe response to winter supplementation programs.

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Table 1. Block and pellet percent composition (DM basis)[a]

	Block	Pellets
Crude protein	80.0	25.0
Crude fat	1.0	3.5
Crude fiber	5.0	7.8
Calcium	5.0	0.2
Phosphorus	4.0	0.8
Salt	4.4	0.1

[a] Provided by manufacturer.

Table 2. Body weight, body condition score, and lambing percentage of ewes fed 28 g of CP daily for 30 days either by ad libitum access to an 80% CP cooked molasses blocks or 114 g •ewe^{-1}•day^{-1} of a 25% protein pellet

	Block[a]	Pellet[b]	SE	P value
Body weight, kg				
Beginning	66.0	66.7	.48	.34
End	65.0	67.5	.53	.001
Change	-1.0	1.2	.25	.001
Body condition score				
Beginning	2.9	3.0	.04	.60
End	2.1	2.1	.03	.50
Change	-.80	-.85	.03	.28
Lambing %	131	136		.61

[a] Ewes supplemented with the 80% CP block (n = 350).

[b] Ewes supplemented with the 25% CP pellet (n = 348).

Table 3. Wool characteristics of ewes fed 28 g of CP daily for 30 days either by ad libitum access to an 80% CP cooked molasses blocks or 114 g •ewe•$^{-1}$day^{-1} of a 25% protein pellet

	Block[a]	Pellet[b]	SE	P value
Grease fleece wt, lbs	4.1	4.1	.04	.69
Clean wool fiber %	54.1	54.2	.91	.91
Base, µm	24.2	23.6	.31	.16
Mid, µm	23.9	23.8	.35	.87
Tip, µm	23.5	23.6	.34	.76

[a] Ewes supplemented with the 80% CP block (n = 59).

[b] Ewes supplemented with the 25% CP pellet (n = 60).

News Briefs

In Memory of Dr. Clair Terrill

Dr. Clair Terrill, a longtime U. S. sheep industry researcher, died November 12, 2001 in Maryland.

Terrill had been prominent in sheep research programs since 1936, when he first joined the U.S. Department of Agriculture's Sheep Experiment Station in Dubois, Idaho.

From 1955 to 1972 , Terrill directed all federal research involving sheep and fur animals. Work under his direction resulted in increased efficiency of meat, wool, and fur production from sheep and other animals. He helped introduce such technology as artificial rearing of lambs, pregnancy diagnostics, high fertility, selection for year-round lambing and crossbreeding to increase reproductive rates.

Long awaited plan announced by USDA

Scrapie eradication will require dedication of producers, industry

A plan to eradicate the fatal disease scrapie from the nation's sheep flocks and goat herds, announced by the US Department of Agriculture, will require dedication and commitment of producers and other stakeholders, say industry leaders.

"To be successful, the scrapie eradication program will require the cooperation of every segment of the industry, from producer to meat packer, including local veterinarians, and state animal health officials," says Glenn Slack, President and Chief Executive Officer of the National Institute for Animal Agriculture (NIAA).

"We are tackling scrapie because it has the potential to jeopardize the future of sheep and goat production in the United States."

The USDA-announced plan to eliminate scrapie from the U.S. will be administered by the Agriculture Department's Animal and Plant Health Inspection Service (APHIS).

Key elements include:

- Interstate movement restrictions on animals from infected and source flocks and high risk and exposed animals from other flocks;
- An indemnification program for owners of high risk, test positive, and suspect animals;
- A nationwide individual identification program for breeding sheep and goats and sheep over 18 months of age;
- Surveillance and testing of sheep at slaughter; and
- Uniform minimum standards for state scrapie programs.

Especially important is that each flock identified as scrapie-infected will be required to prepare a plan to eradicate the disease and to monitor for recurrence of the disease in that flock or herd. To that end, producers will be provided with professional expertise, testing, and indemnity for animals required to be removed. The federal government earmarked $10 million for the program in the 2001 budget.

"As with the other eradication programs, this will take a long term commitment from everyone involved," states Dr. Cindy Wolf, a small ruminant specialist at the University of Minnesota and a flock owner. "While this may be a tough time for producers because of low prices, drought and a number of other problems, it is important that we get on with the eradication program because of the length of time it will take," she says.

"The disease takes two to five years to show clinical signs, therefore we expect that it will take a minimum of a decade to eradicate scrapie. In addition, it will take another seven years without a scrapie outbreak for the US to be recognized internationally as 'scrapie free.' So this is at least a 17 year project," she concludes.

"Further, increased concern and attention is being paid to all transmissible spongiform encephalopathy (TSE) diseases, including scrapie, as a result of the discovery of TSEs in cattle, cats and people in Europe," concludes Dr. Wolf.

According to the American Sheep Industry Association (ASI), scrapie costs American sheep and goat producers an estimated $20 to $25 million annually.

Frank Moore, president of ASI and a Wyoming sheep producer, said "ASI has requested since 1996 that USDA take assertive action on a national scrapie eradication program."

"We will work closely with APHIS and the states to successfully implement this eradication program and to help assure that it has the least negative impact possible," said Moore.

Information about the eradication program and the National Scrapie Eradication Initiative is available on the Internet at www.animalagriculture.org/scrapie.

Veneman: 'Extraordinary Focus' on Protecting Food Supply

USDA Secretary Addresses Animal Agriculture Protection at NIAA Annual Meeting

Education, information sharing and finding solutions are more important than ever in protecting the U.S. animal agriculture industry against agroterrorism. The National Institute for Animal Agriculture (NIAA) offered that very opportunity when it brought industry representatives together at its Annual Meeting, March 25-28 in Chicago.

With the theme of, "Animal Agriculture – Dealing with New Realities," NIAA's gathering drew approximately 200 participants, including livestock producers, veterinarians, business executives, scientists, academicians, state and federal animal health officials and other stakeholders in the animal food and fiber industry.

Keynote speaker Secretary of Agriculture Ann Veneman and other NIAA presentations and discussion focused on food and agricultural secutity, bioterrorism, animal health safeguarding and emerging diseases.

"We are engaged in looking at the entire food supply with the idea of protecting it – not just against unintentional threats, but also against intentional threats," said Veneman. "Many of the issues we dealt with all last year, particularly foot-and-mouth disease (in the United Kingdom), are the very issues we worry about when we worry about intentional threats." So the mission at the U.S. Department of Agriculture has been one of "extraordinary focus on these issues."

Veneman explained USDA's stepped-up prevention programs March 26 at the NIAA recognition banquet. She emphasized how Sept. 11 has strengthened the working partnerships among state and federal government, universities and industry. This type of cooperative model was used at the California Department of Food & Agriculture, where she worked as Secretary of Agriculture prior to taking the national office. She credited Dr. Richard Breitmeyer, California state veterinarian and NIAA board member, for teaching her the value of cooperation.

"USDA is now working closely with Gov. Tom Ridge and the Office of Homeland Security staff in understanding the whole issue of protecting our food supply," said Veneman. She is especially pleased with the commitment USDA has seen from the Bush Administration. The Defense Appropriations Act, signed in January, provided an additional $328 million in USDA funding for homeland security.

Extra security for our nation's food supply could soon be boosted more. USDA's proposed budget for fiscal year 2003, released in February, includes $2.367 billion to fight sabotage and protect the nations food supply from plant and animal disease. That amount is up $146 million from the current USDA budget. A $48 million increase has been targeted for animal health monitoring by the Animal and Plant Health Inspection Service (APHIS), said Veneman. An extra $19 million will go to support agricultural quarantine inspection programs, which will provide additional inspectors, canine teams and high definition x-ray machines at high-risk port of entry.

USDA will continue to look for ways to strengthen its partnerships and efficiently use resources, said Veneman. She commended the NIAA organization for bringing different parties to the table to talk about how to improve our food and agricultural systems. "That's the type of cooperation we need throughout all of our programs," said Veneman. "It's important to address agroterrorism and other industry issues and look to the future of animal agriculture."

The National Institute for Animal Agriculture, Bowling Green, Ky., is a membership-based organization, which began operations in 2000. It is a successor to the Livestock Conservation Institute. NIAA's mission is to be the forum for building consensus and advancing solutions for animal agriculture and to provide continuing education and communication linkages to animal agriculture professionals.

Minnesota small ruminant specialist receives NIAA President's Award

The National Institute of Animal Agriculture has awarded Dr. Cindy Wolf its 2002 President's Award. The honor is presented to the organization's Outstanding Committee Chairperson of the Year.

NIAA President and Chief Executive Officer Glenn Slack presented the award to Dr. Wolf, citing "exemplary leadership and dedication" to NIAA and the NIAA Sheep Health Committee.

Dr. Wolf is a small-ruminant specialist with the University of Minnesota College of Veterinary Medicine. During the past two years, Dr. Wolf has led NIAA's efforts in carrying out the National Scrapie Eradication Initiative, an informational campaign charged with educating producers, veterinarians and other sheep industry stakeholders about new interstate movement and identification requirements designed to eliminate scrapie from sheep and goats across the U.S.

Testing to continue on imported sheep confiscated last year

The U.S. Department of Agriculture has announced that tests conducted on a flock of sheep confiscated last year from a farm in Vermont confirm that two of the 125 sheep tested positive for an atypical undifferentiated transmissible spongiform encephalopathy (TSE) of foreign origin.

The flock of 125 sheep was confiscated in March 2001 after four animals from an associated flock tested positive for TSE in July 2000. USDA will continue to conduct additional tests to determine the type of TSE in these sheep.

Final rule issues on establishment of lamb, promotion and research and information order

The final rule establishing a national, industry-funded lamb promotion, research and information program has been issued by the U.S. Department of Agriculture's (USDA) Agricultural Marketing Service.

The American lamb checkoff order was published in the April 11th 2002 Federal Register, which follows the public comment period conducted last fall.

Under the program, U.S. lamb producers, feeders and lamb packers will all pay an assessment. Individual U.S. lamb producers and feeders will pay a one-half ($.005) cent per pound assessment based on live weight, and the first handler, primarily lamb packers, will pay an additional 30 cents per carcass. The proposed order calls for a deduction at sale, however, remittance will occur at the slaughter level for most transactions.

"Publishing this order lays out the logistics of how the program will work, who will be assessed and other details," American Sheep Industry Association President Frank Moore said. "The next step is to issue rules, which will set a date at which collections will begin, followed by the procedures to nominate board members."

Moore added, "It is an exciting step for the American lamb industry to move forward with an industry-wide board to work on our lamb market. The program is the first national livestock assessment to include slaughter companies."

The order calls for a delayed referendum to be conducted no later than three years after assessments begin. During this time period, refunds may be requested.

Lamb imports will not be assessed under the order.

A lamb checkoff program has been in development since May 1999, when USDA brought together a task force of all segments of the industry to investigate lamb checkoff possibilities. The program is expected to raise $3 million plus each year and will fund promotion, research and information programs.

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Sheep and Goat Research Journal
Guidelines for Authors

Objective

The aim of the *Sheep & Goat Research Journal* is to publish timely sheep and goat research findings that can be used by scientists, educators, extension agents, and producers alike. Specifically, the *Journal* aims to encourage producer use of research that has practical application.

Editorial Policy

The *Sheep & Goat Research Journal* publishes articles of research relating to all aspects of sheep and goat production including marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and / or their products. All research articles must represent unpublished original research and conclusions reached must be supported by research results. Articles that promote commercial products or services will not be approved for publication. Articles that promote practical applied research are encouraged. The submission of review articles is accepted but will require the same review process as other submitted articles. At least one author of each submitted article must subscribe to the Journal. All manuscripts and correspondence should be addressed to Sheep & Goat Research Journal, c/o National Institute for Animal Agriculture, 1910 Lyda Avenue, Bowling Green, KY 42104-5809. Inquiries may also be sent via electronic mail to **sgrj@animalagriculture.org**.

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Manuscripts should be mailed to the Sheep & Goat Research Journal, c/o National Institute for Animal Agriculture, 1910 Lyda Avenue, Bowling Green, KY 42104-5809. Five copies of each manuscript must be submitted. Each manuscript must be accompanied by a cover letter from the main corresponding author. The cover letter must include the mailing address, telephone and fax numbers, and e-mail address of the corresponding author. As a style reference, authors may refer to the *Publication Manual of the American Physiological Association*. Every effort is made to publish papers promptly. Normally, a paper is published approximately six months after it is received from the authors.

Format

Manuscripts must be typed and double-spaced. The lines on all pages, including those pages for Literature Cited and Figure Legends, must be numbered in the left margin beginning with the numeral one (1) at the top of the page. Submission of excessive tabular data is discouraged; tables should be limited to that data that is considered essential to the research findings. Tables must be typed, double-spaced, and placed on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

The following format should be used when submitting research manuscripts:

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7th	**Literature Cited**

When citing literature in the text, use both authors if there are only two. If there are more than two, use the first author and "et al." Please provide "interpretive summaries" for use by the sheep and goat industries in other media.

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SPECIAL ISSUE: Breeding for Improvement of Meat Production in Sheep

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Contents:

Preface and Overview

Maurice Shelton
Texas Agricultural Experiment Station (Retired)

Introduction

On a world basis, sheep are kept for a variety of reasons, but in this country the primary uses have been meat and fiber production. At present there is also a limited and growing interest in milk production from sheep. One of the more recent and growing roles for sheep is that of vegetation management, including optimum grazing and range management practices (Havstad, 1994), control or assisting in the control of noxious vegetation (Olson and Lacey, 1994), reduction of fuel loads for fire control or retardation (Taylor, 1994), and reducing vegetative competition in reforestation efforts (Sharrow, 1994). Even flocks used for vegetative management must produce a marketable commodity to justify their costs or to provide an outlet for surplus animals. Because a majority of the world's sheep are wool producers (at some level) it seems likely that in earlier periods fiber production was viewed as their more important contribution. Historically wool was an important item in world trade, but this special place is declining.

In Texas, cash receipts from wool exceeded those from meat (lamb and mutton) until approximately 1954 (Shelton and Kensing 1980). With incentive payments included, the income from wool exceeded that from meat until apptoximately 1964. Since 1964 the relative value of these prodncts has shifted markedly in favor of lamb production, with some years in which wool represented 10% or less of the gross income. This situation has no doubt existed for a much longer period of time in farm states, in which medium wool sheep represented a larger percent of the total. Except for a brief period in the late 1980's, the contribution of wool to flock income has trended downward for half of a century. At the time of this writing (fall - 2001) the cost of production, harvesting and marketing wool exceeds the income obtained from it. What the future holds for the demand for wool is not known, but a reversal of this trend is not apparent at present. This is unfortunate, and the loss of wool income has no doubt contributed in a substantial degree to the decline in sheep numbers in the U.S. The genetic and nutritional resources and management practices required to produce a good clip of wool are simpler than those required to produce a good lamb crop. The situation is made more difficult by the fact that there is, to some degree, a negative relationship between meat and fiber production (Shelton, 1994; Cronje and Smuts, 1994), especially under conditions where nutrition is a limiting factor. Unless there is a significant and early reversal in the prices received for wool, the U.S. sheep industry can survive and reverse the decline in numbers only by doing a better job of lamb production.

In the past when prodncers have exercised selection for meat production they have primarily emphasized size (or growth rate) and conformation. Selection for size has been highly successful (Parker and Pope, 1983). As shown in Figure 1, the weights of most breeds of sheep have consistently increased over at least the last 40 years. However, size is only one component of meat production, and a continued increase in size is nnlikely to be desirable in all production situations and market outlets. Conformation is a much more nebulous term, and it is not clear that selection for conformation has had a positive influence on the industry. Selection goals in respect to conformation have ranged over time from small, compact, blocky animals with a large amount of subcutaneous fat to tall, upstanding, leggy animals that lacked fitness or adaptation to grazing environments. The only legitimate goals for conformation are that slaughter animals possess the optimum amount of subcutaneous fat (to meet market demands or grading standards) or that the animals produce a carcass with a higher percent of the weight in the more valuable cuts. It cannot be shown that this latter goal has been accomplished. It is theoretically possible to change body proportions (Waldron - this issue), but this will be difficult and require more resources than have been or are likely to be devoted to this cause.

The Components of Meat Production

The most important factor contributing to meat production from sheep is numbers. The situation pertaining to stock sheep numbers in this country is all too obvious with the downward trend starting around 1940 (Figure 1). The goal of all concerned with the industry must be to reverse this trend. The purpose of this special issue of the journal is to summarize information which could be used to improve efficiency of producing and marketing quality products and thus contribute to a revival of the industry. Genetics (breeding) is one of the approaches to accomplishing this goal, but it requires that one take a long-term view.

With a constant or stable number of sheep, the most important factor contributing to meat (lamb) production is net reproductive rate (percent lamb crop raised and marketed). The only lambs available for slaughter are male or wether lambs plus any ewe lambs that are surplus to replacement needs. If flock numbers are to be increased, relatively few ewe lambs would be available for slaughter. Mutton (meat from older animals) production is largely limited to cull or older ewes. Assuming a stable population, the numbers of ewes available for slaughter represent the replacements (ewe lambs added to the flock) less the death losses over the productive life of the ewes. Typical annual replacement rates are on the order of 25%. Contributing factors to the lamb crop raised are age at sexual maturity, frequency of lambing, the percent of ewes bred and lambing, ovulation and/or lambing rate, lamb survival and the length of productive life of the ewes. Many of these factors are discussed by authors contributing to this special issue. All of these factors have genetic, environmental and management components and thus are subject to some degree of control by producers.

The third factor contributing to meat production is slaughter weight, and yield (dressing percent) and percent of the carcass in retail or consumer cuts. The average slaughter weight for sheep in this country has continuously increased from 1960 through 1990 (Williams and Davis, 1998). This has resulted from larger breeding stock (Parker and Pope, 1983), from an increase in the proportion of the lamb crop that spends some time in feedlots (Field and Whipple, 1998) and from a tendency to hold these in the feedlots to heavier weights. The merchandising of heavier lambs may be viewed as positive to some segments of the industry, as there will be some improvement in efficiency to the feedlot operator, as well as the packer and in the merchandising process. However, there are almost certainly problems associated with an ever-increasing slaughter weight. It should be remembered that it is not the feedlot operator, packer or the end processor that determine sheep numbers in this country, but it is the producers who maintain the ewe flocks and produce the lambs. If it is assumed that the average weight of the breeding stock is held constant, any increase in slaughter weight will result in an almost linear increase in the amount of fat in the carcass (Bradford - this issue). This has been documented in many studies as having happened in the U.S. and to have contributed to the perception that lamb meat is high in fat content (Berg, et al., 1998). This is thought to have contributed to the decline in lamb meat consumption.

If size of the breeding ewe is increased (or is allowed to increase) as has happened with most breeds, any improvement in efficiency at the producer level will be minor, and may be negative if the increase in size results in a reduction in adaptation to the production environment or has an adverse effect on other traits such as reproductive rate. Barlow (1984) stated that "there is little justification for selecting for growth rate (e.g. size) to improve efficiency of meat production of cattle or sheep thar function largely as maternal breeds." Scholtz and Roux (1984) state that "there are indications from the literature that selection for increased body mass or growth rate may have adverse effects on fertility." The contrast in trend lines between the numbers of stock sheep in this country and the average slaughter weight is very evident (Figure1). This does not prove a cause and effect relationship, but it is obvious that an increase in slaughter weight has not resolved the problems of this industry. Across species and across breeds within species (especially sheep) there tends to be a negative relationship between size and realized reproductive rate. Even within species and breeds it has been shown that extremes in weight suffer some loss in reproductive rate and longevity (Shelton, 1959).

In respect to slaughter weight, it is not clear that consumers have a strong preference for cuts from any specific size of carcass, although there must be a preference for larger loin chops that would derive from larger carcasses. In present market channels heavier carcasses are priced lower, but this in part represents discrimination against their actual or perceived higher fat content. This discrimination might be reduced or eliminated if carcasses could be marketed based on their yield of fat-standardized consumer cuts (Waldron - this issue).

It should be noted that the two growth market outlets for lamb (exports to Mexico and the ethnic markets in this country) express a strong preference and pay a premium for smaller animals. Exploiting these markets equates well with the development and use of more prolific types of sheep. On a world basis and in areas where the sheep industry has persisted and thrived, the industry is based on a type or breed of sheep which is well adapted to the environment and production conditions and which produced a product or products that are in demand. There are many examples that fit this description. One example of this is the Merino, or breeds such as the Rambouillet and Targhee derived from the Merino. The Merino sheep thrived at many places in the world when wool prices were reasonably favorable. However, it can be shown that it is possible to put "too much" wool on these animals, resulting in some reduction in their ability to thrive under adverse conditions and produce a good lamb crop (Willingham et al., 1994). Many strains of Merino must be crossed to other breeds to produce an acceptable market lamb. This cross may be a terminal sire breed to produce market lambs or to a breed specifically chosen to produce a desired type of F1 ewe for market lamb production, e.g. the Border Leicester breed, which has been extensively used for this purpose in Britain, Australia, and New Zealand. The use of such specialized "ewe sire" breeds has not been a common practice in the U.S. (especially in the Southwest), but it is a practice that should be reconsidered in light of current wool prices. One of the problems may be the lack of a suitable breed that is adapted to this region. This should perhaps be addressed in future research or development projects.

Efficiency of Production

Efficiency of production may be expressed as a function of any of the resources or inputs required. Producers will usually be concerned about the most limiting or most expensive inputs. For ruminant species this most likely would be feed or nutrients. Some producers who choose to increase reproductive rate through intensive management, especially at lambing, may view labor or facilities as limiting resources. For many, efficiency is defined as gain per unit of feed consumed by an individual animal and most will be aware that this efficiency decreases with age of the animal. This is due primarily to two factors: feed intake relative to body weight is higher in younger animals, resulting in a lower proportion used for maintenance, and gains made by the young animal consist mostly of lean growth as opposed to fat. However, on a flock or industry basis, the cost of gains for an individual market animal represents only a small part of the total feed cost. It is generally assumed that as much as 70% of the feed required to produce a pound of lamb meat is that consumed by the breeding flock (mostly the ewe). If ewe replacement costs are included, this would be even greater. This is a major reason why meat production from ruminant animals cannot compete (on the basis of efficiency) with that of swine or poultry where the breeding animal cost per market animal is much lower.

Thus any factor which tends to reduce the ewe or flock maintenance cost per market animal has a major impact on efficiency of production from sheep. Traditionally wool income has been viewed as a means to recover or reduce flock maintenance cost. Numerous studies have shown that the ewe component in production costs (more appropriately nutrients required) can be reduced through spreading this cost over a higher level of productivity by marketing more or heavier lambs or both (Hogue,1968; Large, 1970). Of the two, the simpler or most easily accomplished is to market larger lambs, and as shown in figure 1, the industry has moved markedly in this direction. However, in a purebreeding system, producing larger lambs through maintaining larger ewes represents little or no gain in efficiency at the producer level, whereas producing larger lambs from the same sized parent results in overfat lambs. This has been documented in many studies (Tatum et al., 1988) and resulted in an image of lamb meat as being overly fat.

A series of modeling studies (Wang and Dickerson, 1991) were carried out based on data from the U.S. Meat Animal Research Center. These authors report the following traits in order of their contribution to efficient meat production from sheep (TDN per lb. of lean meat): lamb survival, lambing rate, and conception rate (fertility). Other traits, including size of ewe and milking ability, were of much less importance with near zero contribution. It is important to remember that these calculations are based on inputs from the research flock involved and that this flock included animals from some of the more prolific types of sheep.

Although the case for improving the net reproductive rate and the potential (with sheep) for doing so is quite great, the industry has not readily endorsed recommendations for improvement in reproductive efficiency throngh genetic means (see Hamilton and Hamilton - this issue - for an exception). No doubt lamb mortality, which certainly increases with higher prolificacy, and the time and effort required to change these factors through selection provides a partial explanation. However, the very survival of the industry may require more effective application of this approach.

Improvement in reproductive efficiency through genetic means may be approached through selection within breeds or lines, crossbreeding to realize the gains offered through heterosis or breed complementarity, or by introduction of inheritance from more prolific breeds (Leymaster - this issue). The latter two, especially the use of more prolific genotypes, offers the potential for immediate gains, but long term selection within breeds for fitness and reproductive rate (overall productivity) should be strongly considered as well.

Some Conclusions and Recommendations

1. Producers should exercise caution in selecting for increased size in dam breeds or general purpose breeds where fitness and reproductive rate make the greatest contribution to production efficiency.
2. Selection for size and/or growth rate and carcass merit may be largely restricted to sire breeds. Limitations on size might be considered in the case of poor breeding efficiency of rams or where dystocia becomes a problem in ewes to which they are bred. Efforts to improve carcass merit, aside from the amount of fat, will likely require a group effort such as group breeding schemes or multiflock efforts.
3. Major emphasis in dam lines or breeds and general purpose breeds should be in selecting for ewe fitness and productivity. These may be accomplished through three different approaches:

(a) Selecting within breeds or flocks (Bradford - this issue). The heritability of the different components of reproductive efficiency is low and thus progress in selecting for these individually will be slow. Thus it may be preferable that selection be exercised for a composite trait such as total lambs weaned. The heritability of this trait is improved if the records are compiled over a period of years (Shelton and Menzies, 1968). Another alternative is to select for total lamb weight weaned (Snowder - this issue). This is a composite trait that not only includes reproductive efficiency, but weight of the lambs weaned as well. In the study on which the above report was based, selection for total weight weaned resulted in some increase in the size of the ewe as well as level of milk production. These latter measures require more feed intake and may not result in the same relative gain in efficiency as selecting for reproductive efficiency alone. Also this paper reports greater gains from selection than most other studies of this nature. This may reflect in part the fact that a larger population of animals was involved than is the case with many research projects, and thus highlight the fact that larger numbers are needed to bring about genetic progress in difficult traits such as reproductive efficiency, carcass composition or meat quality. This suggests the need for some type of group effort such as the NSIP.

(b) Crossbreeding to obtain the advantages of heterosis and breed complementarity. The advantages of crossbreeding are well documented in the literature (Leymaster - this issue). However, there may be problems or questions as to choice of breeds. Although there are nearly 50 breeds of sheep in the U.S., many of these may not be adapted to the production conditions involved or may not possess the traits desired in crossbreeding programs. The choice of sire breeds usually represents less of a problem than the choice of the most desirable breeds to produce Fl ewes unless one chooses to use one of the more prolific types. Space does not permit the discussion of the individual breeds at this point, but the breeds are discussed in detail in the Sheep Producers Handbook (1997).

(c) Crossing with one of the more prolific breeds or genetic types (Hamilton and Hamilton - this issue). Clearly the best opportunity to increase reproductive rate in the near term is to introduce prolific breed inheritance into existing flocks. The two best known prolific breeds are the Finnish Landrace and Romanov, both examples of the North European Short Tailed group. These breeds have the advantage that they transmit their high prolificacy additively, thus permitting adjustment of flock mean prolificacy to the desired level by varying the proportion (e.g. 0.25, 0.38, or 0.50) of prolific breed inheritance introduced. In addition to the above breeds, the Booroola gene (FecB) should be considered. This can produce an immediate large increase in number of lambs born, but has the limitation that the increase achieved may be more than desired. The use of the homozygous individual (two copies of this gene) should be ruled out in commercial programs, and even the heterozygous individual often gives more lambs than desired. The (Booroola) package in which this gene was introduced was found to be somewhat unsatisfactory for lamb production in this country, but the potential exists and has been accomplished to transfer this gene to other breeds or types in which it may be more useful, especially in smaller and more intensively managed flocks.

4. Producers should be open to the potential offered by accelerated lambing programs. One of the advantages of sheep, at least as compared to cattle, is their ability to reproduce at less than 12 month intervals. This potential advantage has not been pursued by the industry to the extent that it might be. Complications in the management of accelerated lambing programs are obvious. Also there is a need to identify or create populations of animals without serious seasonal restrictions to mating (Notter - this issue). This trait has been shown to be both repeatable and heritable. One management system (the Star System) is outlined in the above-mentioned paper. It is likely that the most desirable accelerated lambing system is unique to the resources available to each producer.
5. In view of the present low prices for wool and the difficulties of getting sheep sheared, there is no doubt a need for development work with non-wooled sheep as an option. This need is almost certainly greater at the more southern locations, but there is interest in this type of sheep throughout the country. At present, the available genetic resources are short in both quality and quantity. The hair sheep option may be of greater interest for the potential they offer in accelerated lambing programs.

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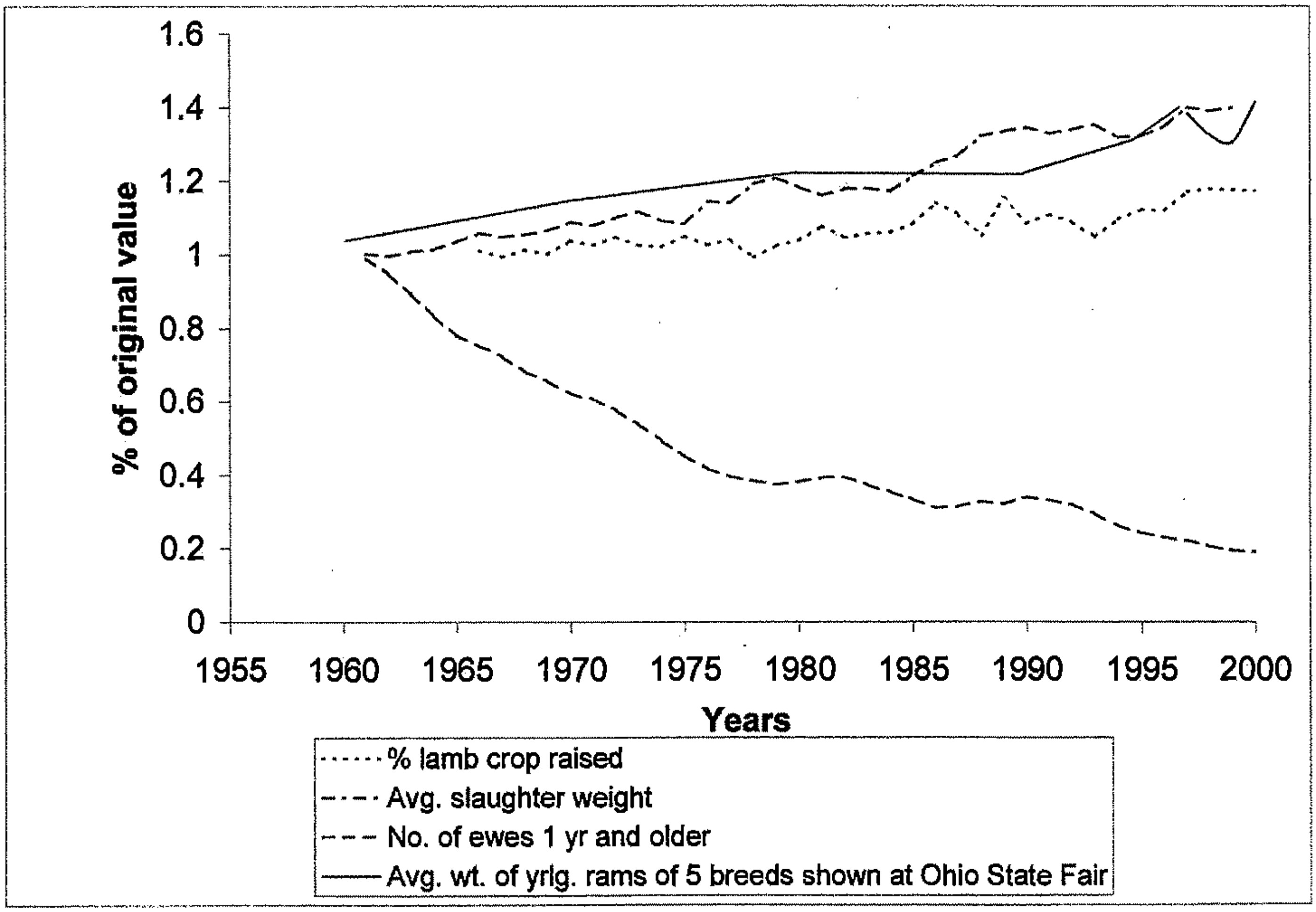

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Years
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Avg. slaughter weight
No. of ewes 1 yr and older
Avg. wt. of yrlg. rams of 5 breeds shown at Ohio State Fair

Selection for Reproductive Efficiency

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Number of lambs weaned per breeding ewe has a greater influence on productivity of the sheep enterprise than any other trait. Net reproductive rate is determined by several components, with fertility, prolificacy (litter size) and lamb livability having the greatest influence (Wang and Dickerson, 1991). Age at puberty, prenatal viability and, in some enterprises, out-of-season fertility, can also contribute.

Fertility and lamb viability.
Fertility does not usually receive direct emphasis in selection programs, since it is obviously subject to continuous natural selection, and reported heritability estimates average less than 0.10 (Fogarty, 1995). However, heritability estimates are on average positive, and the importance of the trait indicates it merits attention, at least in flocks/environments where mean performance is low (less than 90%). Ewes dry in any year can be culled, or, if the cost of replacements and history of subsequent performance of such ewes in the flock indicates they should be kept for economic reasons, it is recommended they not be included in the group producing replacements in future years. Since most genetic change in sheep flocks results from sire selection, rams should be consistently selected from dams that have lambed every year. The National Sheep Improvement Program (NSIP) can provide genetic evaluations for fertility if producers do a good job of recording all breeding opportunities, deaths, disposals, etc. on the NSIP data input sheets. However, at present not all producers do so.

Lamb survival is also a trait for which heritability estimates average less than 0.10 (Fogarty, 1995; Matos et al. 2000; Morris et al. 2000). Also, as for fertility, survival data are often not well recorded; lambs that do not survive as well as ewes that do not lamb may not be included. However, as emphasized by Shelton and Willingham (this issue), reducing lamb mortality offers one of the best opportunities to increase flock productivity. Selection for improved lamb survival may be a means of contributing to that goal. The reports by Matos et al. (2000) and Morris et al. (2000) indicate that maternal genetic effects may be as large as or larger than direct genetic effects on this trait, and that additive direct and additive maternal effects are positively correlated. Thus selection programs that utilize both direct and maternal variance may lead to significantly more response than indicated by direct heritability only, reinforcing the value of complete recording and genetic analyses.

The existence of useful genetic variation in fertility and lamb livability is also indicated by differences among breeds (Cundiff et al., 1982; Fogarty et al., 1984b) and among selected lines (Bradford et al., 1999) in these traits. Where use of different breeds or lines is feasible, such information may be used to improve genetic potential.

Litter Size.
Of the three most important components of reproduction, the one with the greatest potential for change by selection is litter size, i. e. number of lambs born per ewe lambing. There is also much variation between breeds; breeds are available with mean litter size ranging from slightly above 1.0 to above 3.0 (Leymaster, this issue). There are many reports, for example by Dickerson (1977), Hulet, (1984), Snowder (2001) documenting the use of breed variation in the development of composite populations with higher mean litter size than traditional US breeds. A case history documenting use of such variation to increase productivity of a commercial flock is reported elsewhere in this issue (Hamilton and Hamilton). Where market demand and environmental conditions permit use of some prolific breed inheritance, litter size can be increased substantially in one generation, i. e. much more rapidly than by selection. However, there are situations where selection within a breed will be the approach of choice.

Within breeds, typical heritability estimates for this trait are quite low, of the order of 10% or less (Fogarty, 1995; Notter, 1998; Bromley et al., 2000; Lee et al., 2000). However, the coefficient of variation is high, about 35% (Sakul et al., 1999; Rao and Notter, 2000), compared to 13-15% for adjusted weaning weight (Sakul et al., 1999). This permits quite large selection differentials for litter size, and there are several reports of substantial change effected by within flock selection. The earliest well-documented reports were those by Turner et al. (1962), and Wallace (1964). Bradford (1985) reviewed the results of those and several other selection trials, and concluded that an annual increase of 1-2% in average litter size could be achieved by selection. Responses to selection for litter size or twinning rate reported by Burfening et al. (1993) and Saboulard et al. (1995) in western US range sheep were also within this range.

The conclusion of 1-2% per year was based on experiments carried out before the availability of the animal model for genetic evaluations. This statistical method permits systematic use of information on all recorded relatives, which can significantly increase rate of response to selection. While no actual selection experiments to measure the amount of increase in rate of response for litter size have been reported to date, it seems probable that a rate of 2%/yr, the high end of the range listed, and possibly more, could be achieved. Utilization of this potential will depend on parentage identification of all animals, recording of numbers of lambs born in all lambings, genetic evaluations from the resulting data, and use of the results in selection decisions, particularly in sire selection.

The annual gains listed may seem small, but an increase of 20%, suggested as possible over a 10-year period, may represent as much increase as desired. There is also the possibility of "jump starting" the process by an initial screening of exceptionally prolific ewes from a larger population to establish the foundation flock. Several of the experiments evaluating the effects of selection for litter size have involved selection of the most prolific ewes from a larger population to initiate the improvement program. The initial screening generally produced a substantial difference, as much as 10% of the base flock mean, in the first generation progeny (Wallace, 1964; Turner, 1978; Hanrahan, 1982; Sakul et al., 1999). Subsequent response varied, from slow response for more than 10 generations (Sakul et al., 1999), to little response for some time and then a rapid response (Clarke, 1972), to continuous good response (Hanrahan, 1982). Although there have not been enough experiments for firm generalizations, it appears that initial screening, where feasible, is an effective means of producing an immediate increase in genetic potential for litter size, and that this does not preclude subsequent response to selection within the screened group.

The heritability of 0.10 for litter size mentioned above relates to individual records, i.e. to the response expected form selection based on one record per ewe. The heritability of the average of two or more records will be higher. If single record heritability is 0.10, that for the mean of 2, 3, 4 and 5 records is expected to be approximately 0.18, 0.24, 0.29 and 0.33, respectively, suggesting use of lifetime prolificacy as a means of increasing selection response. Supporting this conclusion, Shelton and Menzies (1968) reported heritability estimates above 0.20 for mean numbers of lambs born and weaned, based on records from all years the ewes were in the flock. Generation interval may be longer if selection decisions are deferred until additional records are available. However, ewes normally stay in the flock for several years in any case, and all available records should be used. The problem of longer generation interval can be minimized by selecting rams from dams with several records but turning ram generations rapidly, for example by using ram lambs where that is feasible, and using rams in seedstock flocks only one year.

Okut et al. (1999) present evidence that heritability of litter size differs with ewe age, and that genetic correlations vary between records at different ages. They suggest that accuracy of selection could be increased by considering age of ewe as part of the trait, rather than simply adjusting for ewe age.

Ovulation rate is the most important factor affecting litter size, and it has been suggested that selection on ovulation rate would be an effective means of increasing the rate of genetic change in litter size (Hanrahan, 1974, 1982; Hanrahan and Quirke, 1985). Waldron and Thomas (1992) estimated that adding information on ovulation rate would increase rate of genetic change in litter size by 23% compared to use of litter size data only. An experienced operator can measure ovulation rate rapidly and accurately by means of laparoscopy, and this trait has the advantage of permitting repeated measurements within a season. It is a potentially useful aid to selection, but the extra cost of obtaining the information may be justified only in breeding flocks with an effective marketing program for improved breeding stock.

Scrotal circumference has also been suggested as an aid to selection for litter size (Waldron and Thomas, 1992; Burfening and Davis, 1998). However, as these reports indicate, the genetic relationship with litter size is quite low, and an apparent negative genetic association between testis size and body weight (Land, 1982; Burfening and Davis, 1998) raise doubts about the value of including information on this trait in a selection program to improve litter size.

It is often assumed that the ewe determines the number of lambs born, and that the ram (once the eggs are fertilized), and the genotype of the embryo, have little or no influence. A number of reports support that conclusion (Bradford, 1972; Hanrahan, 1982; Hanrahan and Quirke, 1985; Burfening and Davis, 1996). However, results of some trials indicate significant effects of the genotype of the male and/or embryo on litter size. Compelling evidence comes from differences in litter size of ewes with two ovulations mated to rams of different breeds (Meyer, this issue). Vakil et al. (1968) reported significantly larger litter size for ewes of the same birth type when mated to twin-born than to single-born rams. Burfening et al. (1977) reported significantly more embryos from use of rams from a high- than from a low-prolificacy line, when both were mated to unrelated ewes. Clearly, genotype of the sire or embryo can contribute to variation in litter size, and it may be possible in programs such as NSIP to obtain estimated breeding values that utilize this variation.

Regardless of the strategy followed to increase litter size, it is important to keep in mind that the optimum is not necessarily the maximum achievable. A target mean value appropriate to the particular management system, feed resources and lambing season for the flock(s) in question should be set before a selection (or crossing) program is initiated.

Optimum litter size at birth is influenced by survival rates of singles, twins and higher multiples, and by the growth rate of survivors. Bradford et al. (1991) summarized results from several studies that gave average numbers of lambs weaned of 0.89, 1.63 and 1.63 for litter sizes of 1, 2 and 3 at birth, although it must be emphasized that survival rate varies widely between flocks, especially for triplets. The advantage in total weight of lamb weaned for twin compared to single births is generally very large, even with the lower individual weaning weight of twins. Thus twin births will nearly always be preferable to single births, at least for mature ewes. However, based on the above mean survival rates, there would be no advantage for triplets compared to twins, and possibly some disadvantage, considering the more variable and, on average, lower weaning weight of triplet born than twin born lambs.

Survival rates for triplet lambs can be increased, in some cases substantially, with improved management at lambing and a good lamb fostering program, improving the relative performance of ewes bearing triplets. Also, there are flocks where the milk production potential, nutrition and management are such that a higher percentage of ewes can raise triplets successfully, which would also improve the relative value of triplet births. However, in the majority of US sheep operations, at least at present, two may be the maximum number of lambs that ewes can raise satisfactorily. In this situation, the optimum mean litter size is likely to be that which results in no more triplets than those from which the third lamb can be successfully grafted to ewes with singles or that have lost lambs. Thus a mean of, say, 1.85 born (25, 65 and 10% of ewes with 1, 2 and 3, respectively) might be the maximum acceptable. A flock with less variation, e. g. 15, 80 and 5 % 1's, 2's and 3's (mean 1.90) would be preferable, but variation due to ewe age, nutrition and unknown environmental factors as well as genetic differences among ewes usually results in greater variation than this.

There may also be management situations where twinning is desirable but with essentially zero tolerance for triplets. In such flocks the optimum mean may be of the order of 1.6 (40% singles, 60% twins), since most flocks with a twinning rate above 60% will have at least a few triplets.

The above refers to target mean litter sizes for ewes 2 years and over at lambing. Both the optimum and actual mean for yearling ewes will be lower.

It is also important to note that season of lambing and prebreeding nutrition each has a substantial influence on litter size. Ewes of the same genetic potential lambing in fall will have significantly lower litter size than the same ewes, in the same condition, lambing in late winter or spring. Shelton and Morrow (1965) reported litter sizes of 1.27, 1.26, 1.50 and 1.55 for comparable groups of Rambouillet ewes lambing in August, November, February and May, respectively. Fogarty et al., 1984a; Sakul et al. (1999) and Notter (2000) also reported large differences in litter size at different seasons. Body condition and nutrition level prior to and at the time of mating can also affect mean litter size to at least a comparable extent. Thus in setting a target litter size, or assessing whether a particular breed or cross will meet a defined target, the information used should come from the season and under the nutrition and management conditions in which the ewes will be expected to perform.

Age at puberty.

In annual lambing systems, ewes may be bred to lamb first at either one year (12-15 mo.) or at two years of age. The primary factor affecting choice is usually feed supply – are the ewes well enough grown out to have good fertility at 7-10 months, and is nutrition during pregnancy and lactation adequate for satisfactory survival and growth of their lambs? Another consideration is whether an extended lambing season is compatible with feed, management and markets; performance at 14-15 months tends to be much better than at 12 months. Notter (2000) reported that 15-month old ewes averaged 0.21 more lambs born than 12-month old ewes. However, the 15-month age means lambing these ewes 3 months later than the older ewes in the flock. Where the latter works, it can represent a very productive system (Hamilton and Hamilton, this issue).

In a number of production systems in the US, lambing ewes at one year of age is not feasible, and in this case age at puberty is not a consideration. However, if the average ewe leaves the flock at 5.5 years of age, she will have four years production if she lambs first at two years, and five years if she lambs as a yearling. Assuming first year lamb production is 60% of the average at later ages, lifetime lamb production will be 15% higher (4.6/4.0) for ewes lambing as yearlings. This represents potentially a significant advantage in net income of the operation, although the extra feed and labor for the yearling ewes may result in a net improvement somewhat less than 15%.

Where successful breeding of ewe lambs is compatible with the management system of the flock, early puberty is an essential attribute. A conception rate of 80% or better is suggested as a target if first year breeding is to justify the extra investment in feed and labor required, particularly in larger flocks where this group is likely to be a separate management unit. Most "farm flock" breeds under the feed conditions of that production system will have good fertility as ewe lambs. However, range breeds such as the Rambouillet tend to have later puberty (Dickerson and Laster, 1975; Quirke et al., 1985) and thus lower fertility their first year, even under relatively good conditions.

The estimated heritability of age at puberty is about .25 (SID, 1997), and improvement will almost certainly result from selection. If some but not all ewe lambs will breed and lamb as yearlings, several generations of selecting rams and ewes from dams that have lambed as yearlings should produce a steady increase in first year performance.

An alternative approach is to introduce some inheritance from an early puberty breed. The Finnsheep and Romanov breeds consistently show very early puberty. Crossbreds or composites that have 25% (or more) of their inheritance from one of these breeds have been shown to have very good fertility as ewe lambs in any environment which will adequately support first year lambing. Thus use of a 50% Finnsheep or Romanov ram on ewes of a later puberty breed can produce, in one generation, a marked improvement in first year breeding performance. The many years saved compared to within breed selection in achieving consistent first year breeding performance could compensate for the somewhat lower performance in fleece and carcass traits typical of crosses of these two early puberty breeds. These breeds also contribute increased prolificacy, and selection can improve fleece and carcass traits if these are important to the operation.

Genetic variation in prenatal survival (Meyer) and selection for out-of-season breeding (Notter) are considered elsewhere in this issue. A practical means of selecting for out-of-season fertility is to use the rams intended as sires of replacement ewes (or ewes and rams) only for the first few weeks of the breeding season, and to use other rams, e. g. terminal sire breed rams, for the remainder of the season. In this way, all replacements will come from early lambing ewes. (The practice, occasionally observed in some flocks, of using whiteface rams at the end of the season to produce replacements will select against early season fertility).

Much of the research related to genetic parameter estimation and selecrion for reproductive rate has focussed on components of reproduction – litter size, fertility, etc. Selection for traits such as litter size does increase flock productivity, for example total weight of lamb weaned per ewe, as shown by the results of several of the experiments cited in this review. However, the results from the US Sheep Research Station at Dubois reported by Ercanbrack and Knight (1998) and Snowder (this issue) make a strong case that selecting directly for total weight of lamb weaned per ewe will lead to more improvement. The selection responses reported by those authors were surprisingly large. Other long term evaluations of direct selection for total litter weight have not been reported, but typical results of selection for performance traits in sheep suggest that response may be less than realized in those experiments. Nevertheless, total litter weight weaned represents a "biological index" which incorporates variation in fertility, litter size, viability, and growth rate, and no doubt other components not normally recorded. Selecting directly for it should in fact result in more improvement than selecting for components. No extra recording is required, since information on total litter weight will be available if its principal components, numbers of lambs weaned and weaning weights, are recorded. It is therefore recommended as a practical and useful selection criterion to improve flock productivity.

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Genetic and Environmental Impacts on Prenatal Lamb Loss[1]

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Introduction

Four 'facts' apply to most commercial sheep flocks:

1. Number of lambs sold has a greater influence on flock income than any other factor under the producer's control.

2. Ewes producing single lambs are money losers!

3. Producers put in great effort ar lambing to maximize lamb survival and then fight predators to keep lambs alive until marketing.

4. **MANY SHEEP FLOCKS LOSE MORE LAMBS BEFORE LAMBING THAN AFTER.**

The average flock loses about 15% of lambs from birth to weaning. Numerous studies have shown that the embryonic loss rate in the first 30 days after mating often exceeds 20%. These are potential lambs which the producer never knew existed; however, they are just as surely lambs not marketed as are lambs eaten by coyotes, although lambs that die after birth will usually represent greater investment of feed and labor than those lost prenatally.

To the producer, the most important prenatal losses occur in ewes that ovulate two eggs but give birth to only one lamb. The ewe's costs for maintenance, labor, and depreciation are unchanged and usually more than the sale value of her resulting single lamb. Research results indicate that the percentage of twin-ovulators that lose one embryo ranges from about 10% to over 40%.

This paper will look at loss of potential lambs before lambing and some of the factors affecting loss rates.

Sequence of Events Before Lambing

Ovulation is the start of the reproductive process, and ovulation rate (number of eggs released by the ewe) sets the potential or upper limit of litter size. Breed, age of ewe, body condition, season, and pre-mating nutrition all influence ovulation rate. Ova have three major hurdles to cross before they appear as lambs - fertilization to become embryos, implantation of embryos, and survival of embryos/fetuses to parturition.

Ram fertility obviously plays a big role in fertilization of ova and resulting conception of ewes. Fertilization of multiple ova tends to be an all-or-none event, i.e. if any eggs are fertilized, they probably all are fertilized (Restall et al., 1976). That means that subfertile rams may reduce conception rates and result in a spread-out lambing, but they will not have a strong effect on twinning rate of pregnant ewes. Studying the reasons for fertilization failure is very difficult since there is no way of knowing which eggs are not fertilized until they are no longer in the system, and then it is too late to examine them.

Fertilized eggs (embryos) implant in the uterus at around 19 days following mating. By then the embryos have become cell masses that have sent out pregnancy signals to the reproductive system resulting in blockage of the next ovulation and estrus, and preparation of the uterus for implantation. Prior to implantation, embryos are distributed between the two uterine horns by an unknown mechanism. In ewes conceiving to a single ovulation, nearly 100% of the lambs develop in the horn adjacent to the ovarian source of the egg. In ewes conceiving to twin ovulations, nearly all ewes implant one embryo in each horn of the uterus, regardless of ovulation site. Since ovulation is a random event between ovaries, half of all twin ovulations are the result of both eggs coming from one ovary. Somehow, one of these eggs is 'sent' to the other horn of the uterus.

Embryos failing to implant at the critical time are lost. If no embryos implant, the ewe will return to service, typically at 24-28 days after the previous estrus. This probably explains many of the 'long cycles' observed in single-sire mating systems.

During a short 'colonization' period, multiple embryos compete for uterine attachment sites (caruncles) through which they will receive all nourishment during gestation. The number of caruncles in the uterus is limited, and it has been shown that there is a positive relationship between the birth weight of a lamb and the number of attachments between its placenta and its mother's uterus. Single lambs are not limited to attachments within one horn of the uterus - a portion of single placentas spread into the other uterine horn.

Real competition arises when ewes have

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multiple embryos within one uterine horn. Embryos with too few attachments ('feeding sites') have increased chance of loss; however, surviving embryos do not benefit greatly from the embryonic loss of sibs since the 'claiming period' for caruncles is past. Our ovulation rate/litter size data suggest that the fairly common observation of twin lambs differing greatly in birth weight is usually the result of a triple ovulation - the larger twin had one uterine horn to itself while the smaller twin is the survivor of two embryos which competed for caruncles in the second uterine horn. Likewise, the observation of light birth weights for single lambs born to Finnsheep or Booroola Merino mothers is probably a case of the lamb being a sole survivor from a high ovulation conception.

Embryos that successfully implant and survive to 30 days seem to suffer little mortality thereafter. We have seen very little loss after 30 days, the earliest time that embryos can be reliably counted by ultrasound.

Defining Embryo Loss

Embryonic losses might be considered in two categories - total loss and partial loss. Even when ewes are group mated to semen-tested high-fertility rams, a substantial proportion do not conceive at a single estrus. Results from large studies typically show 80% of ewes lambing in the first cycle; however, 80% of the remainder (i.e. about 16%) lamb in the second cycle and a portion of remaining ewes will lamb to matings in the third cycle if mating continues that long. As mentioned previously, some returning ewes had fertilized ova and were temporarily pregnant, however implantation failure resulted in the ewe returning to service in what would appear as a long cycle. The net portion of a ewe flock with total loss of all embryos is typically 2-5%.

A greater proportion of ewes are multiple ovulators who successfully implant at least one embryo but also lose at least one potential lamb. Current techniques do not allow determination of whether the loss of potential lamb(s) is due to failure in fertilization, implantation failure, or loss post-implantation.

One approach to addressing this difficulty on a flock or group basis is to combine all losses and analyze litter size relative to ovulation rate for ewes conceiving to multiple ovulations. Since it takes one embryo to establish pregnancy, one can then look at the success of turning additional eggs into lambs. This has been termed uterine efficiency (UE) by Meyer (1985) and defined as the mean increase in litter size resulting from ovulation of one additional egg. For twin ovulators, this amounts to the proportion of ewes that give birth to twins (since all had to be successful with at least one egg). For triple ovulators, UE is the difference in mean litter size between triple ovulators and twin ovulators. The same calculation is extended to higher ovulation records for studies involving prolific breeds.

Sources of Variation Affecting Embryo Loss

Ovulation Rate

Since ewes lambing as a result of conception to a single ovulation must produce one lamb, they are, by definition, 100% efficient. If they failed to produce a lamb, they would be counted as dry ewes. As described above, ewes conceiving to twin ovulation must be successful with one egg, but a proportion are not successful with both. As ovulation rate increases, success of additional eggs declines so that the difference in litter size between triple and twin ovulators (advantage due to third egg) will be less than the difference in litter size between twin and single ovulators (advantage of second egg) (Meyer, 1985; Robinson and Scaramuzzi, 1986; Meyer et al, 1994). It has been shown with prolific breeds that litter size peaks at about five ova - at higher ovulation rates litter size actually declines (Hanrahan, 1976; Piper and Bindon, 1981). This is probably due to the embryo competition for limited numbers of caruncles resulting in high embryonic losses (mentioned earlier).

Management Stress

Circumstantial evidence from New Zealand indicates that pre-implantation embryos may be especially susceptible to losses due to ewe stress occurring 10 to 15 days post-mating. Flocks that have been shorn during the mating season often exhibit a break in the lambing pattern. In some cases, lambing virtually ceases for several days. The lambing break occurs 132 to 137 days after shearing, corresponding to a time when shorn ewes would have been 10 to 15 days post-mating. Ewes either side of this time window seem to be largely unaffected.

Nutritional Stress/Body Condition

Ewes in poor body condition at mating, in addition to having lower ovulation rates, also experience increased embryo loss compared to ewes in good body condition. The impact of poor body condition may depend upon the genotype of the ewe.

Two studies conducted at Oregon State University produced ewes that were in either good or poor or body condition at mating (West, et al., 1991). Ewes in each group were then subjected to either good or poor nutrition for a period immediately following mating. In addition to the expected result that ewes in good body condition had higher ovulation rates than ewes in poor body condition, effects of body condition and post-mating nutrition on uterine efficiency of multiple-ovulating ewes were:

1. Body condition affected uterine efficiency:
   - Ewes in good body condition at mating produced more lambs from the same number of eggs than did ewes in poor body condition at mating.
   - Poor body condition reduced litter size more in triplet ovulators (by .35 lambs) than in twin ovulators (.15 lambs).
2. Post-mating nutrition affected uterine efficiency:
   - Dropping the nutrition level of good condition ewes resulted in lower uterine efficiency.
   - Returning flushed low condition ewes to poor nutrition resulted in loss of most of the lambs potentially gained from flushing.
3. Post-mating nutrition could not overcome the effects of pre-mating body condition:
   - Good feeding of poor condition ewes after conception did not overcome the effects of their poor body condition.

4. Effect of body condition on uterine efficiency depended upon ewe genotype:
   - Among ewes conceiving to twin ovulations, poor body condition reduced litter size of Coopworth x Polypay ewes but did not reduce litter size of Polypay ewes; however, poor body condition did reduce litter size among Polypay ewes conceiving to triple ovulations.

Similar effects of body condition on UE have been observed in Targhee and Finn x Targhee ewes (Meyer and Bradford, 1973): both genotypes exhibited reduced UE when in poor body condition; the effect was greater for triple than for twin ovulators; and negative effects on UE were less for the more prolific genotype.

Ewe Genotype

Numerous studies have shown that breeds differ in uterine efficiency. Initial studies indicated that genotypes of typically low litter size had both lower ovulation rates than other breeds and then produced fewer lambs even when they conceived to multiple ovulations. This has been reported in Australia for Merinos vs. Merino crossbred ewes and in New Zealand for Romneys vs. Romney crosses. In both cases, purebred ewes had both lower ovulation rates and lower litter size even when conceiving to twin ovulations. In Australia, as few as 50% of Merinos conceiving to twin ovulations prodnce twins (Kleeman et al., 1990; Wilkins, 1989). A study comparing Merinos and their crosses reported a UE value of .58 for purebred Merinos vs. .67 for Dorset crosses and .77 for Border Leicester crosses (Meyer et al., 1994). Data from New Zealand indicate that the portion of twin-ovulating Romneys producing twins may be as low as 50-60% (Quinlivan et al., 1966; Meyer and Clarke, 1982; Meyer et al., 1983). In a study where higher UE values were observed, litter size of twin-ovulating ewes ranged from 1.71 for Romneys to 1.75 for Dorset x Romneys, 1.88 for Border Leicester x Romneys and 1.93 for Finn x Romneys (Meyer, 1979).

The above results with ewes of Border Leicester or Finn breeding warrant further comment. The consistently high UE for Border Leicester crosses among non-exotic breeds (see also Cummings et al., 1975, and Meyer and Clarke, 1982) explains in part their popularity as a ewe sire breed in different countries and has served as the basis for their choice as recipients in several embryo transfer/multiplication programs.

The very positive effect of Finnsheep on embryo survival likewise appears to be a consistent breed characteristic. In a study of Targhee and Finn x Targhee ewes conceiving to twin ovulations, 90% of the Finn crosses managed to produce twins compared to only 70% of the straightbred Targhees (Meyer and Bradford, 1973). The previously mentioned body condition study including Polypay ewes (which are 1/4 Finn) also found an advantage of Polypays over Polypay crosses in which the Finn component is reduced. This was suppotred in a subsequent study (Nawaz and Meyer, 1991) in which purebred Polypay ewes conceiving to twin ovulations exhibited a mean UE of .96 compared to .85 for three Polypay crossbred genotypes and .74 for two genotypes containing no Polypay breeding.

Reports concerning other prolific sheep such as the Romanov (Ricordeau et al., 1982) and Javanese breeds (Bradford et al., 1986) suggest that the effect noted in the Finn may be common to prolific breeds. The highly prolific Booroola Merino in which prolificacy is due to a single allele shows a substantial UE superiority over other Merinos (Bindon et al., 1980) but does not achieve the levels seen in other prolific breeds (Meyer et al., 1994). The previously mentioned Border Leicester effect was quite evident in Border Leicester x Booroola crosses with the crosses having higher UE than purebred Booroolas at ovulation rates of two, three and four.

Further evidence of an effect of ewe genotype on uterine efficiency comes from a two-year study of immunization to increase litter size (Meyer et al., 1988). The study was conducted in a large crossbred commercial flock in which ewes were identified as to whether they were heavily blackface or showed no sign of blackface breeding - 'smutface' and brockle-face ewes were exclnded from the study. Among ewes conceiving to twin ovulations, mean litter size of whiteface ewes (1.84) was .12 lambs greater than the average for blackface ewes (1.72) over two years. All ewes had been run together since birth and were group mated to the same rams.

Our ongoing studies with various ewe genotypes reinforce the above observation. In a recently completed five year study, whiteface ewes consistently demonstrated equal or higher uterine efficiency than Hampshire x whiteface crosses. In every year of the study, purebred Hampshires demonstrated the lowest uterine efficiency. Apart from the second year of the study (in which all ewes were in poor body condition at mating), whiteface ewes have averaged 89% of twin ovulators producing twin lambs compared to 83% for Hamp crosses and only 64% for purebred Hamps. In the second year of the study, all three groups ranged from 60 to 64% twinning, reflecting the earlier observation that poor body condition can have major negative effects on uterine efficiency.

Embryo Genotype

Although the effect appears to be smaller, there is evidence that genotype of the embryo (i.e. breed of ram used) may also affect embryo success. In the above study with whiteface, Hamp crossbred and purebred Hampshire ewes, a variety of sire breeds were randomized across ewe genotypes. However, in each of the five years, one of the sire breeds used was Suffolk with the rams used each year coming from the same large purebred flock with care taken to insure that rams were unrelated. In evety year, twin-ovulating ewes mated to Suffolk rams have had lower litter size than ewes mated to whiteface rams.

In the second year of the above trial, when body condition of ewes was low, twin-ovulators conceiving to Suffolk rams had a mean litter size of only 1.46 compared to 1.73 and 1.81 for ewes mated to Texel and Dorset rams, respectively. The low UE of ewes mated to Suffolk rams was not due to low values for a single ram, since the three Suffolk rams had values of 1.43, 1.45, and 1.50 lambs born from conceptions to twin ovulations - all were below the lowest value for any Texel or Dorset ram.

The effects of embryo genotype and ewe genotype may be additive. The lowest UE observed for any ewe x sire combination consistently came from purebred Hampshire ewes mated to Suffolk rams - only 40% of these ewes produced twins after conceiving to twin ovulations.

Ewe Age

Few studies of embryo loss have been large enough to examine the effect of ewe age on loss rates. An exception was a large trial involving 2246 ovulation/lambing records of Booroola and Merino-derived genotypes (Meyer et al., 1994). Young (two- and three-yr.-old) ewes consistently exhibited the lowest UE with litter sizes averaging 10% below the overall means for respective ovulation rates. Within ovulation classes, four-through six-year-old ewes exhibited comparable mean litter sizes with litter size dropping off among seven-year-old ewes.

Summary/ Recommendations

1. Recognize that body condition affects uterine efficiency and that while flushing increases ovulation rate, only a portion of the extra eggs will be realized as lambs.

2. Post-mating nutrition is important for embryonic success, especially if ewes are in poor body condition. Good nutrition should extend as least three weeks beyond mating. It is better to sort off the 50% of ewes in poorest body condition and flush them both before and after mating rather than to flush all of the flock before mating and discontinue the extra nutrition early.

3. Among genetic effects, both Border Leicester and Finn genes increase embryonic survival with Finn genes having the larger effect.

4. Choice of ram breeds may inflnence embryo loss (and definirely affects post-natal losses), especially if ewes are in poor body condition. Blackface breeding seems to be detrimental to embryo survival compared to whiteface breeding.

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Lamb Mortality

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Introduction

It has been established that net reproductive rate (lamb crops weaned) is the largest contributing factor to efficiency of lamb meat production (Large, 1970). With the present low rate of return from wool production, it is imperative that producers who will survive must produce meat more efficiently. There is also a need to increase overall numbers of lambs produced in order to justify the maintenance of the necessary infrastructure to sustain the indnstry. On a flock basis there are a number of components of net reproductive efficiency including age at sexual maturity, length of productive life, seasonality of reproduction, frequency of lambing, ewe fertility, ovulation rate, embryo mortality and lamb survival. Among these, it has been suggested that under some conditions, reducing lamb mortality offers the greatest opportunity to improve the efficiency of the flock (Wang and Dickerson, 1991).

The Potential

For a single or given season, the potential or upper limit for reproductive rate is represented by the ovulation rate of the ewes exposed for mating. The difference between the potential and the lamb crop raised is often referred to as reproductive wastage. Attempts have been made to estimate and partition these losses which will obviously vary with conditions. One such study reported by Willingham, Shelton, and Thompson (1986) for finewool ewes under Texas range conditions is shown in Figure 1. In this study the potential lamb crop, based on ovulation data, was estimated at approximately 151.9%, whereas the actual lamb crop raised was 100.7%. The two major areas of loss were the difference between ovulation rate and embryos present (34 lambs per 100 ewes or 22.4% of total ovulations) and the difference between lambs born and lambs weaned (15.9 lambs per 100 ewes or 13.6% of the total lambs born). In these data, few prenatal losses occurred after 24 days of gestation. These findings are consistent with other works suggesting that 20-30% of fertilized ova are lost during pregnancy (Edey, 1969) with much of this loss occurring within 19 days of conception (Michels et al., 1998). At this time there are few clues as to how to reduce the loss between ovulation and implantation, but it is thought to be, in part, a matter of chance which individual ewes fail to become pregnant or multiple ovulating ewes become pregnant with only one embryo. These data were obtained using range Rambouillet ewes, and both prenatal and postnatal losses would likely have been greater if more prolific types were used. The options to increase the number of lambs raised consist of increasing the fertility (number of ewes becoming pregnant) increasing the ovulation rate, lambing more frequently, and reducing lamb mortality. The latter is the subject of this paper.

Although postnatal losses as low as 2% (Schwulst et al., 1999) have been reported under intensively managed conditions, the writers consider 10 percent as a practical minimum under production conditions. The percent of stillborn lambs under field conditions will usually exceed the 2% figure (8.4% of total death losses - Rook 1989), but some of the reported stillbirths may be reduced if workers are present at parturition. From the suggested minimum of 10%, losses approaching 100% have been observed. Losses of this magnitude are usually associated with heavy predation or some calamitous event such as storms (heavy snows) at lambing or serious disease outbreaks.

In well managed flocks (but not barn or shed lambed), death losses tend to run from eight to 12% for singles and 16 to 20% for twins and for litter sizes above two, mortality is much higher.

Flocks with litter sizes above two tend to be those with ewes from the more prolific breeds such as the North European Short Tail group (Finnish Landrace and Romanov) or those carrying the FecB gene of Booroola origin. Mortality rates for triplets tend to approach 30% (even with intense management) and with four or more lambs the mortality tends to be 50% and above (Willingham and Shelton, 1990). The net result is that litter sizes above two may not result in an increase in the lamb weight weaned. This may not be the case for triplets if they can be intensively managed.

The above discussion suggests that: (a) lamb mortality is a serious problem to be dealt with, (b) this problem is likely to increase with efforts to increase lambing rate, (c) more intense management at lambing may contribute to improved lamb survival, and (d) the reduced flock sizes associated with the decline in ewe numbers may make it feasible to provide more intense management at lambing.

Even with intense management at lambing, and certainly in the absence of this, producers need to develop breeding and management strategies that maximize or optimize lamb survival and growth.

Factors contributing to lamb survival (or losses) may be divided into genetic and environmental components. Of these, environmental (including management) may be considered to be the most important, but there are genetic components as well.

The Genetic Component

Genetics or breeding systems are contributing factors to lamb mortality or survival in many ways. Genetics is a major contributing factor to litter size which, as outlined above, affects lamb mortality or survival. Litter sizes above two are not frequent enough to present a serious problem, except for the more prolific types. Those (prolific breeds) available in this country include the Finnish Landrace, the Romanov and those carrying the FecB gene of Booroola origin. In commercial lamb production, none of these should be used as purebreds or in the homozygous state with respect to the FecB gene. In the case of the short tail types, the percentage can be diluted to that desired, but the Booroola type can be employed only as homozygote (two copies of the gene) or heterozygote (one copy of the gene). Some data on ovulation and lambing rate for the half Finnish and the heterozygote (one copy of the gene) Booroola gene is shown in Table 1.

These data show that both types have approximately the desired ovulation and lambing rate, but that the Booroola (FecB) carrier has a greater tendency to have litter sizes above two. Experience with the original Booroola genotype has shown that they do a poor job of rearing this number of lambs (Bindon, 1984). There is work in progress to transfer the FecB gene into other genotypes such as the Rambouillet, but it is not known at this time if these will do a better job of rearing multiple births. It is expected that the Rambouillet genotype will provide heavier weaning weights or faster growth rates. For the present discussion, it is suggested that the Romanov would perform similarly to the Finn in this respect (Fahmy, 1996).

In addition to the influence of litter size, it is expected that mating system (heterosis in either the dam or the lamb), when corrected for litter size, will tend to improve lamb survival by two to 5 percent (Wiener et al 1973), but this may vary with the breeds involved.

One of the major factors contributing to lamb mortality is cold stress. It has been shown that a single gene trait results in a hairy birth coat which improves lamb survival of those exposed to cold stress (Slee, 1978). It may be significant to note that none of the prolific breeds currently employed possess this gene.

It has been shown that there is a heritable component to the ability of the dam to raise the lambs born to her (Shelton and Menzies, 1970). The heritability of this trait (.16 in this study) is of a similar to or of greater magnitude to that of the other reproductive traits. Such an effect might be mediated through temperament or mothering ability of the ewe, udder shape, milking ability, etc. It should also be pointed out that in the case of lamb mortality, selection for survival is automatic and may equal the magnitude warranted. However, the ability to rear lambs may be a more important component of selection for lifetime ewe productivity or total lamb weight weaned over a period of years. In addition, lamb survival may well play a part in the choice of cross breeding system and breeds employed for commercial lamb production.

Environmental Factors Contributing to Lamb Survival

As mentioned earlier, serious losses of lambs may occur as a result of predation or disease, although the latter tend to be associated more with prenatal as opposed to postnatal losses. For reasons of time and space these items will not be dealt with in the present discussion, but are issues that the producer will need to address.

Perhaps the greatest single predisposing factor contributing to lamb loss is birth weight; whereas in fact, the major direct causes of losses are starvation and hypothermia. The literature relating to these points is rather extensive and no attempt will be made to review all of this at this time. One such study (Shelton, 1964) based on finewool ewes (mostly Rambouillet) with the moderate level of management necessary to collect experimental data indicated death losses more than 65% for lambs weighing less than 4 pounds at birth. Minimum losses (6.4 to 8.1 percent) occurred for lambs weighing nine to 12 lbs. Losses increased for lambs weighing above 12 lbs., and some ewe losses will be encountered with these heavy weight lambs, especially if ewes are lambed unattended on the pasture or range. However, death losses due to overweight lambs represent a very small part of the problem (0.32% of the number in the above study) involving mostly fall born lambs. The problem of heavy weight lambs will be greater for single lambs born in the spring of the year. At the same time it will be less with increased use of more prolific types of ewes. The only precaution the author would suggest in respect to heavy weight lambs would be to use caution in breeding large sire breeds (such as Suffolk or Hampshire) to first lambing ewes (ewe lambs or yearling ewes) which are bred for spring lambs. Some increased losses of both lambs and ewes have been reported under these conditions (Willingham et al., 1994). Several factors were involved in this instance such as large sire breed rams, and small or underdeveloped females producing mostly single lambs born in the spring of the year.

Since low birth weight is a major predisposing factor to lamb mortality it seems logical to look at factors affecting birth weight.

Unquestionably, litter size has the greatest influence on birth weight, but in any effort to improve efficiency of meat production from sheep, it is not feasible to suggest a reduction in prolificacy as a means of improving birth weight. Perhaps the ideal situation would be for first lambing ewes to produce single lambs and to produce twins at each subsequent lambing. Although this is not likely to be completely realized, efforts should be made to approach this by discriminating against single births (except for young ewes) and litters in excess of two or possibly three. This is the basis in which many producers have used ewes carrying a percentage of one of the more prolific breeds which will often approach this theoretical ideal.

Aside from litter size, the other factors affecting birth weight are nutrition and temperature. The latter also contributes to lamb mortality (or survival) aside from its contribution to birth weight.

Nutrition is not a major factor in birth weight of single lambs from ewes in medium to good flesh which are receiving at least a maintenance ration. If there is a nutritional problem for single bearing ewes it is more likely to be protein, but the average producer is so oriented to providing protein that this practice may be overdone. A single bearing ewe may require only on the order of 180 grams (0.4 lbs.) of protein even in the last trimester of pregnancy, and assuming at least half of this is provided by the pasture forage, as little as 90 grams or 0.4 lbs. of a protein supplement may be required. A good pasture may well provide for all their needs. There may be other reasons for feeding or not feeding during lambing. Ewes which are hungry may be busy feeding and pay less attention to mothering the lamb. Also, if hand feeding is practiced (such as feeding pellets on the ground), the disruption of feeding may cause ewes to abandon newborn lambs.

Feeding during late pregnancy and early postpartum is more critical for litter bearing ewes. The increased demands for the two or more fetuses may place the ewe in a negative energy or protein balance. Fleshy ewes may breakdown body fat to meet their own needs, but there are two problems with relying on this to meet the ewes' energy needs for fetal development. Catabolism of body fats can be used to meet the ewe's direct energy needs, but it cannot be or is a very inefficient source of glucose (the primary nutrient required by the fetus). Thus even with the breakdown of body fat the embryo may be undernourished, and the incomplete breakdown of the body fat may trigger pregnancy toxemia which is fatal to the ewes. Also ewes carrying multiple fetus may have reduced body space as a result of the uterine contents and thus be unable to consume sufficient low quality forage or feedstuffs to meet their needs. Producers may choose to pregnancy test their ewes (ultrasound) in order to sort single from multiple ewes. On the other hand, they may choose to make this distinction based on breeding or their knowledge of the flock. For instance, range raised finewool ewes usually have a relatively low level of twins and seldom have more than two and thus are often treated as single bearing ewes. On the other hand, more prolific types of ewes may be assumed to have a high frequency of multiple births and be treated as such.

A second important environmental factor affecting birth weight and thus lamb mortality is environmental temperature during (late) gestation (Shelton, 1964). High environmental temperatures during late gestation (last 30 to 45 days) will result in fetal dwarfing. The physiological explanation for this is that if the ewes are suffering from heat stress (increased respiratory rate) their (finite) blood supply will be shunted to the lungs and superficial tissue to accommodate heat loss, with a reduced blood supply available to the internal organs (especially the uterus). The result is an undernourished (one or more) fetus, and the degree of this effect is dependent on the amount of heat stress and how long (hours of the day or number of days) it is experienced. This effect is not prevented by feeding or condition or fleshing of the ewe. In fact both of these can have a further negative impact.

Fortunately this problem does have partial or reasonable solutions. The problem is obviously more serious in the more southern climates and among late summer or early fall born lambs. However, some degree of fetal dwarfing can be documented throughout much of the country. In general, fall born lambs weigh approximately one to 2 lbs. less than spring born lambs of similar genotype. This may go largely unnoticed by producers, but it may influence lamb survival in both negative and positive ways (e.g., there may be fewer problems of dystocia). On the other hand, there is a serious interaction between litter size and birth weight of late summer and fall born lambs. It appears that under these conditions there is a finite amount of nutrients available to the uterus and that twin born lambs may weigh only on the order of 1/2 what a single would weigh. The problem is much worse for litter sizes of more than two. The author is aware of reported instances of 50 to 70 percent mortalities of late summer or early fall born lamb crops from the more prolific types of ewes. A reasonably effective solution to these problems is to avoid lambing ewes under these conditions (avoid August and September lambings). In Texas, it is preferable to delay lambing until October 15. Ewes subjected to heat stress in late gestation may be benefitted by providing good shade during the day (possibly open barns) and allowing them to feed at night. For producers operating under extensive conditions or with limited labor, this type of management is often not an option.

The second major effect of temperature on lamb mortality is that of cold stress during lambing (Falck, Carstens and Waldron, 2001). It must be realized that unless protection can be provided for ewes lambing during the cold seasons, hypothermia is a major cause of lamb mortality. It will be recalled that Rook (1989) reported starvation as the major cause of death; however, much of this starvation was predisposed by low birth weights and cold stress at lambing. The degree to which cold stress is a problem would obviously depend on location (latitude). At the more southern locations (e.g., Texas) many producers avoid lambing in late December, January and possibly early February. Other producers in the Northwest may avoid lambing prior to May.

The degree of this problem (cold stress) is also related to litter size (Willingham and Shelton, 1986) in that lamb losses to cold stress are much higher among multiple births than for singles (see Figure 2). In the referenced study, death losses among multiple births were higher for litters born in the winter than for spring or fall, whereas, single born lambs were not similarly affected. Thus, there is an interaction with respect to death losses between lambing rate (litter size) and lambing date. This interaction is no doubt partially explained by the effect of cold stress on low birth weight lambs, but it is also impacted by the fact that with ewes giving birth to two or more lambs, the time the ewe spends with an individual lamb is both reduced and delayed. The end result of this may well show up as a lamb which starved, but in reality the explanation may be more complex. Thus, for producers who are unable to provide intense management at lambing, the breeding or lambing season should be delayed to avoid lambing during the cold season, and this is especially true for the more prolific types of ewes.

No attempt is being made to discuss details of intensive management during lambing in the belief that producers have their own skills. With larger flocks, the industry is likely moving away from lambing in confinement due to the facilities and labor required. However, if flock sizes are reduced along with the use of more prolific types, more intense management during lambing may become both more important and more feasible. In this connection, it should be pointed out that with appropriate management during breeding, the lambing period may be reduced to as little as three weeks per lambing season. The economics of intense management at lambing would be greatly dependent on overall facilities and labor supply.

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Table 1. Distribution of ovulation and lambing rate of the prolific types.

	Ovulation rate (%)					Lambing rate (%)					
Type*	1	2	3	4	avg.	0	1	2	3	4	avg.
Booroola (carrier)	7.8	46.7	37.7	7.8	2.64	5.5	23.6	47.3	20.0	3.6	2.05
1/2 Finn.	16.4	65.9	15.9	1.6	2.11	7.0	25.7	52.6	12.3	2.3	1.85

* Adapted from Willingham, Shelton, and Lupton (1988)

Figure 1. Areas of Reproductive Wastage

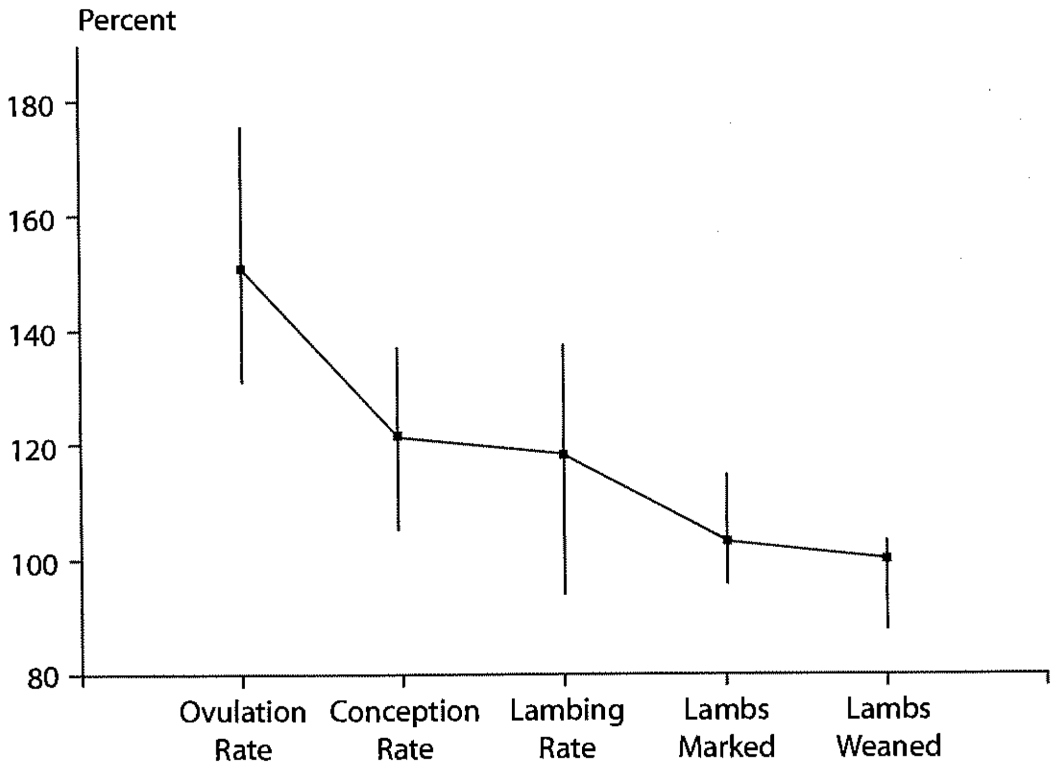
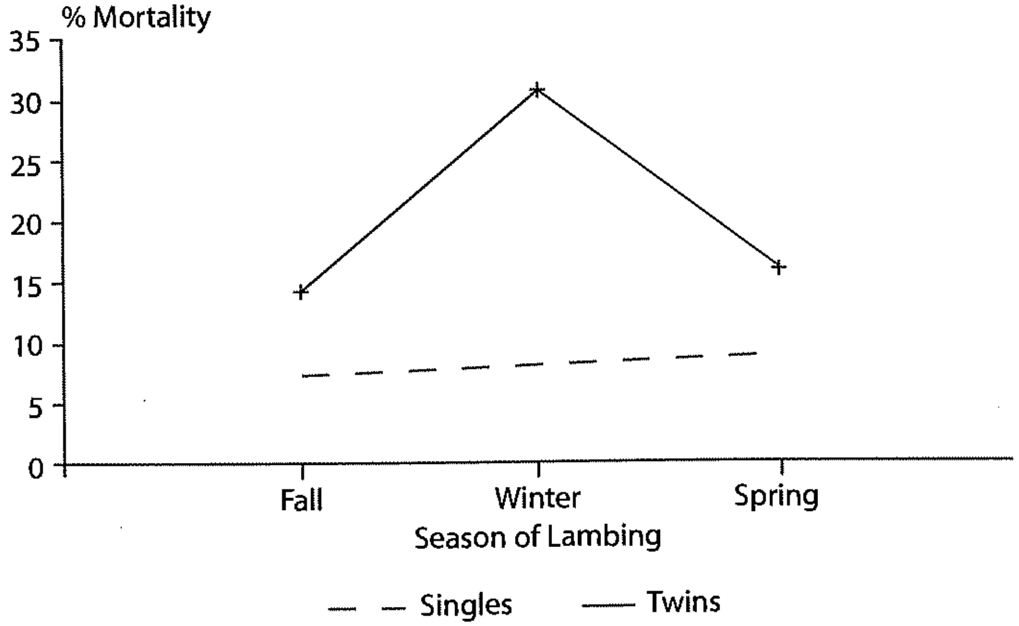


Figure 2. The Influence of Lambing Season and Birth Type on Lamb Mortality



Opportunities to Reduce Seasonality of Breeding in Sheep by Selection

D. R. Notter[1]

Introduction

Seasonal reproduction is a serious problem for the sheep industry, reducing effectiveness of accelerated lambing programs, restricting flexibility to integrate lambing into other farm activities, and limiting access to favorable seasonal markets. Environmental or hormonal stimulation of reproduction requires increased investment in feed, labor, and (or) facilities, increases cost of production, often requires access to products that are not readily available or not approved for use in sheep, and may not be feasible in extensive or semi-extensive production systems. However, less intensive and less costly management interventions are available to improve reproduction; chief among these is use of the ram effect (Oldham and Fisher, 1992). In addition, substantial evidence exists to document genetic differences in seasonality of breeding, leading to opportunities to reduce seasonality by selection.

This review will address potential for genetic improvement of reproduction in sheep in both annual autumn and accelerated lambing systems. Satisfactory reproductive performance in both systems is mainly limited by the need to lengthen the breeding season to encompass spring and summer matings. In annual lambing, a shift in the annual pattern of reproductive behavior may be sufficient to meet the needs of the program, and ram effect is a useful tool for induction of estrus. In contrast, accelerated lambing systems place a premium on rapid rebreeding which is not required in annual lambing. Accelerated systems thus generally require more careful timing of ram effect and greater genetic sensitivity of ewes to ram introduction.

Selection to reduce seasonality of breeding involves application of the principles well-established. Selection among existing breeds is used to establish a flock with desirable initial characteristics. A breeding program is then designed to appropriately utilize complementary breed effects and hybrid vigor. And finally, selection within the flock is implemented to generate genetic improvement in economically important traits.

Seasonal Patterns of Reproduction in Sheep

A typical pattern of seasonal variation in occurrence of estrus for temperate sheep breeds is shown in Figure 1, derived from results summarized by Notter (1992), with dramatically reduced fertility in spring and summer. However, the dates of onset and cessation of anestrus vary widely with breed, latitude, and management. For some breeds and at some locations, the seasonal anestrus may not be absolute, with some ewes in estrus during each month of the year (Wiggins et al., 1970; Hall et al., 1986). However, even in relatively nonseasonal breeds, most ewes appear to become anestrus at some time during the year. Documented continuous cyclicity is rare. Hall et al. (1986) reported that only four of 73 Dorset ewes in a New Zealand experiment cycled continuously for a period of 15 mo. Wiggins et al. (1970) reported that two of 23 Rambouillet ewes in an Alabama flock cycled continuously for 4 yr. More recently, Vincent et al. (2000) documented continuous occurrence of estrus during spring and summer in a high proportion of ewes from a population selected for out-of-season breeding.

The duration of seasonal anestrus in the ewe may be modified by introduction of males to the flock. In anestrous ewes that have been isolated from males, introduction of rams commonly induces ovulation in a proportion of the ewes, whereas ewes that remain isolated from males remain anestrus. Likewise, ewes that have been in continuous contact with rams during anestrus take longer to begin cycling than ewes that were separated from, and then reintroduced to, rams, although the introduction of unfamiliar rams may induce some ewes to cycle.

Variation in number of lambs born is also commonly observed among ewes lambing in different seasons. Ovulation rate is commonly reduced in ewes cycling in spring and summer (Quirke et al., 1988), and embryonic mortality may be increased, especially if ewes are exposed to high summer temperatures during gestation. An example of seasonal variation in number of lambs born per ewe lambing in different ewe types is reproduced in Figure 2 (Notter and Copenhaver, 1980). In general, the average number of lambs born per ewe lambing is reduced by one third to one half of a lamb in adult ewes lambing in autumn. Heat stress during gestation may also influence lamb birth weights and perinatal mortality (Shelton, 1964; Shelton and Huston, 1968). Al-Shorepy and Notter (1998) reported that autumn-born lambs in

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Virginia averaged .6 kg less at birth than spring-born lambs, with associated increases in lamb mortality.

Environmental and Neuroendocrine Control of Seasonal Breeding

Changes in reproductive status in the sheep are associated with changes in day length. The response of the ewe to changing light conditions is mediated by the hormone melatonin from the pineal gland. Cells in the pineal gland possess neuroendocrine connections to the optic nerve and respond to light signals from the eye. In darkness, the pineal typically produces melatonin at mean levels of 100 to 300 ng/ml of circulating blood plasma. During the day, or under artificial lighting, circulating melatonin levels drop precipitously, with mean levels generally below 30 ng/ml. Circulating melatonin levels thus reflect external light conditions. Seasonal changes in the daily pattern of circulating melatonin, as opposed to absolute circulating levels of the hormone, are the main factor controlling seasonal changes in reproduction.

Expression of seasonal reproduction requires cyclic changes in day length. Under controlled lighting, the seasonal reproductive pattern can be accelerated by increasing the rate of change in day length, and two complete cycles of reproductive activity/inactivity can be induced in a 12-mo period by doubling the daily rate of change in day length. However, Robinson and Karsch (1984) and Robinson et al. (1985) have shown that exposure to a constant day length (either long or short) cannot maintain the ewe in a constant reproductive state. Highly seasonal Suffolk ewes maintained under constant light conditions for more than 12 to 13 wk following either the winter or summer solstice exhibited spontaneous changes in reproductive state that were independent of both day length and circulating melatonin levels. This response indicates that there is an internal mechanism in the ewe that is capable of producing cyclical changes in reproductive status. Changes in day length can interact with this internal cycle to modify, but not eliminate, seasonal reproduction. In practical breeding programs, manipulation of reproduction by controlled lighting thus requires modification of the pattern of change in day length rather than simple imposition of a constant, stimulatory photoperiod.

The ram effect is controlled by a pheromone produced by the male, which explains why expression of ram effect requires a period of isolation from males (to prevent ewes from becoming refractory to the pheromone), why males may differ in ability to induce ram effect, and why new rams may be able to induce estrus (differences in chemical structure or level of production of pheromone). The endocrine events that follow ram introduction are well-known (Martin et al., 1986). Ewes that respond to ram effect generally have an increase in pulsatile release of luteinizing hormone (LH) from the anterior pituitary gland within a few minutes of ram exposure. This pattern of LH release causes ovulation, usually within 1 to 2 d of ram introduction. The first ovulation is generally not accompanied by estrus; instead, the first estrus is anticipated to occur at the second ovulation, 18 to 19 d after ram introduction. Also, in some ewes, estrus is further delayed by formation of an incompetent corpus luteum (CL) at first ovulation. In these ewes, the first CL regresses prematurely, 5 to 6 d after ovulation. A second ovulation may then occur 6 to 8 d after ram introduction but is again not usually associated with estrus. If a normal CL is formed after the second ovulation, a third ovulation, now accompanied by the first estrus, is anticipated about 24 d after ram introduction. Classical expression of ram effect in highly responsive Australian Merino ewes thns involves two periods of estrus activity at about 19 and 24 d after ram introduction (Oldham and Fisher, 1992). However, both Nugent et al. (1988) and Cushwa et al. (1992) observed less tightly synchronized responses to ram introduction in U.S. breeds.

Ram effect is most useful in advancing the onset of the breeding season by 4 to 6 wk and is perhaps the most effective management tool available for accomplishing this objective. Some ewes also respond to ram effect in early to mid-anestrus, but fewer ewes generally respond, and the response is less reliable, in part because some ewes ovulate only once (without estrus) and then return to anestrus. Figure 3 displays anticipared responses to ram introduction at diferents seasons (derived from concepts and data presented by Marrin et al., 1996, and Oldham and Fisher, 1992).

Breed Effects and Heterosis

Breed differences in duration and timing of the breeding season are readily demonstrated, beginning with Hafez (1952). Among North American breeds, Dorsets are generally considered to be less seasonal than other breeds. However, Rambouillet and Finnsheep also have considerable potential for out-of-season breeding, and crosses involving Dorset, Rambouillet, and (or) Finnsheep have commonly been superior to other breeds and crosses (Notter and Copenhaver, 1980; Fogarty et al., 1984). Finnsheep may continue cycling longer in spring, but also initiate cycles later in fall, than Rambouillet or Merino ewes (Quirke et al., 1988; Wheeler and Land, 1977). Hulet et al. (1984) demonstrated that Polypay ewes, derived from crosses among Dorset, Rambouillet, Targhee, and Finnsheep, had better out-of-season fertility than several of the component breeds and crosses. Conversely, breeds such as the Suffolk, Hampshire, and Columbia generally are poor out-of-season breeders (Dufour, 1974; Jeffcoate et al., 1984).

Breed differences in responsiveness of ewes to ram effect may contribute to differences in out-of-season breeding. Ewes of Merino type (including American Rambouillet) and most Mediterranean breeds are highly sensitive to ram effect, especially in summer. Nugent et al. (1988) reported that Dorset ewes responded to ram effect in both May and June, whereas Hampshire ewes responded in June but were much less responsive than Dorsets in May. Breed differences in the ability of males to elicit ram effect have been reported. Dorset rams were more effective than Romney rams in inducing estrus in New Zealand Romney ewes (Tervit and Peterson, 1978; Knight et al., 1980). Nugent and Notter (1990) also reported that ewes exposed to Dorset rams lambed earlier than ewes exposed to Suffolk rams. Breed differences in performance in accelerated lambing have also been reported. Notter and Copenhaver (1980) reported that with three lambing opportunities every 2 yr, Finnsheep x Rambouillet ewes lambed more frequently than 25%-Finnsheep, 75%-Rambouillet ewes; Suffolk x Rambouillet ewes lambed least frequently.

Few studies have measured heterosis for traits associated with seasonal breeding. Dufour (1974) reported that ewes of 50% Dorset, 25% Leicester, and 25% Suffolk breeding had a longer breeding season than any of the component breeds, but some selection may have occurred within the crossbreds. Quirke et al. (1988) reported that the breeding season of crosses between Dorset, Rambouillet, and Finnsheep averaged only 9 d longer than that of the purebreds, and Clarke (1985) observed that fertility of Finnsheep x Dorset ewes in April and May was slightly inferior to that of the purebreds. In the male, Whiteman (1976) reported that Suffolk x Hampshire rams settled more ewes than rams of the parent breeds in summer, but not in autumn.

There is perhaps little reason to anticipate heterosis for duration of the breeding season in the sheep. In each breed, natural selection is anticipated to have resulted in establishment of a pattern of breeding behavior appropriate to the evolutionary history of that breed. Genetic mechanisms which control the breeding season are not understood, so strong predictions cannot be made about length and timing of breeding in crossbreds.

Development of Breeding Programs

Breeding programs for out-of-season or accelerated lambing generally involve some sort of terminal sire crossbreeding program. Breeds with the greatest capacity for out-of-season breeding are generally moderate in size and growth rate and relatively early maturing. Increases in lamb value can be attained by crossing such ewes to rams of larger later-maturing breeds to increase growth rate and leanness.

The typical terminal sire breeds (e.g., the Suffolk, Hampshire, Columbia, and Texel) are generally poor out-of-season breeders and not optimal as ewe breeds in out-of-season or accelerated lambing. However, rams of even these seasonal breeds usually do not become completely sexually inactive during spring and summer and, if carefully managed, can often be used in crossbreeding throughout the year. Certainly, when rams of seasonal breeds are used, breeding soundness and serving capacity tests should be administered, ram:ewe ratios should be increased, rams should be equipped with marking harness to monitor mating, and multiple-sire breeding pastures should be favored.

An important decision in designing breeding programs will be whether to use breeding rams of less seasonal breeds such as the Dorset instead of rams of larger, but also usually more seasonal, meat breeds. Use of rams of less seasonal breeds may enhance fertility but can reduce lamb growth rates and carcass value. This decision likely will be influenced by the prevalence of other factors that may potentiate unfavorable light conditions, including high temperature, high humidity, little access to shade, and difficult, extensive grazing conditions. As the number of seasonal stress factors goes up, the potential value of less seasonal sire breeds also increases, as does the need for more intensive management of breeding rams.

Selection

Selection to reduce seasonality in a fixed annual season or to improve overall performance in accelerated lambing presents unique challenges relative to other genetic improvement programs. While principles of genetic improvement are common to all traits, their application is more difficult for complex reproductive traits.

Annual, out-of-season lambing.

Genetic improvement of fertility in spring and summer requires that animals be allowed to express genetic differences in fertility, whereas profitable sheep production dictates that every effort be made to maximize reproductive performance. Thus, breeding programs directed at genetic improvement usually involve two phases: 1) a challenge phase, in which animals are given the opportunity to express genetic differences, and 2) a clean-up phase in which animals that do not become pregnant in the challenge phase are given a second opportunity to conceive under either more favorable environmental conditions or more intensive reproductive management.

The objective of the selection is to improve performance during the challenge phase to a level that will allow clean-up matings to become unnecessary. Further, the clean-up phase must be designed so that it will not have a negative impact on ewe performance in next year's challenge phase. Figure 4 shows a scheme for a primary spring breeding followed by late-summer clean-up matings. In addition, the primary spring mating is structured to allow discrimination between ewes that are naturally cycling at the start of mating and those that are induced to cycle by ram effect. Early weaning (at 45 to 60 d) of lambs from clean-up matings provides ewes with adequate time to recover from lactation and express their rebreeding potential at the next spring mating. Dzabirski and Notter (1989) found that Dorset ewes lambing in January were less likely than ewes that lambed in October to cycle spontaneously in the following April, but did not differ from ewes that had lambed in October in mean fertility or lambing date.

This design was used at Virginia to develop animals with increased fertility in May and June (Al-Shorepy and Notter, 1996, 1997; Notter et al., 1998). In the early years of the project, when mean fertility of adult ewes averaged about .5, all ewes were exposed to several vasectomized rams in a single group for 2 wk before the start of the May breeding. As mean performance improved, use of teaser rams was eventually discontinued and ewes were isolated from rams before breeding. Under this protocol, shown in Figure 4, ewes that lamb in the first 2 wk of the lambing season were assumed to have been cycling at the time of ram introduction and were favored in selection. Later-born lambs were more likely to have been born to ewes that responded to ram effect and were discriminated against, particularly in choosing male replacements.

The schedule shown in Figure 4 is preferable to leaving rams with ewes until the start of the next natural breeding season. Ewes can be isolated from rams during July and thereby respond to ram effect when rams are reintroduced in August. Continuous ram exposure can cause ewes to become desensitized to ram effect, reducing fertility in clean-up matings.

An alternative plan for the clean-up phase (Figure 4) would be to use some sort of pharmacological treatment on ewes at the end of the challenge phase. Such a strategy must be designed with care to avoid negative effects on ewes that become pregnant early in the challenge phase, but treatments involving melangesterol acetate, controlled lighting, or melatonin supplementation would potentially be useful. This sort of intensive treatment during the clean-up phase will likely be required if ewes are to be bred before August. Results in the Virginia Tech selection project suggest that most ewes that conceive during the challenge phase do so within the first 30 d of breeding (D. R. Notter, unpublished); ewes that are not cycling spontaneously and do not respond to ram effect in May appear unlikely to begin cycling in June. In that experiment, treatments to stimulate clean-up matings could have been imposed by June 1 without compromising selection.

A particular concern in annual out-of-season lambing programs is how to best introduce replacement ewe lambs to the system. Fertility of autumn-born ewe lambs exposed in spring to lamb for the first time at 12 mo of age is almost always poor, yet these are the animals that are expected to be genetically superior as adults in out-of-season breeding. Notter et al. (1998) reported that selection increased fertility of adult ewes in May to over 80% but that fertility of 7-mo-old selected ewe lambs averaged only 15% and had not responded to selection. Under the scheme shown in Figure 4, most ewe lambs will lamb for the first time in January at 15 mo of age. Care is required in managing these animals to maximize their probability of rebreeding. They should be separated from adult ewes and weaning of lambs should occur as early as practical.

Matings during the challenge phase usually involve single-sire breeding pastures to provide pedigree information used in genetic evaluation. Careful evaluation of ram breeding status is critical to avoid infertile rams with associated loss in information about ewe genetic merit. At Virginia Tech, 7-mo-old fall-born ram lambs did not show the same problems in breeding that were observed in ewe lambs. In most years, a few ram lambs were sexually inactive based on serving capacity tests, but among males that passed serving capacity and breeding soundness exams, fertility did not differ between ram lambs and older males, albeit at low ram:ewe ratios of about 1:15.

Direct selection in males for reduced seasonality, or for other reproductive traits that may be associated with seasonality, is also possible. Sheep breeds differ in their ability to elicit the ram effect, and individual animal differences likely also exist. However, very few studies have documented effects of selection to improve male fertility in sheep. Direct selection of males for fertility in spring and summer matings is generally not feasible because relatively few males are actually used in breeding. Instead, some sort of screening procedure such as the serving capacity tests described by Perkins et al. (1992) must be used. Selection of males could directly improve breeding capacity of the male in spring and summer (Perkins and Fitzgerald, 1994) or could result in correlated changes in female traits associated with seasonality. Thus when Haley et al. (1990) selected for rapid early testicular growth relative to body size in males, daughters of selected males were observed to have an earlier date of onset of the breeding season.

Requirements for data recording in annual lambing programs are relatively straightforward. Breeding records must be maintained, along with information on which ewes lamb and their date of lambing to allow discrimination among ewes that lamb to matings during the challenge phase, the clean-up phase, or not at all. Records on ewe disposals or deaths are required to account for animals removed from the flock between breeding and lambing. The number of lambs born should be recorded; ovulation rates are normally reduced in spring matings, and animals that produce multiple births may be less seasonal than those that produce singles (Al-Shorepy and Notter, 1996). Records of birth weights are recommended; low birth weights and associated increases in lamb mortality in autumn lambs can occur in some environments and have a significant maternal genetic component (Al-Shorepy and Notter, 1998). Other characteristics (body weights, wool characteristics, etc.) should be recorded as needed to support genetic improvement in other economically important traits.

Most sheep recording programs permit, but do not require, detailed recording of mating and ewe disposal dates. The U.S. National Sheep Improvement Program (NSIP) encourages breeders to report complete mating and ewe disposal information, but many breeders focus on lambing rather than mating records when reporting data. Mating information on ewes that do not lamb is often missing.

Genetic analysis of reproductive traits in general and fertility records in particular presents a number of unique challenges. Most reproductive traits are lowly heritable, commonly 10% or less (Fogarty, 1995), but have reasonably high levels of variation which can support annual rates of improvement of 1 to 2% per year. Records of reproductive performance usually fall into one of a few distinct categories (e.g., pregnant or not; produced one, two, or three lambs; lambed during the challenge phase, clean-up phase, or not at all) rather than producing a continuous distribution of values characteristic of traits such as weaning weight or fiber diameter.

Categorical expression of performance (Figure 5) complicates discrimination among candidates for selection. The model commonly used for expression of categorical traits assumes that animals in the flock possess an underlying continuous distribution of lambing potentials. This underlying distribution of potentials is translated to the observed performance categories by invoking a series of thresholds. In Figure 5a, the 5% of ewes with the highest lambing potential have triplets, the 40% with the lowest potential have singles, and the remaining 55% have twins. The location of the thresholds is influenced by nongenetic effects such as ewe age. Thus the ewe lambs shown in Figure 5b have a similar distribution of lambing potentials to the adult ewes in Figure 5a, but a different set of thresholds, leading to different frequencies of multiple births.

In Figure 5, each category contains animals with substantial differences in underlying lambing potential. Only rarely will the number of replacements required correspond exactly to the number of individuals found in the most desired class(es). In Figure 5, selection of replacement males from those born as triplets would come close to maximizing intensity of selection for number born. But in choosing replacement females, some twin lambs will be kept while others will be rejected.

Comparison of animals in different age groups is more difficult for categorical traits than for continuously distributed traits. A ewe lamb with twins is, on average, better in terms of underlying reproductive potential than an adult ewe with twins, but the two groups overlap in term of underlying reproductive potential. Optimal solution to the problem of predicting genetic merit for these reproductive traits involves:

1. Application of relatively sophisticated statistical methodology to directly account for the categorical expression of most reproductive traits and to properly weight records made by ewes of different ages or evaluated under different conditions. These methods are not widely accessible, although they have been applied to genetic evaluation of calving difficulty in beef and dairy cattle.
2. Use of repeated records to increase the number of categories and thereby make it easier to discriminate among candidates for selection. Thus, if the data represented in Figure 5a were collected over 2 yr, there would be six outcome groups (single-single, single-twin, single-triplet, twin-twin, twin-triplet, and triplet-triplet) making discrimination easier, but still leaving the problem of deciding if a twin-twin or a triplet-single pattern is more desirable. [Note that in Figure 5a, the triplet-single pattern is slightly more desirable based on mean value on the underlying scale.]
3. Use of records of relatives to augment individual records and thereby make the distribution of records more continuous. This strategy is currently the basis for genetic evaluation in most programs, including NSIP, and also accounts for animals with different numbers of records.

Results presented by Notter et al. (1998) suggest that genetic improvement in spring fertility can be achieved without use of explicit categorical methodology, although use of these methods should accelerate genetic improvement. Vincent et al. (2000) also demonstrated that this selection was successful in lengthening the breeding season. Genetic evaluations for out-of-season fertility in a single annual breeding season would thus be relatively easy to incorporate into existing programs such as NSIP.

Accelerated lambing.
Genetic improvement of reproductive performance in accelerated lambing involves most of the issues discussed above for annual, out-of-season lambing as well as an array of additional issues involving the need for ewes to rebreed quickly after weaning lambs. Breeding seasons under accelerated lambing are usually short, with animals that do not become pregnant advancing to the next breeding season within a few weeks while animals that conceive go on to lamb and then return to breeding at a later date. Animals that do not breed in spring or summer accumulate, with most eventually conceiving at a late-summer or autumn breeding that effectively represents the "clean-up" matings of Figure 4.

Opportunities to use ram effect in accelerated systems are limited. In the STAR system (Figure 6; Hogue et al., 1980), ewes go into breeding 7 d after weaning their lambs and breeding seasons are only 30 d long, so ram effect must be generated by breeding rams. Because ewes responding to ram effect usually conceive 19 to 20 or 25 d after ram introduction, early lambing in accelerated systems requires that ewes be cycling at the start of breeding. Notter (1989) demonstrated that introduction of vasectomized rams before weaning did not advance the date of first estrus. Use of vasectomized rams of a lowly seasonal, high-libido breed such as the Finnsheep, Romanov, or Barbados Blackbelly in the breeding pastures might merit study. Care would be required to avoid dominance of the vasectomized ram over the intact breeding ram.

Selection and management of replacement females is particularly challenging in accelerated lambing. Ewe lambs born in autumn are anticipated to be genetically superior, but usually have very poor fertility in the next spring, and are unlikely to lamb at 12 mo of age. In the system of three lambings every 2 yr shown in Figure 7, autumn-born ewe lambs are unlikely to conceive until August at 11 mo of age. In contrast, most lambs born in January or April should be able to mate at 7 mo and lamb at 12 mo of age but, on average, are not expected to be genetically superior for out-of-season breeding. A solution to this conundrum is to use prior lambing records of the dams to identify superior spring-born lambs. In Figure 7, ewes that lamb in September are anticipated to next lamb in April. April-born daughters of these ewes can be retained and allowed to lamb for the first time the next April, and are then anticipated to be capable of good performance in later, out-of-season matings.

Recording of performance in accelerated lambing is a challenge. Accurate records of matings, lambings, and ewe deaths or sales are required to ensure that both successful and unsuccessful matings are properly recorded. Descriptions of accelerated programs such as those in Figures 6 and 7 generally indicate that all nonpregnant ewes are to be placed with rams at each mating season. However, this recommendation is not always followed; producers commonly modify systems to meet specific management and marketing goals. Thus in a system like STAR, ewes that lamb very late in one season may be judged to be unable to breed in the next available season and not exposed until a later season. Breeding of ewes may also at times be deferred for a season to even out numbers of lambs produced at different times. These decisions can cause ewes to fail to lamb on schedule, and unless mating records are scrupulously maintained, can result in ewes being improperly penalized for not lambing. Use of data from accelerated lambing in NSIP will likely require records of the starting and ending date of each mating period, of the ewes placed with rams in each period, and of all subsequent lambings.

Accurate ewe disposal records are also needed to ensure that ewes that die or are sold after breeding but before lambing are not entered into the data as open ewes. While such errors are not important to evaluation of the ewe herself, under most genetic evaluation systems, records of a ewe also impact the genetic evaluation of her relatives who may still be in the flock.

More factors influence performance in accelerated lambing than in annual lambing, and care must be taken to recognize, and in some cases adjust for, these factors. Since ewes are expected to rebreed shortly after weaning lambs, factors associated with the previous lactation may impact the ewes' condition and (or) physiological state of the start at breeding, thereby influencing subsequent fertility. Many of these factors are themselves under partial genetic control and may be influenced by selection to enhance reproduction. Time of previous lambing has important effects on current fertility. Thus ewes that did not lactate immediately before entry into breeding may be genetically inferior, since they missed at least one previous lambing opportunity, but have had more time to recover from their last lactation, which is expected to make them more likely to cycle and conceive. Even among ewes that are being rebred just after weaning, date of previous lambing may influence subsequent performance. Thus ewes that lamb late in one season are less likely to conceive at their next opportunity. Initial poor performance by such ewes thus places them in a situation that is conducive to repeated poor performance. Procedures to adjust for the non-genetic portion of this relationship, while not compromising genetic information, still need to be developed.

Selection for rapid rebreeding potential may have negative correlated effects on milk production because ewes that give less milk are anticipated to be in better condition at breeding. Similarly, ewes that can produce twins and triplets in autumn may be less seasonal than ewes that produce singles but the additional nursing stimulus of multiple lambs may affect rebreeding and subsequent ovulation rates. Genetic relationships involving these traits have not been determined, but it will be important in accelerated systems to evaluate ewes for the full spectrum of performance traits.

Perhaps the main complication to properly analyzing data from accelerated lambing systems is that the ewes are not maintained as a single contemporary group. Instead, ewes have different breeding patterns over time and these patterns depend on previous performance. After each breeding, the open ewes and the pregnant ewes follow different paths and subsequently end up in different breeding groups. Average genetic merit is thus expected to differ among ewes in different breeding groups. These differences should be accounted for in genetic evaluation but this requires application of relatively sophisticated methodology.

The issues of how to properly collect, adjust, analyze, and report data from accelerated lambing systems have not yet been adequately addressed. Lewis et al. (1998), in an analysis of the Cornell University STAR Dorset flock, reported that age at first lambing and the length of the first two lambing intervals were heritable traits which could be useful in genetic improvement. But lengths of later lambing intervals were not heritable, suggesting that cumulative environmental effects progressively complicated genetic evaluations in older ewes. Incorporation of these traits into NSIP was proposed (Notter, 1998) but has not yet been accomplished. The alternative of imposing a categorical genetic evaluation model to use results of all exposures for each ewe is likewise being considered but would require a substantial development effort.

Molecular Approaches to Reducing Seasonality

Use of molecular techniques to aid in identification of genetically superior individuals is appealing for traits involved in seasonal breeding. Direct selection for these traits is difficult. As noted above, a challenge phase of some sort is required to allow expression of individual differences in performance but, unless carefully managed and coupled with an effective clean-up phase, may reduce overall flock productivity and profitability. In addition, seasonality is difficult to measure in large numbers of males, effectively limiting expression of performance to ewes; low fertility in ewe lambs postpones evaluation of performance to the second and subsequent lambing opportunities; and heritability is low, even under the best of conditions. Under conditions of low heritability, with expression of the trait limited to one sex and to relatively advanced ages, the identification of DNA-based molecular markers would be advantageous, allowing results of DNA testing of animals of both sexes early in life to be used as a preliminary criterion to identify genetically superior individuals. Also, reliance on the challenge phase to identify superior individuals might be reduced, although probably not eliminated.

Two broad options exist for use of molecular information in genetic improvement of seasonality. The first involves direct identification of genes that control seasonal breeding and development of DNA tests to identify favorable variants at these loci. This approach has been taken for the deleterious Spider Lamb condition, and for the Booroola Fecundity gene. Both arise from mutations that can now be identified by DNA tests (Cockett et al., 1999; Wilson et al., 2001). The Invermay fecundity gene in New Zealand Romney sheep (Galloway et al., 2000) increases ovulation rate and results from a mutation on the X chromosome. Recent studies by Pelletier et al. (2000) and Notter et al. 2002 suggest that seasonality may be associated with genetic variation in the melatonin receptor gene.

An alternative strategy may be used when the location of a gene influencing performance is not known. This approach involves use of marker genes, bits of polymorphic DNA which do not themselves influence seasonality but which are known to be associated with genes that do, through proximity to these genes on a chromosome. However, marker genes normally differ among breeds and families within breeds, so reliable use of marker genes requires relatively extensive genotyping of animals in each flock. Marker associations can also be disrupted by recombination and thus must be periodically reassessed. Genetic markers have been identified for the callipyge gene (Berghmans et al., 2000), but the actual mutation has not yet been identified.

The cost of using molecular data in selection is modest, but the cost of locating genes or establishing genetic marker associations is substantial, especially when a gene of major effect is not already known to exist. Large numbers of matings with intensive evaluation of animals for traits of interest are required to identify useful genes or markers. Such investments have been made by some swine and poultry breeding companies but will be more difficult for the smaller, less-organized U.S. sheep industry.

Conclusions

Genetic differences in seasonal breeding patterns clearly are present among and within U.S. sheep breeds. Appropriate choices among ewe breeds and crosses, when coupled with careful management of breeding rams and use of the ram effect, can result in fertility levels of 50 to 70% in most seasons. Selection within breeds can further reduce seasonality but requires carefully designed evaluation programs to accurately identify superior individuals. Collection of data for evaluation of seasonality in industry programs such as NSIP is possible but will require detailed reporting of mating, lambing, and ewe disposal information.

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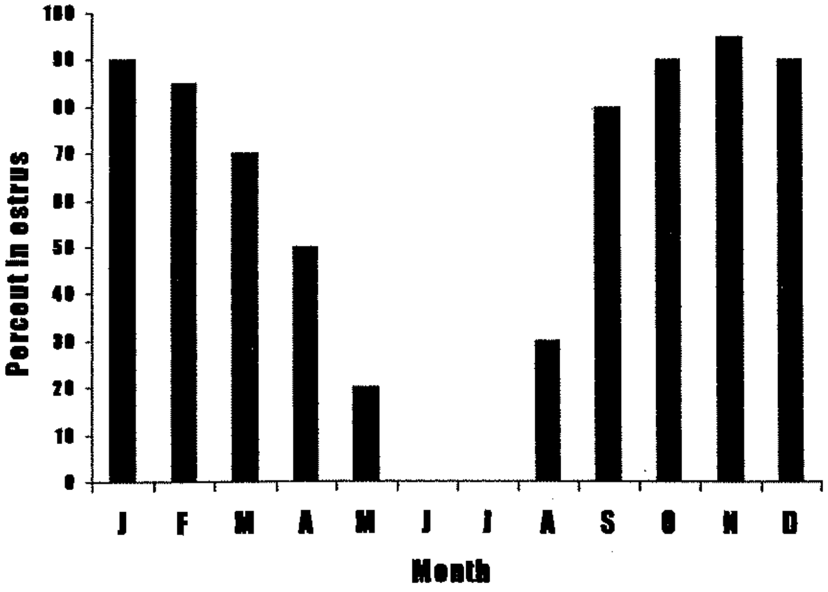

Figure 1. Anticipated proportion of ewes exhibiting estrus in different months (derived from results summarized by Notter, 1992).

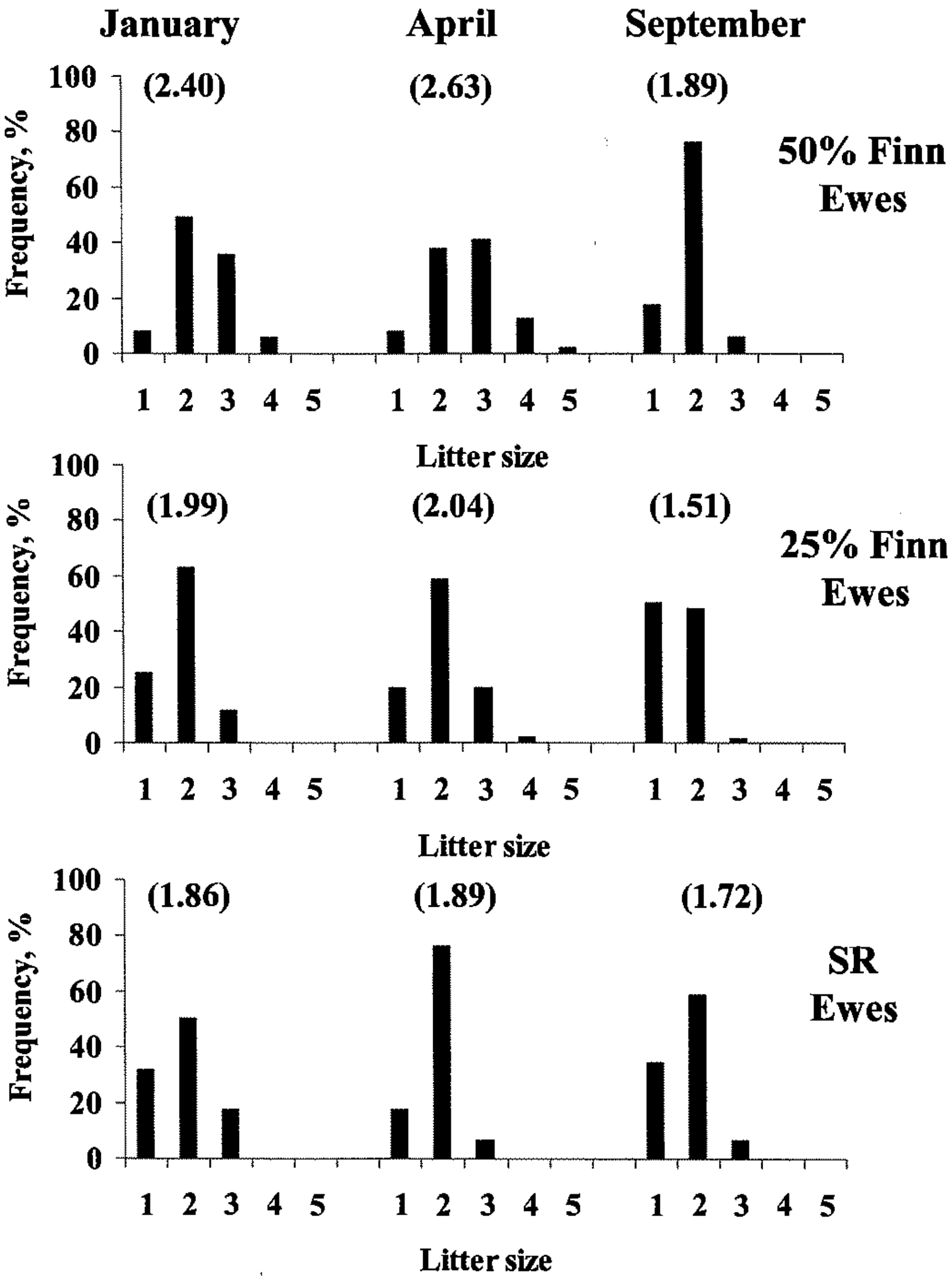

Figure 2. Distribution of litter sizes for 50% Finnsheep, 50% Rambouillet (top); 25% Finnsheep, 75% Rambouillet (center); and 50% Suffolk, 50% Rambouillet (bottom) ewes lambing in January, April, or September (from Notter and Copenhaver, 1980). Mean litter size is shown in parentheses for each season and breed type. ©J. Anim. Sci. 54:1039.

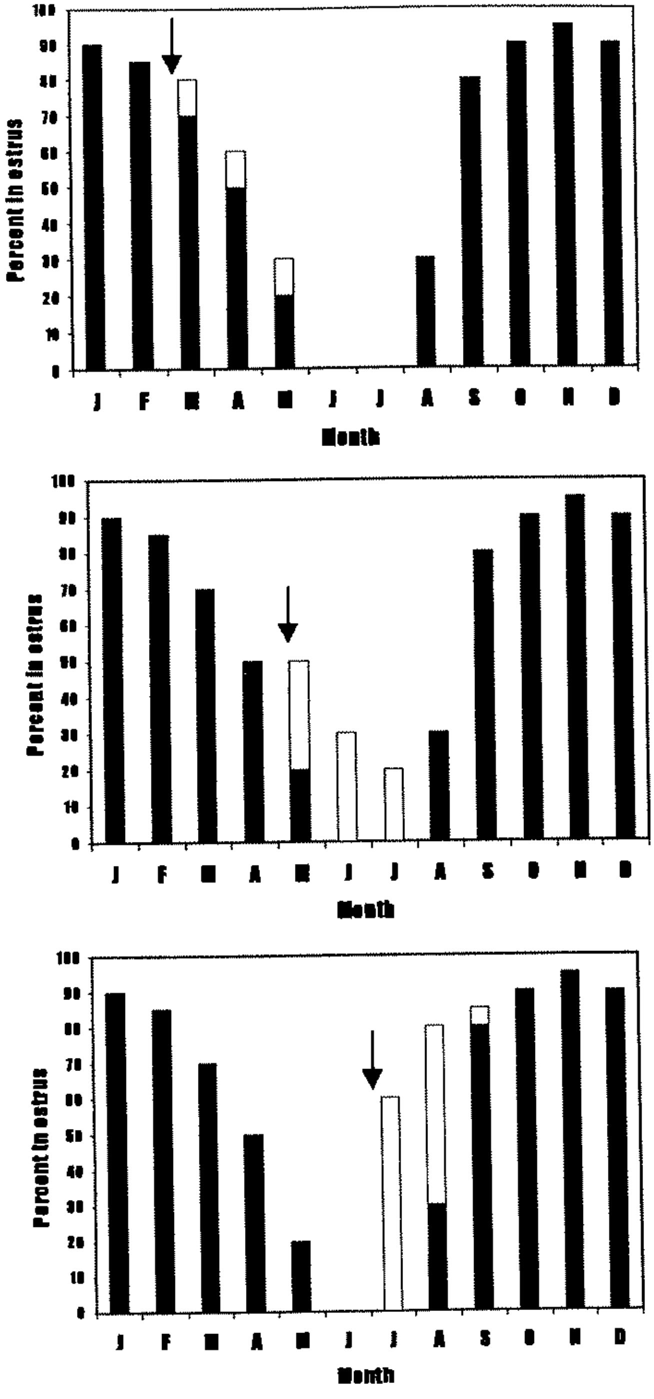

Figure 3. Anticipated effect of ram introduction at different times of the year on occurrence of estrus. Arrows designate the time of ram introduction. Closed bars show the frequency of estrus in ewes continually exposed to rams. Open bars show anticipated frequency of estrus with use of ram effect.

Month	Activity
Jan	
Feb	
Mar	Ram isolation
Apr	Ram isolation
May	Challenge breeding
June	Challenge breeding
July	Ram isolation
Aug	Clean-up breeding
Sept	
Oct	Challenge lambing
Nov	Challenge lambing
Dec	Challenge weaning (Dec. 20)
Jan	Clean-up lambing
Feb	
Mar	Clean-up weaning (Mar. 15) Ram isolation
Apr	Ram isolation
May	Challenge breeding
June	Challenge breeding
July	

or

Mar. 15-April 14	Ram isolation
April 15-30	Teaser rams

detail

Oct. 1-14	Lambs born to ewes that were cycling
Oct. 15-31	Lambs born to ewes induced to cycle by ram effect
Nov. 1-30	Lambs born to 2nd matings or to late responders to ram effect

Figure 4. A breeding schedule for evaluation of seasonality. This program assumes isolation of ewes from rams in March and April but can be modified as shown to incorporate use of teaser rams before breeding. The relationship between lambing date and ewe mating behavior is also shown in detail for ewes that were not teased before the start of breeding.

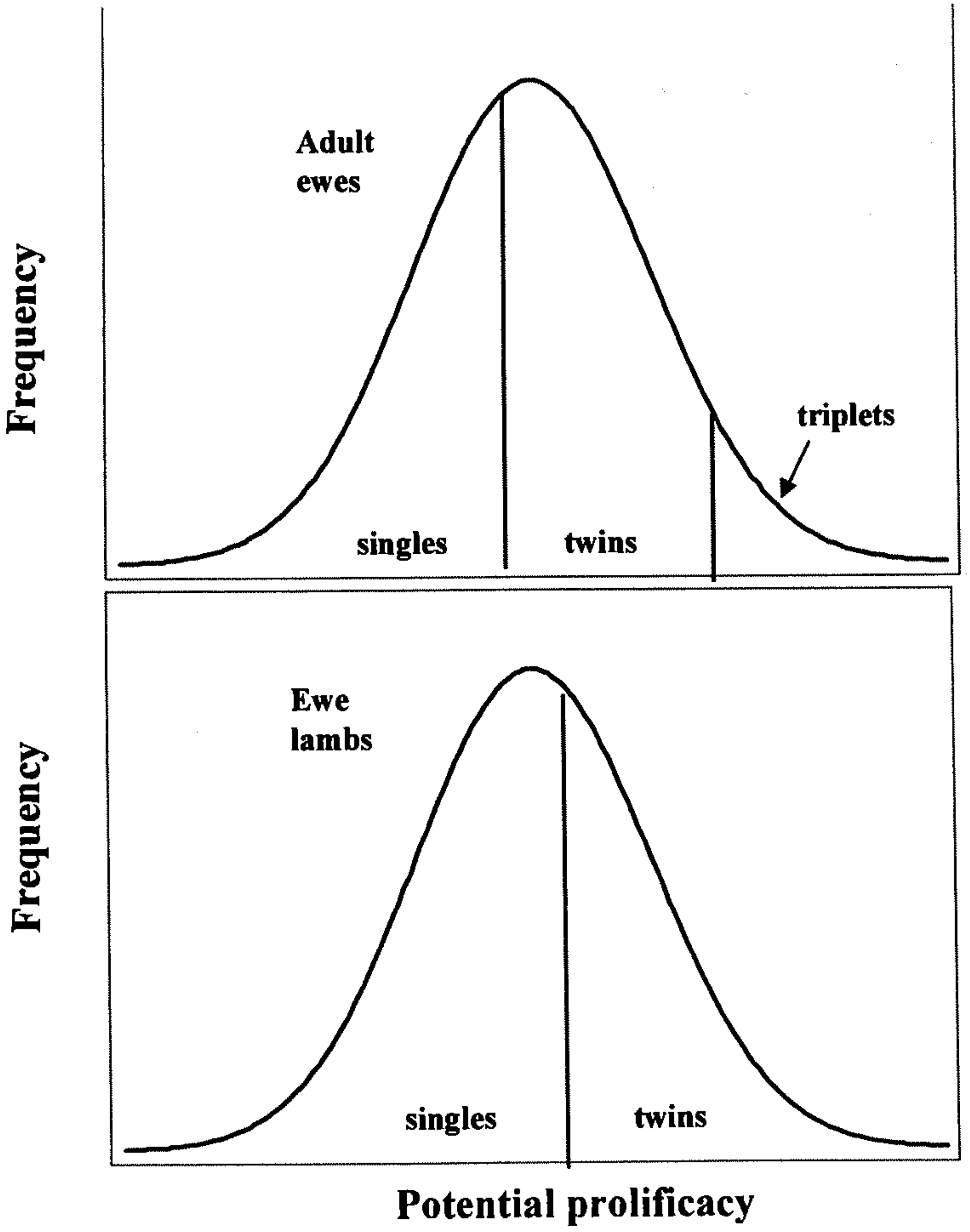

Figure 5. An example of categorical expression of a reproductive trait (litter size). Adult ewes and ewe lambs are assumed to have the same distribution of potential prolificacy on the horizontal axis. Animals that exceed critical levels (thresholds) in underlying potentials produce twins or triplets whereas remaining ewes produce singles. Effects of ewe age on litter size are produced by varying the location of the thresholds.

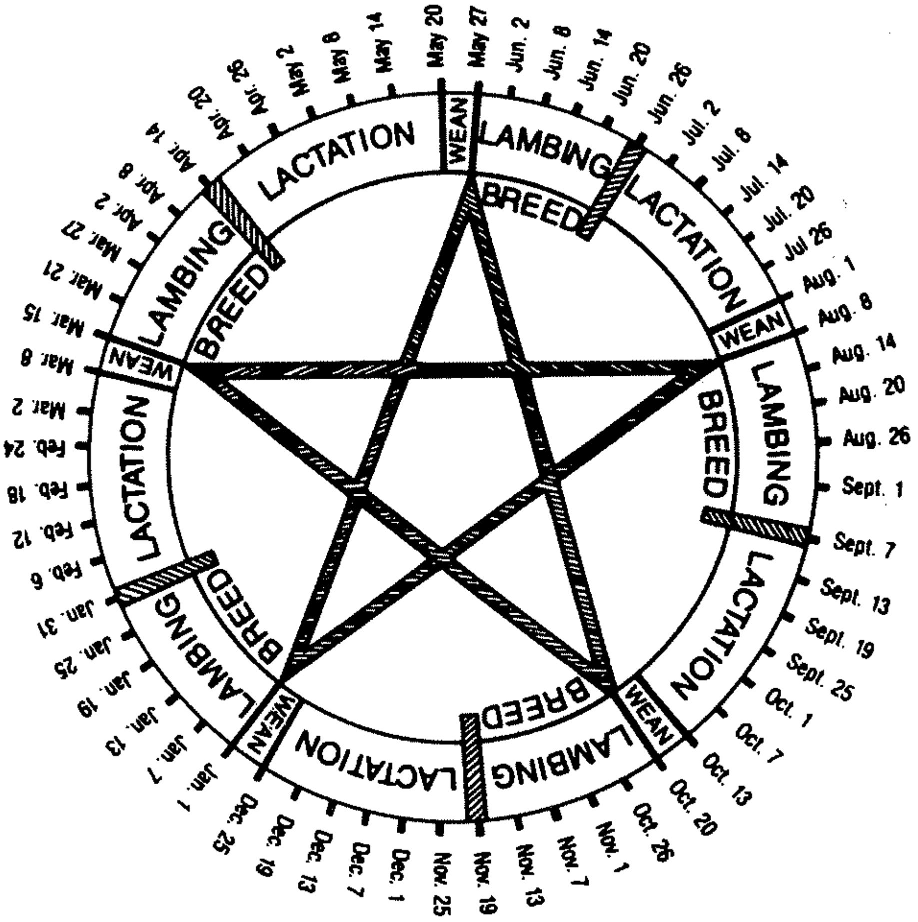

Figure 6. The STAR accelerated lambing system (Hogue et al., 1980). ©Cornell Research Foundation (1984).

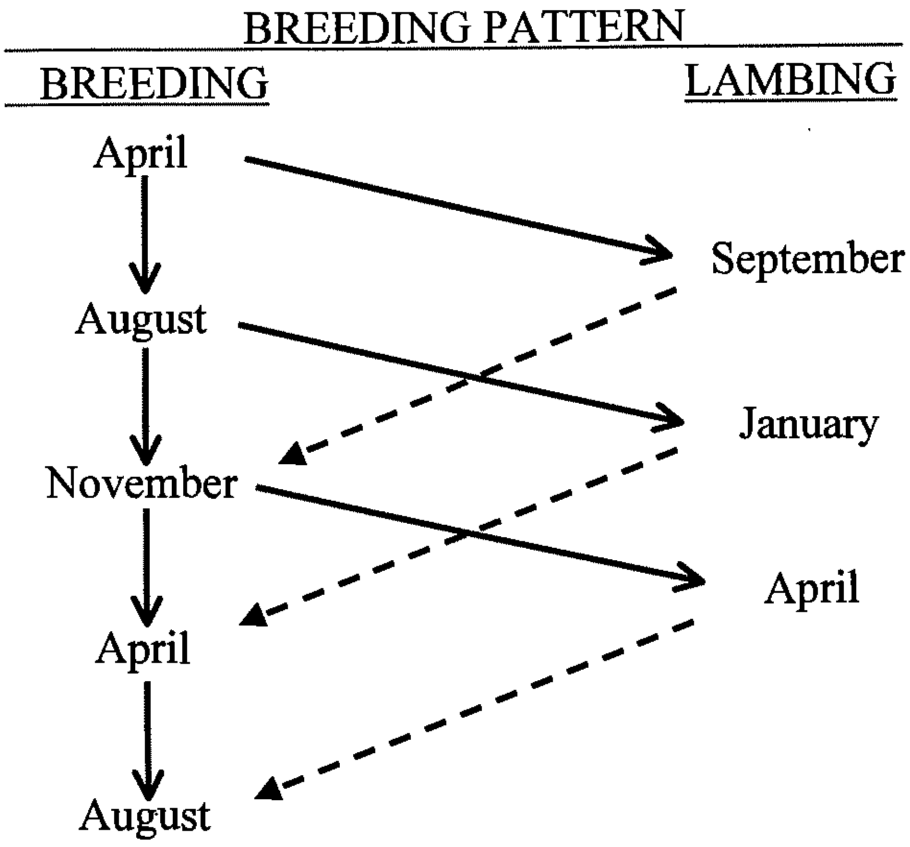

Figure 7. An example of a breeding schedule for three lambing opportunities in 2 years, from Notter and Copenhaver (1980). Solid lines designate the possible movement of open or pregnant ewes after breeding. Dashed lines indicate the pattern of return to breeding after lambing. ©J. Anim. Sci. 51:1034.

Strategies for Genetic Improvement of Carcass Value in Lambs

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Introduction

Improving carcass composition is one factor that can have an impact on lamb consumption and demand (Ward, 1995; Purcell, 1998). Increased size of cuts and decreased fatness are two factors that affect consumer acceptability of lamb (Jeremiah et al., 1993). The lamb producer that markets superior carcasses, with greater consumer appeal, expects to realize financial rewards from doing so. The expectation of greater income received from marketing superior lambs is motivation for producers to develop a strategy to improve carcass value through selection of genetically superior breeding stock. Using genetic selection to change traits measured on carcasses is different from many traits that can be measured on live animals because direct measurements are not available on the animals to be used for breeding stock. However, progress from selection on correlated traits can yield substantial changes over time.

The importance of increasing our knowledge of lamb carcass composition has been recognized for years. There were several publications from US scientists in the 1960's that addressed prediction of lamb carcass composition, (Field et al., 1963; Judge et al., 1966; Spurlock & Bradford, 1965) lamb carcass value, (Carpenter et al., 1964; Carpenter et al., 1969; Cunningham et al., 1967) and genetic selection for improvements in carcass traits (Botkin, et al., 1969; Bradford, 1967). These US publications were preceded by earlier work of scientists in New Zealand (Barton and Kirton, 1958; Kirton and Barton, 1962; Kirton et al., 1962) and the UK (Bichard and Yalcin, 1964; Bowman et al., 1968). The 57th Annual Meeting of the American Society of Animal Science, held in 1965, included an invited presentation by Dr. G. E. Bradford (1967) titled: "Genetic and economic aspects of selecting for lamb carcass quality". The working definition of quality in this paper was "percent of lean meat, especially in the preferred cuts, and having desirable eating quality." One of Dr. Bradford's conclusions was "... significant genetic improvement in lamb carcass quality will depend upon the development of reasonably accurate live animal measures of carcass quality."

Considerable developments have occurred in the technology available to measure body composition in live animals. However, the change in carcass composition of US lambs has been limited. Although the technology to measure body composition is available, the financial incentive to make genetic improvement in body composition has not been large enough to encourage breeders to place much emphasis on carcass traits. Therefore, the issue of genetic improvement of carcass composition involves not only genetics and measurement of body composition, but also economics. Nsoso et al. (1999) reviewed several aspects of selection for growth and carcass composition. The purpose of this paper is to review issues relevant to developing a strategy for US lamb producers to select for improved carcass value in lambs.

Determinants of Carcass Value

There are several factors that determine carcass value: carcass weight, composition of carcass (% lean, fat, and bone), pelt condition, animal health, etc. Carcass weight and composition are influenced, in the short term, by choice of feeding regimen, and, in the long term, by choice of breeds and animals within breeds. In general, as weight increases, animals get fatter. However, selection for animals that will produce a heavier carcass while maintaining desirable composition can be accomplished with the use of multiple-trait selection. The response to selection for any one trait depends on the extent to which the trait is under genetic control, the amount of variation, and the accuracy of predicting genetic merit for the trait from the available phenotypic measurements. Response to selection for multiple traits is also a function of the quantitative relationship between the traits. Selection for carcass traits is hindered by the fact that carcass measurements are not available from animals that are candidates for selection. Therefore, genetic merit of the candidates for selection must be predicted from carcass measurements of related animals, or from correlated traits that can be measured on live animals.

Because of the differences in value of the different cuts from a lamb carcass, increases in proportion of lean in the higher value cuts would lead to greater carcass value. Breed differences, and within-breed genetic variation, for distribution of lean tissue within a carcass have been studied by Wolf (1982). He reported heritability estimates ranging from .15 to .46 for proportion of total carcass lean in specific cuts. However, the coefficients of variation were generally low when heritability estimates were high. The difficulty in measuring lean tissue distribution in live animals and the cost of measuring it on carcasses indicate that lean tissue distribution is not likely to be changed by traditional quantitative genetic methods. The Callipyge gene reported in US sheep in the 1990's (Freking et al., 1998) does result in a desirable change in tissue distribution. However, undesirable effects on meat quality/tenderness (Duckett et al., 2000) have prevented widespread industry acceptance and use of the Callipyge gene. The substantial change in the size of some muscles due to the Callipyge gene has the potential to impact the lamb industry. The effects of this single gene, which can be realized in one generation, are greater than what could be produced by several generations of selection in the absence of a major gene. While work is being conducted to address the meat quality issue, the lamb industry should also pursue other genetic means of improving carcass value.

The selection objectives of increasing carcass weight and improving carcass composition should be considered together because an increase in carcass weight coupled with a decline in composition, or improved carcass composition (greater % lean and lower % fat) coupled with a lower carcass weight may not result in a net gain in carcass value. Bradford & Spurlock (1972) concluded that weight per day of age is the single best selection criterion for increased lean meat production per animal. This conclusion is supported by high genetic correlation estimates among live weight, carcass weight, and lean or fat-free weight (Bennett et al., 1991; Waldron et al., 1992) from New Zealand studies. However, other selection criteria can be used to alter body composition while selecting for improved growth rate. The correct balance between selecting for more lean tissue and greater growth rate versus less fat tissne and improved carcass composition should be determined as a function of the relative economic value of changes in these traits. The value-based New Zealand lamb market has been shown to financially reward heavier carcasses and penalize fat carcasses (Waldron et al., 1991). It is anticipated that the US lamb market will become more value-based in the future as advances in information technology allow for more carcass data being used to assess value and communicate that value to the producer through financial incentives. Consumer's preference for cuts of lamb is affected by fatness (Jeremiah et al., 1993) and even though the prices paid to US producers do not indicate a strong financial disincentive for overfat lambs, continued production of overfat lambs may lead to a further decrease in consumption of lamb. Therefore, lamb producers and sheep breeders who are making genetic improvement in lamb growth and carcass composition will be positioned to realize the rewards available in a value-based market and they may help the sheep industry to produce a superior product that will build demand.

How then should we select toward the goal of increased growth rate and improved composition?

Measurement of Composition on Live Animals

Substantial resources have gone into research and development of methods of prediction of lamb carcass composition from live animal measurements over the last 35 yr. A goal of live animal measurement is to predict carcass traits that are determinants of carcass value.

Which method(s) of prediction will have an impact depends on accuracy, cost, and availability. The live-animal measurements that have the greatest potential are: real-time ultrasound (RTUS), bioelectrical impedance analysis (BIA), magnetic resonance imaging (MRI), and x-ray computed tomography (CT). A review by Stanford et al. (1998) of published research on these methods concluded that the relatively higher costs of MRI and CT will prohibit their use on large numbers of animals. Because genetic merit is evaluated from a combination of the animal's own record and the records of related animals, not having large nnmbers of records on related animals is a disadvantage for these two methods, even though CT and MRI have advantages in accuracy. Unless there are substantial changes in the cost of CT and MRI, they are unlikely to have an impact on the US sheep industry. However, in countries where genetic gain in carcass traits can be spread to a larger population of lambs to be slaughtered, CT has been used for evaluating body composition in elite rams (Simm, 1992; Jopson et al., 1995). Jopson et al. (1997) estimated a positive return on investment for using CT scanning on a 1400-ewe nucleus flock and rapidly disseminating the improved genetics to a large (100,000 ewes) commercial flock. Young et al. (1999) have identified scanning positions that provide for accurate prediction of carcass components using multiple scans.

Both, BIA and RTUS are less expensive and more portable than CT and MRI and therefore obtaining measurements on a large number of animals is more feasible. Bioelectrical impedance analysis uses the difference in electrical properties of the different tissues in the body. Berg et al. (1998) reviewed several studies where BIA measurements were used along with carcass weight to predict carcass composition. Generally, the BIA information reduced residual variation after carcass weight was taken into account, but Slanger et al. (1994) reported that using carcass weight and 12th rib fat was as useful as carcass weight and BIA information for predicting total weight of retail-ready cuts. Jenkins et al. (1988) reported similar results, where the predictive value of BIA information was similar to that of a carcass fat depth measurement. The use of BIA in live animals has been evaluated by Slanger et al. (1994) who reported lower precision when using BIA in live lambs relative to carcasses, while the results of Berg and Marchello (1994) showed live animal prediction equations to have R2 values similar to the carcass equations. However, BIA does not provide information about the distribution of lean or fat within a carcass.

The cost of CT scanning in the analysis of Jopson et al. (1997) was 90 times the cost of RTUS scanning. Because of the lower cost of RTUS scanning, and the availability of portable RTUS machines, RTUS has the greatest potential to impact selection practices for improved carcass value. The lower cost of RTUS, compared to CT, must be weighed against the lower accuracy. The lower cost makes it feasible to measure more animals and collect repeated measures on the same animal. The accuracy of measurements obtained from RTUS images has been reviewed by Houghton & Turlington (1992) and was reported to be influenced by the ultrasound equipment used and the skill of the operator. The technology of the equipment and quality of images available has increased since the 1950s and therefore not all research results are directly comparable. In a summary of reports from 1977 to

1989, Wilson et al. (1992) found that ultrasound fat measurements were more often reported to be useful in predicting carcass composition than ultrasound muscle measurements. Genetic evaluations in beef cattle have used measurements from carcasses and ultrasound measurements. The trend seems to be toward making more use of ultrasound measurements because of the ability to get measurements on more animals and a broader range of animals (Wilson et al., 2000). Therefore, the use of RTUS of live lambs appears to have more potential to impact selection practices for improving carcass value than other methods.

Selection Objective

To increase carcass value at a given age of lamb, the weight of lean tissue (muscle) should be increased and the weight of fat tissue decreased. The relative emphasis of these two components should be a function of the relative economic values. Historically, the US lamb market has not paid financial incentives for differences in carcass composition. It is anticipated that as the technology becomes more affordable to record measurements on individual carcasses and use that information to calculate returns to the producer, a value-based marketing system for lamb will become a reality in the US. Therefore, breeders interested in improving carcass value should consider the relative economic values of the future when choosing a selection objective. Because the future is uncertain, consequences to different selection strategies should be evaluated.

Responses to Selection

Clarke et al. (1991) illustrated how the responses to selection for improved carcass value are influenced by the choice of relative economic values for increasing lean and decreasing fat. They reported that selection on live weight at a given age would result in a greater increase in lean compared to fat. Therefore, because lean would increase more than fat, the result is an improvement in percent lean. However, increasing emphasis on selection against fatness, by including additional selection criteria, will lead to greater improvements in carcass composition, but will also result in smaller gains in weight of lean tissue. The goals of decreasing fat and increasing lean must therefore be balanced. The balance can be achieved by using other selection criteria along with live weight. Live weight at a given age is an indicator of growth rate in all three of the primary components of a carcass: lean, fat and bone. Additional selection criteria should be chosen such that they add predictive value for composition. Traits that are positively correlated with one component but independent of, or negatively correlated with, the other components can more effectively discriminate between heavy lambs and heavy, lean lambs.

The high correlation between live weight and weight of lean is due to the part-whole relationship between the traits. Live weight is the single most important trait in selecting for improved carcass value. Live weight is also easy and inexpensive to measure. In order to be effective in increasing carcass value, additional selection criteria must improve the accuracy of prediction of carcass components above that which can be predicted by live weight alone. To be used on a significant portion of the population, the additional trait must be able to be measured inexpensively on a large number of animals. The American Angus Association has calculated genetic evaluations for carcass traits from carcass records of steers. A second genetic evaluation for carcass traits is calculated from RTUS measurements primarily from heifers and bulls (Wilson et al., 2000). It appears that the evaluations calculated from the RTUS are becoming increasingly more valuable than the evaluations calculated from the carcass data because the benefit of using a much larger number of records is greater than the loss due to the lower accuracy of RTUS measurements relative to physical carcass measurements. A single carcass measurement is more valuable than a single RTUS measurement. But, the most significant limitation of carcass data is that it is only available on a subset of the non-breeding animals. Therefore, for genetic evaluation of carcass traits for a breed, RTUS appears to have more potential than carcass measurements.

Which Traits to Use in Selection?

Partial genetic correlations with lean and fat were calculated for combinations of selection criteria (Waldron et al., 1992). The results indicated that among the carcass measurements evaluated, longissumus muscle width was the most useful measure to use along with carcass weight to select for increased carcass value. However, measuring longissumus muscle width accurately by RTUS is difficult because the boundaries between muscle and fat are parallel to the sound waves and RTUS is more suited for showing boundaries that are perpendicular to the sound waves. Several external carcass fat measurements showed to be useful selection criteria in selecting for increased carcass value. Fat depth over the longissumus muscle was the best external carcass fat measurement in terms of selecting for increased carcass lean and decreased carcass fat. Because the boundary between fat and muscle for the measurement of fat depth is perpendicular to the sound waves, fat depth can be measured more accurately than muscle width. Therefore, RTUS measurement of fat depth appears to hold the most promise in improving carcass value. Because RTUS-measured fat depth has strong positive genetic correlations with total carcass fat content (Waldron et al., 1992), leaner carcasses are expected from selection on live weight and RTUS fat depth. Selecting for lower fat depth along with greater live weight is expected to result in more lean tissue and less fat tissue and thus, improved composition (Waldron et al., 1992).

The study reported by Waldron et al. (1992) did not evaluate RTUS muscle measurements. The benefit of including carcass muscle measurements after carcass weight and fat depth are taken into account is small (Bennett, 1991). But, because the marginal cost of obtaining an additional muscle measurement from a RTUS image is small, it is sensible to use the information in calculating genetic evaluations for carcass value. Muscle depth is the muscle measurement that is best suited to RTUS because the boundaries of interest are perpendicular to the sound waves. However, longissumus muscle area and the product of muscle depth and width measured on carcasses are predicted to result in a greater response in carcass value (Waldron et al., 1992). More work is required with modern RTUS equipment to determine the best RTUS muscle measurement to use.

The relative emphasis to place on each of the selection criteria, live weight, fat depth, and longissumus muscle area or depth, should be chosen so that the expected response in carcass value is maximized. New Zealand lamb price schedules indicated that the greatest economic response to the producer called for a relative economic value of 1.25 for increased weight of lean when the value of fat was set at −1 (Waldron et al., 1992). Greater emphasis on increasing the weight of lean will lead to heavier lambs, but not as much improvement in composition. The survey reported by Ward et al. (1995) indicated that improving composition by decreasing fat content is an important factor in efforts to increase lamb consumption. This indicates that more emphasis should be placed on improving composition. The proper balance of selection pressure between increased growth and improved composition depends on customer preferences (consumer or packer) and characteristics of the production and marketing systems (Bennett, 1990). A complete discussion of relative economic values is beyond the scope of this paper.

Application to US Seedstock Industry

Although it is expected that financial incentives for improved carcass value will be seen in the US in the near future, selection on carcass value only is not recommended for all breeds. Greater carcass value may be the primary selection objective for breeds used as terminal sires in crossbreeding programs. However, reproductive rate and adaptability to environmental conditions are important traits for the ewe flock that produces slaughter lambs. Dual-purpose breeds will also need to consider the selection emphasis placed on wool traits.

One factor that limits progress toward selecting sheep for improved carcass value is the low level of performance recording. Performance recording in other countries and other species has been adopted when an economic benefit was perceived. The US lamb market has not provided enough economic incentive to entice lamb producers to invest more in genetic improvement for carcass traits (Purcell, 1998). If the US lamb industry is to grow in the future, it must deliver a product to the consumer that is more desirable. Unfortunately, the present marketing system does not efficiently communicate consumer preferences (Williams & Davis, 1998) to those that are generating breeding stock. Therefore, lamb producers may need to make the first move toward producing and marketing lambs that meet consumer preferences, even if they are not financially rewarded in the short term. Improved communication from the retail consumer through the processor to the producers and breeders would help facilitate change toward larger, leaner carcasses.

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Relationships Among Traits: Growth Rate, Mature Size, Carcass Composition and Reproduction

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Genetic variation in any one trait is often associated with variation in other traits. Thus successful selection for one performance trait may impact other traits affecting efficiency of production. The correlated changes may be favorable or unfavorable, depending on the nature of the genetic relationships among the traits and the contribution of each to production efficiency.

Size and carcass composition.

Average carcass weight of federally inspected lambs slaughtered in the US has increased from 50 lb. in 1968 to 66 lb. in 1998. The principal reason for this trend is apparently packer demand. It costs little more to slaughter and process a lamb producing a 65 lb. carcass than one producing a 50 lb. carcass, and thus the cost/lb. is less for the heavier lamb. Heavier lambs are on average fatter, and fatter lambs in general have a higher dressing percent. The latter is an additional factor in packer preference for heavier lambs.

This shift in carcass weight has important ramifications for the sheep industry, because of basic relationships among growth rate, mature size, carcass composition and adaptability to production environments.

Heavier carcasses can be obtained from lambs of larger breeds, or by feeding animals of smaller breeds for a longer period before slaughter. These two approaches will lead to quite different carcass composition and thus consumer acceptance of the product.

The most important variable in carcass composition is fat content, a trait with an intermediate optimum. Some fat is necessary, for eating quality and for carcass firmness and keeping/shipping quality, while excessive fat reduces consumer acceptance and is usually more expensive to produce.

The proportion of fat in carcasses of continuously grown animals differs to some extent between breeds and sexes, but is most influenced by degree of maturity, i. e. percent of mature weight at slaughter. On average, it is estimated that wether and ewe lambs will have optimum finish (fatness) if slaughtered at 70% to a maximum of 75% of the mature weight of dry ewes (in good condition, condition score 3.0 to 3.5 on a 1 to 5 scale) of their breed or cross. Sakul et al. (1993) calculated equations for predicting carcass fat depth and fat % from slaughter weight, using wether lamb data from crosses of performance-selected Rambouillet and Targhee sheep. Assuming a mature ewe weight of 150 lbs. for such sheep, the recommended lamb slaughter weight would be 105 to 112 lbs., yielding carcasses with about 0.2 in. of backfat and 24-25% fat in the carcass, i. e. yield grade 2. If ewes of a 150 lb. breed are bred to rams of a breed with mature ewe weight of 200 lbs., average parental breed weight will be 175 lbs., and estimated optimum slaughter weight would be 122 to 131 lbs. If slaughtered at heavier weights, they are likely, on average, to be overfat. Since the mature weights used in these examples represent breeds towards the upper end of the size of currently available breeds, it is suggested that lambs slaughtered at weights much above 130 lbs., currently a common practice, are likely to be fatter than desired for optimum consumer acceptance.

Lambs fed to higher degrees of maturity will also, on average, require more feed per pound of gain. However, current low grain prices minimize the economic impact of this effect. Cheap corn has undoubtedly contributed to the observed increase in lamb slaughter weights.

It should also be noted that variation in the growth pattern of animals due to variation in level of nutrition during the growing period can affect carcass composition. Lambs grown out relatively slowly for an extended period will tend to be leaner at a given weight than lambs which continuously grow rapidly, and thus some of the heavier weight lambs currently being marketed may have desired degtee of leanness at weights above the guidelines indicated above. The choice of such a system of production is usually determined by seasonal variation in cost or availability of feed. A disadvantage of this means of producing animals that are lean at heavy weights is that periods of slow growth increase the total feed required for a given amount of meat produced, because of the longer maintenance period.

The relationship of degree of maturity to carcass fatness of continuously grown animals indicates that producing heavier carcasses by feeding lambs of small or intermediate sized breeds to heavier weights is not a good option. In the experiment reported by Sakul et al. (1993), carcasses from lambs sired by the smallest sire breed had the highest fat content when all lambs were slaughtered at the same range of weights. Using breeds of larger mature size, if available, is a better approach, and one that should be a long-term goal if the demand for heavy carcasses persists. However, it is the opinion of this author that current slaughter weights preferred by US packers are too high for the genetic potential of most currently available breeds, and that a reduction in average slaughter weight would result in a product more appealing to consumers. Also, there are other factors related to effects of size on production efficiency that need to be taken into account.

There is a strong genetic relationship between growth rate and mature size. Animals from larger mature size breeds grow more rapidly than those from smaller breeds, or, stated alternatively, a genetic increase in growth rate is almost invariably accompanied by an increase in mature size and therefore maintenance feed cost of the breeding flock. For example, in a long term selection experiment for increased 120-day weight (Sakul et al. 1999; Bradford et al., 1999), mature ewe weight increased more (15lb.) than 120-day weight (11lb.). It was estimated in this case that the increased feed cost of the larger ewes would be more than paid for by the increased lamb weight. However, ewe maintenance cost does need to be taken into account in assessing the net benefits of an increase in genetic potential for growth rate and the accompanying increase in slaughter weight.

Size and reproductive efficiency.
An assumption often made in comparing breeds or individuals of different growth potentials is that reproductive rates are the same for animals of different sizes. This may not be true. Numerous observations on natural populations, and long term selection for measures of growth rate or size in laboratory animals, document that animals farther from the average for the species are less "fit", i. e. they have lower fertility or viability and lower net production per breeding animal. This applies to animals at both the upper and lower end of size ranges.

In sheep, estimates of genetic correlations between measures of growth rate or size and traits such as fertility, prolificacy and lamb livability are highly variable, and include both positive and negative estimates with an average not far from zero (Baker et al., 1982; Fogarty, 1995; Al Shorepy and Notter, 1996; Bromley et al. 2000, 2001). Rao and Notter (2000) analysed NSIP data on three breeds and concluded thar there were no major antagonisms between litter size and weaning weight or post weaning gain. Michels et al. (2000) concluded from their review that "a clearcut relationship between litter weight components and ewe weight cannot be generalized but may vary among differentially selected breeds and lines within them".

Although the information on genetic correlations from the scientific literature does not provide conclusive evidence one way or the orher, the belief that there is a negative relationship between size and reproduction persists (Shelton, this issue). Closer examination of the correlations reported suggests that the relationship between size and prolificacy (ovulation rate and litter size) may be slightly positive (e. g. Rao and Notter, 2000), while those for weight with fertility and viability are slightly negative. However, the variability and low mean values of these estimates preclude firm conclusions. Evidence supporting the postulated relationships comes from results of selection. Lasslo et al. (1985) and Bradford et al. (1999) reported that two lines selected for weaning weight were consistently lower in fertility and lamb livability than an unselected control line or a line selected for multiple births, while litter size increased slightly in one of the weight lines and substantially in the other.

Additional evidence comes from analysis of lifetime production of ewes of different body weights. Shelton (1959) reported a negative relationship between yearling ewe weight and number of years in the breeding flock. Not only did below average weight ewes leave the flock earlier than average ewes, but the heaviest group left the flock almost a year earlier than average weight ewes. A similar pattern held for the relationship between ewe size and lifetime production of pounds of lamb per ewe bred. Some of these differences were probably due to environmental effects on size, but there is evidence, from a wide range of species, of lower fitness of animals farther from the mean in genetic potential for traits such as size.

Differences in fitness tend to be accentuated in stressful environments, for example in situations where feed is scarce or of poor quality part of the year, or the animals are subjected to temperature extremes or serious disease or parasite challenges. Sheep in many production environments unavoidably experience one or more of such stresses. Lower reproductive efficiency of breeds or strains with genetic potential for large mature size are likely to be greatest in stressful environments, and may be of much less concern in favorable production situations. This may contribute to the observed variability among estimates of genetic correlations between size and reproduction.

While increased growth potential and its accompanying increased mature size may be advantageous from the perspective of desired carcass weight, it may result in increased costs of production. For example, lambs from one of two lines selected for increased 120-day weight were significantly leaner than those from an unselected control line when slaughtered at the same weight (Brown et. al., 1987). However, as noted earlier, both weight-selected lines were lower in fertility and lamb viability than either the unselected control or a line selected for multiple births (Bradford et al., 1999).

Because of the indications of a negative relationship between size and reproduction, Shelton (this issue) has proposed that producers use caution in selecting for increased size in dam breeds and general purpose breeds, in which reproductive fitness is critical, and emphasize selection for growth rate only in terminal sire breeds. This will certainly reduce the total impact of a negative association between fitness and reproduction, but the reproductive rate and general fitness of terminal sire breeds also affects overall costs of production, through three pathways.

First, net reproductive rate of the terminal sire pure breeds affects cost of production of the rams used for crossing. This cost is spread over a potentially large number of crossbred lambs for each ram, but is nevertheless an appreciable part of the cost of each lamb. Secondly, the mating capacity, fertility and longevity of the terminal sire breed rams have an important impact on sire cost per lamb. For example, rams from one breed may settle only 25 ewes on average per breeding season, and may average only 2.5 years of productive life in the flock. Rams of another breed that is more active, perhaps less seasonal in breeding capacity, or inherently more fertile may settle 50 or more ewes per year, and breed satisfactorily for an average of 4 years. Differences will be greatest under extensive range conditions, where the largest flocks are found. Thirdly, viability of crossbred lambs may differ between sire breeds. These factors combined can result in a 3- to 4-fold difference in sire cost per crossbred lamb.

Currently in the US, the most commonly used sire breed is the Suffolk, with the closely related Hampshire second, and crosses between the two also used as terminal sires. This is because Suffolks have the highest growth potential and largest mature size of any sheep available; analysis of US NSIP data document their superior growth potential compared to the two other most widely recorded breeds. From this perspective, they provide the best breed for producing heavy, lean carcasses. However, this breed is below average in viability of both purebred (Cundiff et al., 1982; Leymaster, 1991) and crossbred (Bradford et al., 1960; Leymaster and Jenkins, 1993) lambs. The lower prenatal survival of crossbred lambs sired by this breed (Meyer, this issue) also affects relative sire cost of each lamb marketed. While it does not appear to be documented in the scientific literature, producer reports indicate that rams of the breed have a relatively short productive lifespan. The lack of adaptation of ewes of the breed to stressful conditions is widely recognized, and they are generally not used as purebreds for commercial lamb production under range conditions.

The shorter lifespan typically observed for terminal sire breed rams compared to those of other breeds is probably due in part to the fact that the former are usually raised on a very high plane of nutrition, a practice known to shorten lifespan.

Whether the lower lamb and adult viability of the Suffolk breed is associated with their exceptional genetic potential for growth, or simply represents a breed difference independent of growth and size, cannot be stated with certainty.

Producing leaner lambs with desired eating qualities should improve consumer acceptance of US lambs. In the short term, achieving this goal will require either slaughter of lambs at lower average weights than at present, or increasing the genetic potential growth rate/mature size of the breeds used. The latter will not only require time to accomplish, but may increase costs of production as a result of reduced net reproductive rate. It therefore appears that some reduction in slaughter weights would benefit the US sheep industry. If the demand for heavy, lean carcasses from efficiently produced animals is to be met, an important need of the sheep industry is terminal sire breed(s) that combine rapid growth/large mature size with good ram and lamb livability.

Meeting this need could be accomplished by improving the fitness of existing sire breeds, improving the growth potential of higher fitness breeds, or developing new breeds by crossing and subsequent selection. Given enough time, any of these approaches should permit reaching the desired goal, but the time required may be one or more decades. Since growth rate has a higher heritability than fertility and viability, the second and third approaches might take less time than the first. However, attention would need to be paid continuously to fitness, because of the suggested relationship between growth rate and fitness.

An approach that could produce useful results in a much shorter time is comparison of additional existing breeds (including possibly new importations), composites or crosses, as terminal sires. The evaluations should take into account cost of raising the rams, length of service life and numbers of ewes settled per ram, and numbers of lambs marketed per ewe, i. e. sire cost per lamb marketed, as well as growth rate and price received for the lambs.

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Composite Trait Selection for Improving Lamb Production

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Introduction

When the value of wool is low, as at present, there is a greater potential for increasing both biological and economic efficiency of sheep production through improvement in meat production. It has been suggested that biological and economic efficiency can be increased more through genetic selection for improved reproductive rate than in growth rate or body composition (Fogarty et al., 1982). Reproductive rate is the most important component of total litter weight, which is clearly the single most important economic trait in American commercial sheep production. Loss of the Wool Incentive Program and lower wool prices in recent years have increased the economic importance of the total litter weight weaned per ewe. Current farm prices for wool and lamb indicate gross income from lamb exceeds that from wool by up to sixteen fold for most commercial producers of western white faced sheep. Hence, genetically increasing marketable litter weight per ewe is one of the most important contributions genetics can make to the economy of the sheep industry.

Increases in litter weight weaned can be made quickly through crossbreeding especially with prolific breeds. However, introduction of new breeds, often exotic, can result in unadapted genotypes with or without other desirable characteristics. Also, after crossbreeding has been thoronghly exploited, the only recourse for continued genetic progress is via selection for genetically superior individuals within breeds or crosses. It is important, therefore, to determine the relative effectiveness of alternative selection procedures for improving litter weight weaned.

The trait, litter weight weaned, is a composite trait affected by the expression of several genetically influenced traits. Variation in these component traits contributes to the phenotypic variation in the composite trait. Litter weight weaned is a combination of several different aspects of ewe reproduction (fertility, and litter size), ewe viability and offspring growth rate (mothering ability, milking performance, lamb survival, lamb growth rate). Thns, it is a convenient biological and economic measure of ewe productivity (Martin and Smith, 1980; Ercanbrack and Knight, 1985).

Long term selection for a composite trait may (but not necessarily) improve each individual component trait. Component traits within a composite ttait should not be expected to improve at the same rate because they may differ in the genetic parameters involved. However, selecting for a composite trait should result in a balance among the component traits that produces an adapted animal, while selection for an individual trait can result in a reduction in adaptability. For example, selection response for a non-composite trait such as ovulation rate in sheep may be positive but gains in ovulation rate can be offset by decreased embryo survival (Bradford, 1985). Similarly, selection for increased litter size at birth may not be accompanied by increased milking performance and lamb growth rate. There may be limiting factors associated with favorable major genes such as the Booroola (FecB) allele which increases ovine ovulation rate substantially. While the FecB allele will increase litter size, there are associated decreases in lamb survival and weaning weight (Willingham and Waldron, 2000).

Direct selection for the composite trait of litter weight weaned in mice was three times as effective as selection for litter size for increasing litter weight weaned (Luxford and Beilharz, 1990). Long term selection in Targhee sheep for individual lamb weaning weight, rather than total litter weight weaned, resulted in decreases in lamb survival to weaning and ewe fertility (Bradford et al. 1999). From this last study, it is obvious that single trait selection for growth rate to weaning can improve weaning weight but it does not necessarily increase total lamb production per ewe. Thus, litter weight weaned per ewe exposed is the most appropriate composite trait to be used in selection for increasing total lamb production. The objective of this review is to characterize the composite trait litter weight weaned and its component traits.

Review

Limitations to increasing litter weight weaned. Breeders should be mindful that genetic change in animal production results in a biological change of the animal, often requiring a corresponding change in nutritional and management inputs. The upper limits for genetic improvement of a trait are generally determined by the nutritional and management constraints within a production system. In a selection study to increase weaning weight in Targhee sheep in two different environments (range vs irrigated pasture-feedlot) genetic improvement was significantly greater in the better environment (Lasslo et al., 1985).

In relation to litter weight weaned, consider the extensive production situations identified by Bradford (1985). An extensive production system may have limited forage availability with nutritional supplements being scarce or uneconomical and limited labor at lambing. Under a limited extensive system, the goal for increasing litter weight weaned may be restricted to production of only one lamb per ewe with satisfactory growth. However, under an improved extensive production system with better forage availability, especially in the early spring and summer, the litter weight weaned may be greatly improved with multiple births, increased milk production, and improved lamb growth. Thus, it is important for the sheep breeder to recognize environmental potentials and limitations for genetic improvement. In theory, selection response for the composite trait litter weight weaned under any production system should result in an adapted and biologically balanced ewe because she has been selected for her genetic potential to raise a lamb(s) to weaning in that environment, and the component traits of litter weight weaned have changed appropriately for the environmental conditions.

Selection Response for Litter Weight Weaned. A significant selection study for litter weight weaned was conducted at the U.S. Sheep Experiment Station in the years1976 to 1988 (Ercanbrack and Knight, 1998). Selection occurred under western range conditions that included shed-lambing, spring grazing of sagebrush-grass-forb pastures, and summer grazing of mountain range at elevations of 2,000 to 2,900 meters. Selection lines were established in four breeds of sheep (Rambouillet, Targhee, Columbia, and Polypay). Ewes were selected on their lifetime average litter weight weaned and rams were selected on the basis of their dam's record for this trait. Response was positive during the 12 years (1976 - 1988) of selection. Non-selected random bred Rambouillet and Targhee control lines were maintained during the study; the average of these two lines was used for estimating environmental trends. Tables 1 and 2 indicate the phenotypic and genetic responses, respectively, for reproduction and body weight.

Phenotypic trends (Table 1 and Figure 1) were positive for reproductive traits and body weight. Modest increases in phenotypic trends in the control lines indicate improvements in management and(or) environment over the time period. Genetic improvement (Table 2) was generally positive for all traits. Genetic improvement for litter weight weaned averaged 0.69 kg per year. For a flock of 100 ewes this represents an annual increase in marketable lamb of 69 kg. Over a 12 year period, selection for litter weight weaned resulted in a genetic improvement of 8.28 kg/ewe. The economic consequences of selecting for litter weight weaned during this period was a total annual increase in gross value of production per ewe of $21.51 for phenotypic improvement, which reflects the effects of environmental improvement, and $11.40 of which could be attributed directly to genetic gains through selection for litter weight weaned (Ercanbrack and Knight, 1998).

Selection responses for litter weight weaned in all four breeds in this study were positive and significant. However, breed differences in response to selection for litter weight weaned were observed (Ercanbrack and Knight, 1998). Improvements for reproductive traits were less in the Polypay than in the other breeds despite its outstanding superior means for litter weight weaned. The rate of response to selection in the Polypay was negligible during the early years of the experiment but increased after 1984 (Figure 1). At the beginning of this selection study in 1976, the Polypay breed was a newly created breed and several F2 and F3 generation ewes were still present in the flock. The delayed response to selection for litter weight weaned in early generations was examined by Snowder et al. (1996) who reported that at least three generations were necessary to overcome the loss of reproductive performance due to decreased heterosis and recombination loss. Thus, response may be lower in the early years of selection in a newly created composite.

Breed differences for litter weight weaned clearly exist. Shrestha et al. (1992) characterized litter weight weaned in five purebred and two crossbred Canadian breeds under intensive management systems. Litter weight weaned at 91-d postpartum ranged from 47 to 67 kg. The Rideau breed weaned the heaviest litters and the lightest litters were weaned in the Suffolk breed. Although the Finnsheep breed had the highest level of prolificacy (219%), average litter weight weaned (53 kg) was less because lamb growth rates to weaning were lower than for the other breeds. Because of the significant economic differences among breeds for litter weight weaned, individuals entering the commercial sheep production industry should consider breed differences for litter weight weaned when selecting a breed.

Breed specific heritability estimates for litter weight weaned per ewe exposed are low. Martin et al. (1981) reported heritability estimates for litter weight weaned for different ages at weaning in a composite breed in Scotland (0.07 at 4 wk, 0.10 at 8 wk, and 0.14 at 12 wk). Heritability estimates for litter weight weaned for four US breeds at 120-d postpartum varied (Rambouillet, 0.11; Targhee, 0.08; Columbia, 0.02; and Polypay, 0.00; Bromley et al., 2001). Low heritability estimates for a complex trait such as litter weight weaned are expected because the trait is subjected to numerous environmental influences from breeding to weaning. The repeatability for litter weight weaned at 120-d postpartum in four breeds ranged from 0.10 to 0.16 suggesting significant temporary environmental influences on this trait (Bromley et al., 2001). Although the heritability for litter weight weaned is low, the genetic improvement observed in the flocks at the U.S. Sheep Experiment Station indicates the trait responds positively to selection and at a level of economic significance (Ercanbrack and Knight, 1998).

The reason for the positive selection response of this low heritability trait can be explained by examining the three factors influencing selection response: heritability, selection differential and phenotypic variation. The product of these three factors determines selection response. Response to selection for low heritability traits can be significant if the trait has a large phenotypic variation and(or) the selection differential is large. The phenotypic variation for litter weight weaned is large. The coefficient of variation is a statistical value (standard deviation divided by the mean) used to compare variation among different traits. The coefficient of variation for litter weight weaned at the U.S. Sheep Experiment

Station is approximately 50% (Bromley et al., 2001). The coefficients of variation are lower for fertility (35%), prolificacy (36%), weaning weight (19%), and grease fleece weight (23%) in the same population (Bromley et al., 2000). Consequently, the selection response for litter weight weaned can be significant even with a low heritability. More importantly, the greater economic value for each unit increase in litter weight weaned justifies selection for this trait (Ercanbrack and Knight, 1998).

As previously discussed, selection for a component trait of litter weight weaned may or may not result in a favorable correlated response in litter weight weaned. After 30 yr of selection for 120-d weaning weight in Targhee sheep in California, total phenotypic improvement of litter weight weaned was 6.5 to 7.1 kg but less when selection emphasized multiple births (4.5 kg; Bradford et al., 1999), while direct selection for 120-d litter weight weaned in four breeds in Idaho had an average phenotypic improvement of 15.8 kg in only 12 yr (Ercanbrack and Knighr, 1998).

Improving selection response for litter weight weaned. Because litter weight weaned is a sex-limited trait with a low heritability, the accuracy of selection can be improved by considering more information on breeding individuals. This can include records on relatives and multiple observations on a single individual. Martin and Smith (1980) reported that by adding records on the dam and paternal half sibs to those of the ewe increases the rate of genetic response by 10 to 50% for litter weight in sheep. The genetic analyses used in the National Sheep Improvement Program utilize modern statistical approaches that could optimize selection response for litter weight weaned. Another approach to enhance selection response for low heritability traits is to increase the selection differential by maximizing the number of offspring from high performing ewes with multiple ovulation and embryo transfer in a nucleus breeding scheme (Teepker and Smith, 1990).

A potential difficulty in selecting for litter weight weaned is the level of record keeping necessary to optimize selection. This requires proper identification of pedigree relationships and weighing of lambs at weaning. This is not possible in most commercial production systems. However, commercial producers may be able to identify and select rams from ewes that have a history of weaning heavy multiple birth lambs. Another alternative would be to purchase purebred rams with high breeding values for litter weight weaned as reported by the National Sheep Improvement Program.

Although the purpose of this review is to discuss the advantages of using selection to improve the litter weight weaned per ewe, crossbreeding can be an effective breeding tool and should also be considered. It is well established that crossbred ewes exhibit heterosis for fertility and prolificacy rates which contribute to litter weight weaned. However, no studies on crossbred ewes were found which directly report litter weight weaned. Another consideration would be the production of terminal crossbred lambs that are known to exhibit heterosis for lamb survival and pre- and post-weaning growth (Mavrogenis and Louca, 1979; Malik et al., 1980; Sheridan, 1981; Young et al., 1986). Crossbreeding does not result in permanent genetic improvement in litter weight weaned unless direct selection for retained heterosis is practiced following crossbreeding.

Maternal genetic effects on litter weight weaned. Maternal behavior or maternal genetic effects have long been known to influence the pre-weaning growth of their offspring. Improvement of maternal behavior should be associated with an increase in lirter weight weaned. Alexander (1988) in a review of maternal behavior described how maternal effects influence lamb survival and growth as observed in the dam's nesting, parturition, grooming of the newborn, suckling behavior, bonding, spatial association with the offspring, defense against predators, and care of multiple births.

The maternal genetic component of a trait is described by the estimate of maternal heritability. The 40-d weaning weight of crossbred Romanov lambs has an estimated 0.25 maternal heritability (Maria et al., 1993). Maternal genetic effects on lamb growth rates tend to diminish with increasing age of the lamb as evidenced with decreasing maternal heritabilities from birth to increasing weaning age (0.22 to 0.01, Maria et al.,1993; 0.30 to 0.07, Nasholm and Danell, 1996). Some negative genetic correlations between maternal and additive effects for weaning weight have been reported but these varied greatly with the statistical models used in their prediction (Burfening and Kress, 1993).

The correlation between additive genetic and maternal effects for weaning weight can be large (r_g = 0.76, Nasholm and Danell, 1996). Also, the correlation between the additive genetic effect for rate of gain from birth to 120-d weaning with the maternal effect for litter size at weaning can be significant in some breeds (r_g = 0.51 for Columbia, r_g = 0.95 for Rambouillet, and r_g = 0.36 for Targhee; Bromley et al., 2000) but not all (r_g = 0.03 for Polypay). Therefore, increases in lamb weaning weight and total litter weight weaned may be associated with genetic improvements in maternal behavior.

The positive relationship of maternal behavior and litter weight weaned has also been observed in mice selection studies. Postnatal maternal performance in mice did improve significantly when lines were selected solely on litter weight weaned (Wilkinson,1986). Selection only for litter size at birth in mice was not accompanied by improvement of postnatal maternal performance, resulting in a negative estimated phenotypic relationship between numbers born and mouse pup weaning weight (Luxford and Bielharz, 1990).

Contribution of component traits to litter weight weaned. Ercanbrack and Knight (1998) estimated the average annual relative contributions of component traits to genetic change in litter weight weaned over 12 yr for four breeds (Table 3). They fonnd that 37% of the genetic improvement in litter weight weaned was attributed to prolificacy, 27% to number of lambs weaned, 17% to lamb weaning weight, 12% to fertility, and 7% to ewe viability. Improvements in these traits occurred simultaneously during selection for litter weight weaned, both phenotypically (Table 1) and genetically (Table 2). These approximations of component relative contributions have also been confirmed by other studies of the biological differences between the Targhee line selected for litter weight weaned and the Targhee non-selected randomly bred control line at the U.S. Sheep Experiment Station. Improvement in litter weight weaned occurred through at least three biological events: 1) increased ovulation rate and number of live lambs born (Stellflug et al., 1994), 2) heavier lamb weaning weights (Head et al., 1995), and 3) increased pregnancy rate in ewe lambs (Westman, 1993).

Correlated and biological changes in sheep selected for litter weight weaned. Comparative studies of Targhees selected for litter weight weaned compared to a random bred control line have identified significant biological differences (Head et al., 1995, 1996a, 1996b). As previously described, Ercanbrack and Knight (1998) reported increases in fertility, prolificacy, number of lambs weaned, and lamb growth in sheep selected for litter weight weaned compared to control lines. In the selected line, daily milk production increased 13% and lamb weaning weights increased 7% compared to the control line (Head et al., 1995). Similar increases in milk production (10%, Pattie and Trimmer, 1964; 12%, Hinch et al., 1989) were observed when selecting Merino sheep for increased individual lamb weaning weights. Brown et al. (1987), reported increases in peak milk yield of 10 and 29% in two lines of Targhees selected for individual weaning weight. Increases in milk production from the Targhee selected lines at the U. S. Sheep Experiment Station were associated with higher concentrations of growth hormone than control ewes (Head et al., 1996a). The major functions of growth hormone are increased lipolysis, diabetogenesis, protein accretion, bone growth, gluconeogenesis, mammogenesis and galactopoiesis (Bauman and McCrutcheon, 1986). Therefore, the higher growth hormone concentration in the selected line infers the potential presence of other biological differences yet to be identified.

Lamb survival rates may also increase as a result of selecting for litter weight weaned. Litter weight weaned is moderately genetically correlated with neonatal survival rate (r_g = 0.49) but this correlation is large for postnatal survival to weaning at 42 d postpartum (r_g = 0.91; Fogarty et al., 1982). Twin lambs from a Targhee line selected for litter weight weaned had faster growth rates to weaning when compared to twin lambs from a control line (Head et al., 1995). The faster growth rates of the lambs from the litter weight weaned selection line were partially attributed to higher milk consumption and increased levels of dry matter intake (forage). However, post-weaning performance for gain, feed intake and carcass characteristics were similar among lambs from selected and control lines (Head et al., 1996b). The effects of selection for litter weight weaned do not appear to influence post-weaning gain or carcass characteristics. Similar observations were made in Australian Merino sheep selected for high and low weaning weight where selection had no effect on mature muscle-weight distribution (Perry et al., 1988) or adipose volume (Thompson et al., 1988).

Selection for litter weight weaned should also increase ewe fertility. The genetic correlation between litter weight weaned and ewe fertility is positive and large (rg = 0.58; Fogarty et al., 1982). Genetic improvement in litter weight weaned was associated with genetic improvement in ewe fertility rates (Ercanbrack and Knight, 1998). Ewe lamb fertility in the Targhee lines selected for litter weight weaned was 40% (21 percentage units) higher compared to the control line (Hatfield and Stellflug, 1996). It is not known if selection for litter weight weaned will decrease the age at puberty. Selection solely for litter size in Targhee sheep did not decrease age at puberty (Li et al., 1992).

Mature size should be expected to increase with selection for increased lambing performance. Genetic correlations between ewe body weight and lamb weaning weight are positive (Shelton and Menzies, 1968; Stobart et al.,1987; Nasholm and Danell, 1996). Large genetic correlations between ewe mature size and lamb weaning weight (r_g = 0.85, Nasholm and Danell, 1996) or total litter weight (r_g = 0.58 to 0.88, Martin et al., 1981) have been reported.

In the selection study of Ercanbrack and Knight (1998), they observed phenotypic and genetic increases for ewe mature size in all breeds selected for litter weight weaned (Table 1 and 2). This positive correlated response infers selection favored larger ewes more adapted to the nutritional environment under which they were selected. A positive relationship between litter weight weaned and body weight was also reported in mice (Luxford and Beilharz, 1990). Mature ewes selected for litter weight weaned were heavier at breeding and during lactation than control ewes. This was also observed for the body weights of selected ewe lambs which were 4.5 kg or 14% heavier at breeding than control ewe lambs. This increase in body weight does not appear to be related to forage intake expressed as a percent of body weight because this did not differ between Targhee selected and control lines (Head et al., 1995).

Increasing mature body size may have some disadvantages. Although increases in body weight that occur during selection for increased litter weight weaned may be related to adaptability to a production system, ewes of larger mature size will have greater requirements for nutrients and therefore, be more sensitive to environmental factors affecting nutrition such as drought or increased feed costs. Larger ewes are also harder to handle at shearing and lambing.

Increasing litter weight weaned will affect wool production. Pregnancy and lactation have a negative phenotypic effect on wool growth (Corbett, 1979; Shelton, 1998). Increases in litter size and lactation will positively affect litter weight weaned. Twin pregnancies reduce grease fleece weight by 4% compared to a single lamb pregnancy (Ray and Sidwell, 1964) and suckling of twins for 20 wk reduces grease fleece weight by 5 - 8% compared to suckling single lambs (Corbett, 1979). The general cause for the negative phenotypic relationship between lamb and wool production has been attributed to competition for nutrients (Shelton, 1998). The genetic correlation between wool and reproduction tend to be small and negative (Fogarty, 1984). However, these values range from negative to significant positive values (Shelton, 1998). Significant negative genetic correlations between reproduction and wool, ranging from -0.25 to -0.78, have been associated with environments limiting in feed resources and variation in age of ewe at lambing (Shelton, 1998). In more favorable environments, the genetic correlation may be negligible. Ercanbrack and Knight (1998) reported negligible changes in wool production (grease fleece weight and wool grade) after 12 yr of selection for litter weight weaned. Also, the genetic correlations of litter weight weaned with wool traits in this same flock were low ($r_g = -0.07$ for fleece weight, $r_g = 0.02$ for fleece grade score, and $r_g = 0.03$ for staple length; Bromley et al., 2001). Other studies have reported small negative genetic correlations between the number of lambs weaned and grease fleece weight, approximately -0.30 (Shelton and Menzies, 1968; Snowder and Shelton, 1988). The effect of selection on litter weight weaned should have little effect on wool production.

Conclusions

Increasing profitability of a sheep enterprise can be accomplished by several means including genetic improvement of the breeding stock. When selection is practiced to increase profitability, it must focus on the most economically important trait for that production system. Typically, many commercial sheep producers sell lambs by their live weight shortly after weaning; thus, litter weight weaned is the most important economic trait. Direct selection for litter weight weaned will result in significant genetic improvement in most breeds. During selection, component traits contributing to litter weight weaned should favorably respond, with an appropriate balance among components.

Indirect selection for litter weight weaned by selecting for a component trait such as litter size born or lamb weaning weight will increase litter weight weaned but at a slower rate compared to direct selection. Also, component trait selection may not be accompanied with improvements in all other component traits related to litter weight weaned; therefore, indirect selection response for litter weight weaned is expected to be less.

It should be noted that the conclusion of relative effectiveness of selection for litter weight or for its components is based on the results of two experiments using each approach. These two experiments were carried out with different stocks and under quite different feeding, management and environmental conditions (Idaho vs California). While the general conclusion on the advantages of selecting for total litter weight seems clear, the limited number of selection experiments infers that the expected magnitude of the difference in response to direct selection for litter weight compared to selection for a component trait is not well estimated.

Implications

Litter weight weaned is the most economically important trait in most lamb production systems in the USA at the present time. Selection for litter weight weaned may result in increase profitability when the environment and management system favor increased reproductive efficiency. It is possible to achieve genetic improvement for litter weight weaned per ewe exposed in excess of 0.5 kg annually. At present market values for feeder lambs, this results in an annual increase of over $1.00 per ewe.

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Table 1. Linear regression coefficients (annual rates of phenotypic improvement) for reproductive traits and body weight

Breed/Line	Fertility, %	Prolificacy, %	Born live, %	Lambs weaned, %	Ewe viability[a], %	Body weight, kg	Net rate[b], %	Litter wt weaned[c], kg
Rambouillet	.84	2.54	.00	.36	.27	.82	2.77	1.24
Targhee	1.49	1.84	.65	.53	.15	.51	3.68	1.38
Columbia	1.81	1.84	.41	1.17	.25	.82	4.08	1.73
Polypay	.46	1.16	.00	.45	.20	1.03	2.19	1.10
Control[d]	.92	.41	.26	.18	.07	.27	1.37	.67

[a] Ewe viability = percent ewes alive at lambing per ewe into breeding

[b] Net rate = net reproductive rate, lambs weaned per ewes into breeding

[c] Litter weight weaned = total litter weight of lambs weaned (120 d) per ewe into breeding

[d] Control is average of non-selected randomly bred Rambouillet and Targhee lines

Source: Ercanbrack and Knight, 1998.

Table 2. Annual genetic improvement[a] among lines selected for litter weight weaned.

Breed	Fertility, %	Prolificacy, %	Born live, %	Lambs weaned, %	Ewe viability[b], %	Body weight, kg	Net rate[c], %	Litter wt weaned[d], kg
Rambouillet	.00	2.14	-.29	.18	.20	.55	1.40	.57
Targhee	.57	1.43	.39	.35	.08	.24	2.31	.71
Columbia	.89	1.43	.15	.99	.18	.56	2.71	1.06
Polypay	-.46	.75	-.26	.27	.13	.77	.82	.43

[a] Genetic improvement estimated by the difference in regression coefficients between selected and control lines.

[b] Ewe viability = percent ewes alive at lambing per ewe into breeding

[c] Net rate = net reproductive rate, lambs weaned per ewes into breeding

[d] Litter weight weaned = total litter weight of lambs weaned (120 d) per ewe into breeding

Source: Ercanbrack and Knight, 1998.

Table 3. Estimated percentage contribution of component traits for genetic improvement in litter weight weaned

Component trait	Percentage
Fertility	12
Prolificacy	37
Percentage lambs weaned	27
Lamb weaning weight	17
Ewe viability	7

Source: Ercanbrack and Knight, 1998.

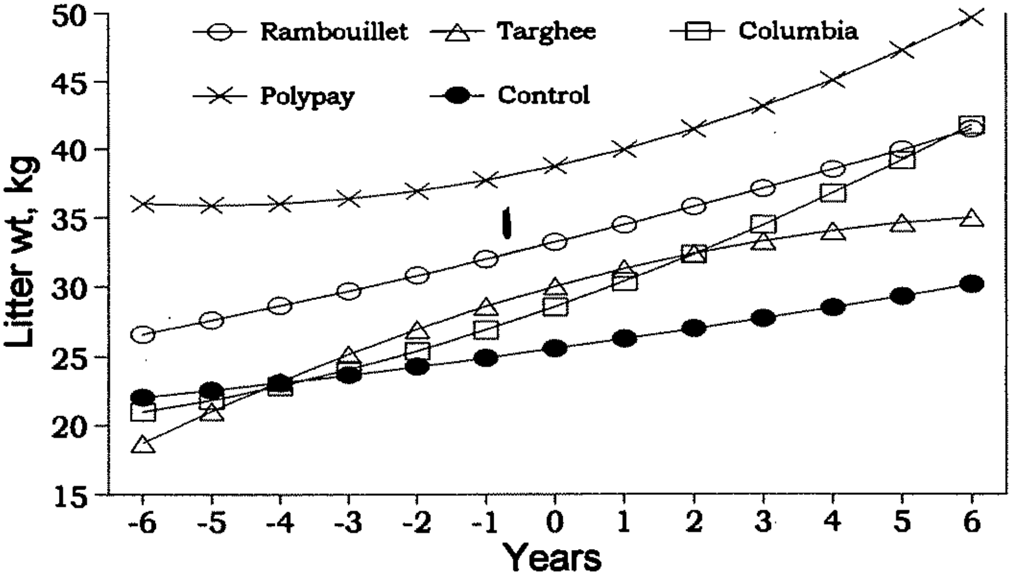

Figure 1. Breed direct response to selection for litter weight weaned expressed as a deviation from the median year (1976 - 1988). Control populations were non-selected randomly bred Rambouillet and Targhee ewes.

Fundamental Aspects of Crossbreeding of Sheep: Use of Breed Diversity to Improve Efficiency of Meat Production

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Introduction

The sheep industry competes against beef, pork, poultry, and fish for food dollars of consumers who have many choices of high-quality meats. To compete effectively, the industry needs to produce uniform, nutritious, lean lamb that satisfies the eating preferences of consumers and to improve reproductive efficiency and reduce labor requirements so that seedstock and commercial flocks are both practical and profitable under a range of production environments. Although this situation indeed represents a difficult challenge, sheep producers have an invaluable resource to make necessary changes - a wealth of biodiversity represented by numerous breeds. Breeds of sheep have evolved over many thousands of years, their utility and function guided by their ability to adapt and survive in specific environments and production systems. Following domestication, further diversification among breeds has stemmed from selection by man for numerous characteristics, for example, appearance, color, size, shape, or wool production. Consequently, breeds of sheep differ markedly in adaptability to different environments and in levels of performance for traits that influence efficiency of production and product quality. Characteristics of each breed have a genetic basis and can therefore be exploited in structured crossbreeding systems designed for specific production-marketing situations. The purpose of this manuscript is to provide guidelines to improve efficiency of meat production through the appropriate use of breeds in crossbreeding systems.

Breed Diversity

There are currently more than 50 recognized breeds of sheep in the U.S. Over the past 20 years, several breeds or strains have been imported from other countries due to specific characteristics. Fot example, Booroola Merino and Romanov were imported primarily for reproductive issues, Texel for carcass ttaits, East Friesian for milk production, and Dorper for easy-care attributes. It is likely that additional breeds will be imported in the future.

For any trait affecting efficiency of meat production, there is useful genetic variation among breeds. A good example is lambing rate, the number of lambs born per ewe lambing. Average lambing rates of breeds vary more than twofold, from perhaps 1.6 for mature Rambouillet ewes to about 3.7 for mature Romanov ewes. This variation does not imply that one breed is "better" than the other. The value of breed diversity is that producers can identify and use a breed or breeds that perform at a level consistent with marketing goals and with production resources such as feed availability, labor, facilities, and managerial skills. Therefore, flocks of Rambouillet ewes are common in arid regions of the U.S., whereas purebred or crossbred Romanov flocks exist in areas with greater feed resources.

Breed diversity is even greater if one considers several traits at once rather than a single trait. A breed that excels for daily gain and carcass traits may be less adaptable to harsh environments. Or, a breed that is parasite tolerant and has extended seasonality may not produce lean carcasses at typical market weights. Examples of breeds and traits are given in Table 1 to emphasize this very important characteristic of breed diversity. These specific four breeds were chosen because of their widespread use and to represent broad ranges in performance levels for key traits affecting efficiency of meat production. More comprehensive information on breeds and traits is provided in the Sheep Production Handbook. Ideally, the relative performance of breeds should be determined from objective, unbiased results of experiments done under relevant environments at state and federal research institutions. In practice, comparative information is limited and decisions about breed usage are often based on tradition and empirical evidence.

One can consider a breed as a package of genetic effects that influence many traits affecting efficiency of meat production. Often breeds have similar levels of performance for certain traits but differ for others, whereas some breeds may differ for most traits. The Finnsheep package is very different from Rambouillet (Table 1). When a producer selects a given breed to use, the total package of genetic effects on all traits is chosen collectively. One occasionally hears that breeds were combined to create a crossbred sheep that has only the desirable characteristics of each breed, avoiding the less attractive characteristics. This notion is not valid. One can't select and use only the specific favorable genetic effects of each breed, such as extended breeding season of Dorset, lambing rate of Finnsheep, hardiness of Rambouillet, and growth of Suffolk. Because each breed has relative strengths and weaknesses across traits, no single breed excels for all relevant traits. Therein lies the basis for strategic use of breeds in structured crossbreeding systems.

Sheep breeds can be classified in many different ways, for example, fineness of wool is a common method. Because this manuscript addresses use of breeds for mear production, breeds will be classified based on roles in crossbreeding systems, that is, as general purpose breeds, specialized dam breeds, and specialized sire breeds. Key traits used for classification purposes include adaptability, longevity, seasonality, age at puberty, lambing rate, mothering ability, lamb survival, leanness, and mature weight. There is disagreement on classification of some breeds, partly because comprehensive comparative results are limited, and the following assignment to a particular class should be considered as a useful guideline, not a definitive statement.

General purpose breeds tend to have acceptable, average levels of performance for most key traits, with extreme performance limited to very few, if any, traits. Examples of general purpose breeds include Cheviot, Columbia, Coopworth, Corriedale, Dorset, Montadale, and Texel. These breeds are occasionally used as specialized dam or sire breeds depending on the production-marketing situation. In fact, Dorsets are used in all three roles, but most commonly as a general purpose breed.

In contrast to general purpose breeds, specialized dam breeds and specialized sire breeds have clear strengths and weaknesses in key traits. Such breeds fit into dam or sire roles based largely on levels of performance for fitness, reproductive, and growth traits and are best used to complement other breeds.

Specialized dam breeds are used predominantly in terminal crossbreeding systems as the breeding flock to produce market lambs. This group of breeds therefore emphasizes fitness and reproductive traits and tends to be less extreme for carcass traits and mature weight. Breeds considered as specialized dam breeds include Merino, Polypay, Rambouillet, and Targhee. Adaptability, longevity, mothering ability, and average mature weight are common characteristics of these four specialized dam breeds that contribute greatly to commercial flocks in the U.S. In addition, Finnsheep and Romanov are used exclusively as specialized dam breeds primarily due to young age at puberty and very high lambing rates (about 3.0 and 3.7 lambs per ewe lambing for mature Finnsheep and Romanov ewes, respectively).

Rams of specialized sire breeds are mated to purebred or crossbred ewes of specialized dam breeds to produce market lambs in terminal crossbreeding systems. Specialized sire breeds should excel for fertility and longevity of rams and survival of crossbred lambs. In addition, sire breeds should produce crossbred lambs that have desirable carcasses and growth rates that are optimal for specific production-marketing situations. For example, Southdown are early maturing and capable of siring lambs of acceptable finish at a light weight on grass. Hampshire, Oxford, Shropshire, Southdown, and Suffolk rams are commonly used as terminal sires.

Heterosis Effects

Effects of heterosis greatly impact productivity of crossbred sheep. Each breed represents a specific package of genetic effects resulting in characteristics that distinguish one breed from another. Sheep with two copies of the same form of a particular gene are said to be homozygous for that gene, whereas sheep with two different forms of the gene are heterozygous. During evolution and development, each breed becomes homozygous for some genes and heterozygous for other genes, creating a unique set of genetic information. For each breed, the average degree of heterozygosity considering all genes (sheep may have roughly 30,000 genes) is a reflection of the genetic history of that breed. When breeds are crossed, new combinations of gene forms are created in crossbred sheep. Therefore, crossbred sheep have increased heterozygosity relative to breeds that produced the crossbred. The increase in heterozygosity is the basis for heterosis or hybrid vigor. Heterosis is defined as the average performance of crossbred sheep relative to the average performance of pure breeds that produced the cross.

Effects of heterosis can be realized through crossbred lambs, ewes, and rams. Lamb heterosis represents the performance of crossbred lambs raised by purebred ewes relative to purebred lambs raised by purebred ewes. An example of lamb heterosis for weaning weight is given in Table 2 to illustrate the concept. The average weaning weight of breed A lambs is 53 pounds and of breed B lambs is 63 pounds. Therefore, the weaning weight of purebred lambs of both breeds averages 58 pounds. The average weaning weight of crossbred lambs by these two breeds is 61 pounds. The effect of heterosis, due to increased heterozygosity, is to increase weaning weight by 3 pounds or 5.2% relative to the average of pure breeds. In this example, the average weaning weight of crossbred lambs (61 pounds) does not exceed the average weaning weight of breed B (63 pounds), the best pure breed. Crosses between other breeds may produce crossbred lambs that are heavier than the best pure breed.

Effects of ewe heterosis represent the performance of crossbred ewes producing crossbred lambs relative to purebred ewes producing crossbred lambs; for example, Rambouillet-Dorset crossbred ewes mated to Hampshire rams compared to Rambouillet and Dorset purebred ewes mated to Hampshire rams. An example for lambing rate is presented in Table 3. The lambing rates of purebred ewes of breeds A and B are 1.70 and 1.90, respectively, giving an average of 1.80 lambs for the two pure breeds. The average lambing rate of crossbred ewes is 1.86 lambs, indicating that the effect of ewe heterosis is 0.06 lambs or 3.3%. The lambing rate of crossbred ewes is greater than the average lambing rate of purebred ewes due to increased heterozygosity of crossbred ewes.

As illustrated in Tables 2 and 3, experiments can be designed to estimate effects of lamb and ewe heterosis on key traits. Such estimates are required to guide optimal use of breed diversity in crossbreeding systems. Differences between pure breeds in levels of performance relative to lamb and ewe heterosis effects determine efficiencies of various crossbreeding systems. Because such information is essential, scientists throughout the world have directed many experiments to estimate effects of heterosis. Results of numerous experiments were summarized by Nitter (1978) to provide consensus estimates of lamb and ewe heterosis effects on numerous traits (Table 4).

Favorable effects of lamb heterosis, particularly on preweaning survival and growth traits, were reported. There was little, if any, evidence that lamb heterosis affected carcass traits. Crossbred ewes had greater conception rates and their progeny grew more rapidly than the average of pure breeds. Effects of lamb heterosis differ among traits, as do effects of ewe heterosis. Furthermore, effects of lamb and ewe heterosis on a specific trait may differ considerably. For example, the heterosis effect on preweaning survival is greater for crossbred lambs (9.8%) than crossbred ewes (2.7%). Heterosis effects on individual traits accumulate so that the combined effect on an overall measure of productivity is greatly enhanced. Crossbred lambs increase litter weaning weight per ewe exposed by 17.8% relative to the average of pure breeds, while the corresponding value for crossbred ewes is 18.0%. In summary, favorable effects of lamb and ewe heterosis greatly increase overall productivity of crossbred sheep beyond the average of pure breeds.

Crossbred rams may also benefit from increased heterozygosity relative to purebred rams, but less is known about effects of ram heterosis than effects of lamb and ewe heterosis. It is likely that ram heterosis influences fitness traits such as libido, conception rate, hardiness, and longevity. Increased fertility of crossbred rams used in spring breeding has been reported, that is, ewes exposed to crossbred rams had greater conception rates than ewes exposed to purebred rams. The usefulness and value of crossbred rams is not fully recognized by the sheep industry.

Complementarity

Complementarity greatly improves efficiency of meat production by mating ewes of specialized dam breeds to rams of specialized sire breeds. The basis of complementarity is that ewes and rams do not equally influence the performance of offspring because lambs are produced, reared, and nurtured by ewes. Breed diversity is the resource that allows producers to benefit from complementarity. As discussed, many breeds have strengths and weaknesses for key traits that result in different merit whether used in dam or sire crossbreeding roles. Specialized dam breeds excel in fitness and reproductive traits, and have moderate feed requirements (maintenance costs) because of light-to-average mature weight. In contrast, specialized sire breeds are superior for growth and carcass traits. By separating dam and sire roles, complementarity allows favorable traits of breeds to be realized while minimizing or completely avoiding less desirable traits in production of market lambs.

Mating Polypay ewes to Suffolk rams is an example of matching complementary strengths of breeds to optimize efficiency of a production system. This cross takes advantage of the high reproductive capacity and moderate maintenance costs of Polypay ewes while producing Suffolk-sired lambs to meet market requirements. The efficiency of this cross would be much greater than the reciprocal mating of Suffolk ewes to Polypay rams. The latter cross would produce genetically equivalent market lambs (half Suffolk and half Polypay), but fewer lambs would be sold and production costs greatly increased due to higher feed requirements of heavy Suffolk ewes compared ro Polypay ewes. Therefore, one way to understand the concept of complementarity is to consider the relative production costs and productivity of reciprocal matings between two breeds (Polypay ewes with Suffolk rams compared to Suffolk ewes with Polypay rams). Furthermore, the systematic efficiency of the complementary cross (Polypay ewes and Suffolk rams) would be significantly greater than straightbred systems using Polypay or Suffolk as pure breeds. Producers of market lambs should use terminal crossbreeding systems to benefit from complementary effects of specialized dam and sire breeds.

Crossbreeding Systems

Crossbreeding is a traditional practice that is widely used as a rapid and cost-effective method to improve efficiency of meat production by mating ewes and rams of two or more pure breeds. All crossbreeding systems are based on breed diversity and, therefore, heterosis influences performance. Some crossbreeding systems also benefit from complementarity. The practical objective of crossbreeding is to improve efficiency relative to the pure breed that performs best in a given production environment and marketing situation.

General-purpose crossbreeding systems. Four genetic types of breeding ewes are used in structured crossbreeding systems: purebred, first cross, rotation, and composite. Mating systems that produce these types of breeding ewes are discussed in the context of general-purpose crossbreeding systems (Table 5). The purebred mating system is included because productivity of purebred sheep serves as a standard for evaluation of all crossbreeding systems.

A purebred flock is managed as a single flock because all ewes and rams are of the same pure breed. A purebred mating system therefore does not benefit from ewe or lamb heterosis effects. Purebred flocks produce replacements and surplus lambs are marketed. There are situations, generally associated with adaptability of a local breed to extreme environmental conditions or a very specialized market, where a purebred mating system is superior to crossbreeding. Such situations are uncommon and use of crossbreeding systems is strongly recommended to improve efficiency of mear production.

Because only a portion of any ewe flock is required to produce replacement ewes, remaining ewes can be mated to rams of a different breed to produce first-cross lambs. This first-cross system requires ewes of only one breed (A) and rams of two breeds (A and B). As all breeding ewes are purebred, ewe heterosis does not exist. The system uses two flocks and is more complex than a purebred system, but has the advantage of 100% lamb heterosis in first-cross lambs.

In a two-breed rotational system, rams of breeds A and B are used in alternating generations. Ewes sired by breed A rams are mated to breed B rams, while ewes by breed B rams are always mated to breed A rams. As all ewes and lambs are crossbred, the system exploits effects of lamb and ewe heterosis. After several generations of rotational crossing, the system will average 67% of possible lamb and ewe heterosis effects. Inclusion of a third breed into the rotational system increases use of lamb and ewe heterosis to 86%. Rotational systems use lamb and ewe heterosis very effectively which is a significanr advantage. However, the rotational approach that provides for heterosis also has drawbacks. The two-breed system requires separation of ewes into two flocks during breeding, one mated to breed A rams and the other to breed B rams. Three flocks are necessary for the three-breed system. Sheep produced in rotational systems also vary considerably in breed composition. In the two-breed rotation, one flock will be 67% A and 33% B and the other 33% A and 67% B. Breed composition of flocks in the three-breed rotation will be 57% A, 29% B, and 14% C for the first flock, 57% B, 29% C, and 14% A for the second flock, and 57% C, 29% A, and 14% B for the third flock. Unless breeds have similar levels of performance, especially for lambing rate and mature weight, variation in breed composition can create different managerial requirements among flocks. For this reason, general-purpose breeds are typically used in rotational crossbreeding systems.

Composite breeds provide a simple method to address problems associated with rotational crossbreeding systems. The base generation of a composite breed is formed by making crosses among two or more foundation breeds. Subsequent generations descend from crossbred parents and selection is often practiced to establish distinct characteristics of the new breed. Although the composite breed is managed thereafter as a single flock, it benefits from lamb and ewe heterosis effects and also any heterosis effects that may exist for ram fertility traits. The percentage of lamb and ewe heterosis maintained in the composite breed increases as more breeds contribute to the crossbred foundation (Table 5). One must be careful to include only breeds that optimize the combined effects of breed composition and heterosis, as inclusion of a marginal breed to gain additional heterosis is counterproductive. In contrast to rotational crossbreeding, breed composition is equivalent among all sheep within a composite breed. Therefore, foundation breeds with diverse performance can be used without creating complexity due to different managerial requirements. Thus, throughout the world, prolific breeds like Finnsheep and Romanov contribute to many composites involving well-adapted, general-purpose breeds. Composite breeds can be designed and developed to serve as general purpose breeds, specialized ewe breeds, and specialized sire breeds. Although rotational systems achieve higher levels of heterosis than composites for a given number of breeds (Table 5), composites are managed as a single flock, maintain very beneficial levels of heterosis, and have stable breed composition. For these practical reasons, many popular breeds in the U.S. originated in this manner. Columbia, Corriedale, Montadale, Polypay, and Targhee are examples of composite breeds.

Long-term expression of heterosis effects in a composite breed depends on maintaining heterozygosity. After the base generation of crossbred sheep is produced, a composite is managed as a closed breed and heterozygosity decreases due to eventual mating of related ewes and rams (inbreeding). To maintain levels of heterosis, a composite breed should use at least 25 rams each generation. Assuming 20 ewes per ram, a flock of at least 500 ewes is suggested. Therefore, creation of a new composite breed is a major undertaking, requiring substantial resources of a single producer or group of producers sharing a common vision. An excellent example of development of a composite breed by private industry is included in this issue of the Sheep and Goat Research Journal (Use of Finnsheep in a Western Commercial Sheep Operation).

Terminal crossbreeding systems.
Mating types, products, and levels of lamb and ewe heterosis are presented in Table 6 for each type of terminal crossbreeding system. Rams of specialized sire breeds are mated to purebred, first cross, rotational, or composite ewes to produce terminally-sired market lambs that express 100% of lamb heterosis. While general-purpose crossbreeding systems exploit genetic effects of breed diversity and heterosis, terminal crossbreeding systems also take advantage of complementarity. Because specialized sire breeds focus on growth and carcass traits, the genetic merit of terminally-sired lambs is different than other replacement and market lambs produced within a system. Terminal crossbreeding systems are more complex to manage than general-purpose crossbreeding systems because an additional flock (ewes mated to the specialized sire breed) is present, but terminal systems have powerful genetic advantages of greater use of lamb heterosis and complementarity.

Terminal crossbreeding systems are generally feasible due to the reproductive rate of sheep. Depending on circumstances, only 15 to 40% of ewes in the breeding flock are required to produce replacements. Remaining ewes can be bred to rams of specialized sire breeds. A key determinant of the relative efficiency of self-contained crossbreeding systems is the percentage of ewes needed to produce replacements. As reproductive rate increases due to use of more prolific breeds and heterosis effects, a greater percentage of ewes can be mated to terminal sires and the system becomes more efficient.

Relative production of crossbreeding systems.
Information provided in Tables 5 and 6 reveals that crossbreeding systems vary considerably in complexity of management, products, and use of lamb heterosis, ewe heterosis, and complementarity. To decide among crossbreeding systems, it is necessary to account for impact of these various genetic effects. It is not possible to directly compare all crossbreeding systems through experimentation with sheep due to limited resources available for research. However, the productivity of crossbreeding systems can be predicted by using reliable estimates of heterosis effects (Table 4), reasonable assumptions about production levels, and crossbreeding theory. A number of assumptions are necessary to predict the productivity of each crossbreeding system.

1. The ewe replacement rate is 20% per year.
2. All replacement ewes are produced within each system, rams are purchased as needed.
3. Averaged across breeds, purebred ewes wean 1.4 purebred lambs per ewe exposed.
4. Effects of lamb heterosis on lambs weaned per ewe exposed is 15% (Table 4).
5. Effects of ewe heterosis on lambs weaned per ewe exposed is 15% (Table 4).
6. Averaged across breeds, purebred lambs weigh 50 pounds at weaning.
7. Effects of lamb heterosis on weaning weight is 5% (Table 4).
8. Effects of ewe heterosis on weaning weight is 6% (Table 4).
9. Use of a specialized sire breed increases weaning weight of lambs by 5%.

The above assumptions were used to predict the total weaning weight produced by each crossbreeding system. The predicted value of purebred flocks was set at 100 and values for other systems expressed relative to purebred flocks. Results are given in Table 7.

Although effects of lamb heterosis and ewe heterosis on individual traits may seem small, effects accumulate to have significant impact on a measure of overall productivity, such as litter weaning weight per ewe exposed. Furthermore, combined effects of lamb heterosis, ewe heterosis, and complementarity can increase production by 40 to 50% relative to the average of purebred flocks of different breeds.

Lamb heterosis in the first-cross, general-purpose system increases production 17% relative to purebred flocks. Rotational and composite general-purpose systems create both lamb and ewe heterozygosity, thereby being more productive than purebred and first-cross general-purpose systems. General-purpose rotational systems achieve greater levels of heterosis than composite systems for a given number of breeds and therefore are more productive. The two-breed rotation has a value of 134 compared to 125 for the two-breed composite. Corresponding values are 143 for the three-breed rotation compared to 131 for the three-breed composite. A four-breed composite is intermediate (138) to two- and three-breed rotational systems (134 and 143, respectively). Similar relationships between rotational and composite programs are predicted in terminal crossbreeding systems. As discussed, composites are less complex to manage than rotational systems and also have stable breed composition.

Comparison between general-purpose and terminal crossbreeding systems within rotational or composite programs, demonstrates effects of increased lamb heterosis and use of complementarity. For example, productivity of the two-breed rotational, general-purpose system is increased from 134 to 146 in the two-breed rotational, terminal system. The increase is partly due to weaning more lambs, but primarily to heavier weaning weight of terminally-sired lambs. Advantages of terminal systems are greater in composite than rotational programs because rotational general-purpose systems achieve greater levels of lamb heterosis than composite general-purpose systems. That is, lamb heterosis increases from 67 to 100% in a two-breed rotation by use of terminal sires, but from 50 to 100% in a two-breed composite. Productivity of the purebred general-purpose system is increased from 100 to 122 in the purebred terminal system.

The first-cross terminal system is also referred to as a three-breed cross or a static terminal-sire system. This is the only system that uses crossbred ewes expressing 100% of ewe heterosis effects (Table 6). The productivity (150) is high and similar to two-breed (146) and three-breed (153) rotational terminal systems and three-breed (145) and four-breed (150) composite terminal systems. The managerial complexity of the first-cross terminal system is less than the three-breed rotational terminal system, equal to the two-breed rotational terminal systems, but greater than composite terminal systems.

In summary, crossbreeding systems vary in degree of complexity and use of lamb heterosis, ewe heterosis, and complementarity. Crossbreeding exploits these genetic effects and significantly increases productivity relative to purebred flocks. Efficiency of meat production is maximized in terminal crossbreeding systems by use of specialized sire breeds to complement characteristics of crossbred ewes.

Choice of Breeds

Tables 5, 6, and 7 provide information to evaluate advantages and disadvantages of numerous crossbreeding systems. Obviously, breeds used within any specific crossbreeding system greatly influence efficiency of meat production. Selection of breeds should be made only after careful forethought. Initially, production resources and limitations should be identified. Understanding resources such as labor, facilities, land, feedstuffs, managerial skill, etc., helps to define an appropriate production system. Sheep characteristics that most impact efficiency in the production system should be determined and reasonable target levels of performance established for each characteristic. This process provides a blueprint to describe ideal rams, ewes, and lambs for the specific production system and marketing goal. The blueprint guides selection of suitable breeds based on knowledge of breed characteristics in the relevant environment and determination of proper breed composition of crossbred sheep. At this point, crossbreeding systems can be evaluated to determine the system that most efficiently produces the ideal sheep, especially crossbred replacement ewes.

An important factor affecting efficiency of meat production is lambing rate. Because breeds of sheep vary greatly for lambing rate, it is critical to design the breed composition of crossbred ewes to meet target levels. Preliminary results from research at the U.S. Meat Animal Research Center illustrate the effect of breed composition on lambing rate. Dorset and Finnsheep rams were mated to Rambouillet ewes to produce contemporary first-cross ewes for comparison. Both types of crossbred ewes were terminally-sire mated to Suffolk rams. The average lambing rate of mature Dorset-Rambouillet ewes was 1.70 lambs, whereas, mature Finnsheep-Rambouillet ewes produced an average of 2.46 lambs. It is essential to select breeds and determine breed composition that achieve the targeted lambing rate of the production system.

Use of Crossbred Rams

Crossbred rams may benefit from increased fertility associated with ram heterosis, particularly in spring breeding, but their primary value is to optimize breed composition of crossbred ewes. Two-breed crossbred rams (AB) mated to ewes of a third breed (C) produce lambs that are 25% A, 25% B, and 50% C. This approach requires a producer to have a flock of breed C ewes and to buy crossbred AB rams. A more complex method to produce the same three-breed cross uses only purebred rams. A producer would mate breed A ewes to breed B rams to produce AB replacement ewes that are in turn mated to breed C rams. Use of crossbred rams simplifies production of sheep where less than 50% contribution of a breed is optimal.

The most common use of crossbred rams is to produce replacement ewes that are either 25% Finnsheep or Romanov. For example, a target lambing rate of 2.10 lambs might be well-suited for a given production system. Finnsheep-Rambouillet crossbred rams mated to Targhee ewes would produce replacement ewes that average about 2.10 for lambing rate. The value of Finnsheep and Romanov breeds is greatly enhanced by the productivity of quarter-blood ewes in production systems that support that level of prolificacy. There is an opportunity for seedstock producers to develop and market specific types of crossbred rams more effectively.

Production of Replacement Ewes

It is generally possible to produce crossbred ewes of similar or equivalent breed composition by use of first-cross, rotation, or composite systems. Suppose a producer decides that a crossbred ewe of 50% Cheviot and 50% Columbia is appropriate. Crosses between the two pure breeds would produce a first-cross replacement ewe. A two-breed rotation of Cheviot and Columbia rams would result in two flocks, one flock 67% Cheviot and 33% Columbia and the other flock 33% Cheviot and 67% Columbia. As Cheviot and Columbia are both general-purpose breeds, performance and therefore managerial requirements of the two flocks would be fairly similar. Finally, a composite breed could be developed that is 50% Cheviot and 50% Columbia; in fact, the Montadale is such a breed. First-cross, rotation, and composite ewes would express 100, 67, and 50% ewe heterosis, respectively, with performance related to the degree of heterosis as discussed (Table 7).

An intensive production system might support a crossbred ewe with very high lambing rate. Romanov ewes could be mated to Dorset-Rambouillet crossbred rams to produce first-cross replacement ewes that are 50% Romanov, 25% Dorset, and 25% Rambouillet. Another approach to produce ewes of similar breed composition is to use crossbred rams in a rotation system. Romanov-Dorset and Romanov-Rambouillet crossbred rams could be used in alternating generations. Resulting replacement ewes would always be 50% Romanov and either 33% Dorset and 17% Rambouillet or 17% Dorset and 33% Rambouillet. A three-breed composite that is 50% Romanov, 25% Dorset, and 25% Rambouillet could also be developed. Breed composition of first-cross, rotation, and composite ewes would be very similar and corresponding levels of ewe heterosis would be 100, 67, and 62.5%, respectively. Differences among these systems in use of heterosis would affect performance (Table 7).

These examples illustrate production of two-breed and three-breed replacement ewes in first-cross, rotational, and composite programs. In practice, the best system of producing replacement ewes is often relatively simple. If the system is too complex for the producer to manage, an efficient type of crossbred ewe may be abandoned. The problem may lie in the system of production, not the breed composition. Producers should carefully consider the long-term practical ramifications of different crossbreeding systems before developing a specific plan.

Changing breed composition of crossbred ewes in a commercial flock requires several years if 10 to 20% of ewes are replaced annually. Because younger ewes are less productive than older ewes, the impact on overall flock productivity is realized even less gradually. This situation emphasizes the importance of determining appropriate breed composition in a timely manner, as it is inefficient to repeatedly pursue a changing goal. Once the need to alter breed composition is apparent, one should immediately develop breeding plans to implement change.

Seedstock and Commercial Production

Discussion of the relative merit of crossbreeding systems assumed systems are self-contained, that is, all replacement ewes are produced within the system and rams are purchased as necessary. An individual producer can operate a self-contained system or specialize in one or more distinct segments of a system. A first-cross terminal system serves as an example (Figure 1). Dorset ewes and rams are mated to produce purebred replacements, Dorset ewes are mated to Rambouillet-Finnsheep crossbred rams to produce first-cross replacement ewes, and first-cross ewes are mated to Suffolk rams to produce terminally-sired market lambs. This system consists of purebred seedstock, crossbred seedstock, and commercial segments.

In a self-contained system, all three segments would be used by a producer. Or, a producer could focus on seedstock production, selling purebred and/or crossbred seedstock. Many commercial producers like to raise their own crossbred replacement ewes and, therefore, buy purebred seedstock to produce replacements for their commercial flock. Other producers prefer to specialize in commercial production and buy crossbred replacement ewes for their commercial flocks.

Final Recommendations

Advantages and disadvantages of many crossbreeding systems have been presented. From an industry-wide perspective, which system provides the greatest opportunities to address challenges facing the sheep industry?

Use of first-cross terminal systems is recommended. Widespread implementation would require greater communication, cooperation, and integration to wisely nse breed diversity and improve the genetic structure of the sheep industry. It would encourage producers and breed associations to understand roles of breeds in a crossbreeding context and, therefore, to practice selection for traits that are relevant for crossbred seedstock and market lambs. Purebred and crossbred Finnsheep and Romanov ewes can efficiently produce prolific first-cross ewes. Additionally, purebred and crossbred Finnsheep and Romanov rams can be mated to ewes of well-adapted breeds to produce first-cross replacement ewes. Adjustments to breed composition of first-cross ewes can be made quicky by simply changing sire breed of the first cross. First-cross ewes would express 100% of ewe heterosis that greatly impacts lifetime productivity.

If the sheep industry is not willing to integrate use of breed diversity and therefore is unable to broadly implement first-cross terminal systems, then composite terminal systems are an excellent alternative. Composite breeds can be designed and developed as specialized ewe breeds to achieve targeted levels of performance appropriate for environmental conditions and to complement characteristics of specialized sire breeds in terminal crossbreeding systems. The primary advantage of composite terminal systems is simplicity.

Suggested Additional Reading

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Table 1. Relative levels of performance of breeds for several traits.

Breed	Length of season	Age at puberty	Lambing rate	Mature weight	Hardiness
Dorset	long	average	average	average	average
Finnsheep	average	young	very high	light	average
Rambouillet	long	old	low	average	high
Suffolk	average	average	high	heavy	low

Table 2. Lamb heterosis for weaning weight (pounds).

	Purebred lambs		Crossbred lambs	
Item	A	B	BA	AB
Weight	53	63	62	60
Average	58		61	
Heterosis	3 pounds (61 - 58) 5.2% (3/58)			

Table 3. Ewe heterosis for lambing rate.

	Purebred ewes		Crossbred ewes	
Item	A	B	AB	BA
Lambing rate	1.70	1.90	1.84	1.88
Average	1.80		1.86	
Heterosis	0.06 lambs (1.86 - 1.80) 3.3% (0.06/1.80)			

Table 4. Estimates of lamb and ewe heterosis effects[a].

Trait	Lamb	Ewe
Birth weight	3.2	5.1
Weaning weight	5.0	6.3
Preweaning daily gain	5.3	-
Postweaning daily gain	6.6	-
Yearling weight	5.2	5.0
Conception rate	2.6	8.7
Lambing rate	2.8	3.2
Preweaning survival	9.8	2.7
Lambs born per ewe exposed	5.3	11.5
Lambs weaned per ewe exposed	15.2	14.7
Litter weaning weight per ewe exposed	17.8	18.0

[a] Effects expressed as a percentage of the purebred average (Nitter, G., 1978).

Table 5. Mating types, products, and heterosis realized in general purpose crossbreeding systems.

			Heterosis[a]	
Genetic type of lamb	Mating type[b]	Products[c]	Lamb	Ewe
Purebred	A x A	Replacement, market	0	0
First cross	A x A	Replacement, market	0	0
	A x B	Market	100	0
Rotation				
Two-breed	AB_R	Replacement, market	67	67
	BA_R	Replacement, market	67	67
Three-breed	ABC_R	Replacement, market	86	86
	BCA_R	Replacement, market	86	86
	CAB_R	Replacement, market	86	86
Composite				
Two-breed	AB_C	Replacement, market	50	50
Three-breed	ABC_C	Replacement, market	62	62
Four-breed	$ABCD_C$	Replacement, market	75	75

[a] Percentages of maximum possible lamb and ewe heterosis effects.

[b] A, B, C, and D represent breeds, subscripts R and C indicate rotation and composite, respectively.

[c] Products of matings are replacement ewes and market lambs.

Table 6. Mating types, products, and heterosis realized in terminal crossbreeding systems.

			Heterosis[a]	
Genetic type of ewe[b]	Mating type[c]	Products[d]	Lamb	Ewe
Purebred	A x A	Replacement, market	0	0
	T x A	Terminal market	100	0
First cross	A x A	Replacement, market	0	0
	A x B	Replacement, market	100	0
	T x AB	Terminal market	100	100
Rotation				
Two-breed	AB_R	Replacement, market	67	67
	BA_R	Replacement, market	67	67
	T x AB_R, BA_R	Terminal market	100	67
Three-breed	ABC_R	Replacement, market	86	86
	BCA_R	Replacement, market	86	86
	CAB_R	Replacement, market	86	86
	T x ABC_R, BCA_R, CAB_R	Terminal market	100	86
Composite				
Two-breed	AB_C	Replacement, market	50	50
	T x AB_C	Terminal market	100	50
Three-breed	ABC_C	Replacement, market	62	62
	T x ABC_C	Terminal market	100	62
Four-breed	$ABCD_C$	Replacement, market	75	75
	T x $ABCD_C$	Terminal market	100	75

[a] Percentages of maximum possible lamb and ewe heterosis effects.

[b] Genetic type of ewes mated to specialized sire breed.

[c] A, B, C, and D represent dam breeds, T represents a specialized sire breed, and subscripts R and C indicate rotation and composite, respectively.

[d] Products of matings are replacement ewes, market lambs, and terminally-sired market lambs.

Table 7. Relative production of different crossbreeding systems[a].

Genetic type	General purpose[b]	Terminal[c]
Purebred	100	122
First cross	117	150
Rotation		
Two-breed	134	146
Three-breed	143	153
Composite		
Two-breed	125	141
Three-breed	131	145
Four-breed	138	150

[a] Production relative to total pounds weaned from a purebred flock.
[b] See Table 5 for mating types, products, and heterosis associated with each genetic type.
[c] See Table 6 for mating types, products, and heterosis associated with each genetic type.

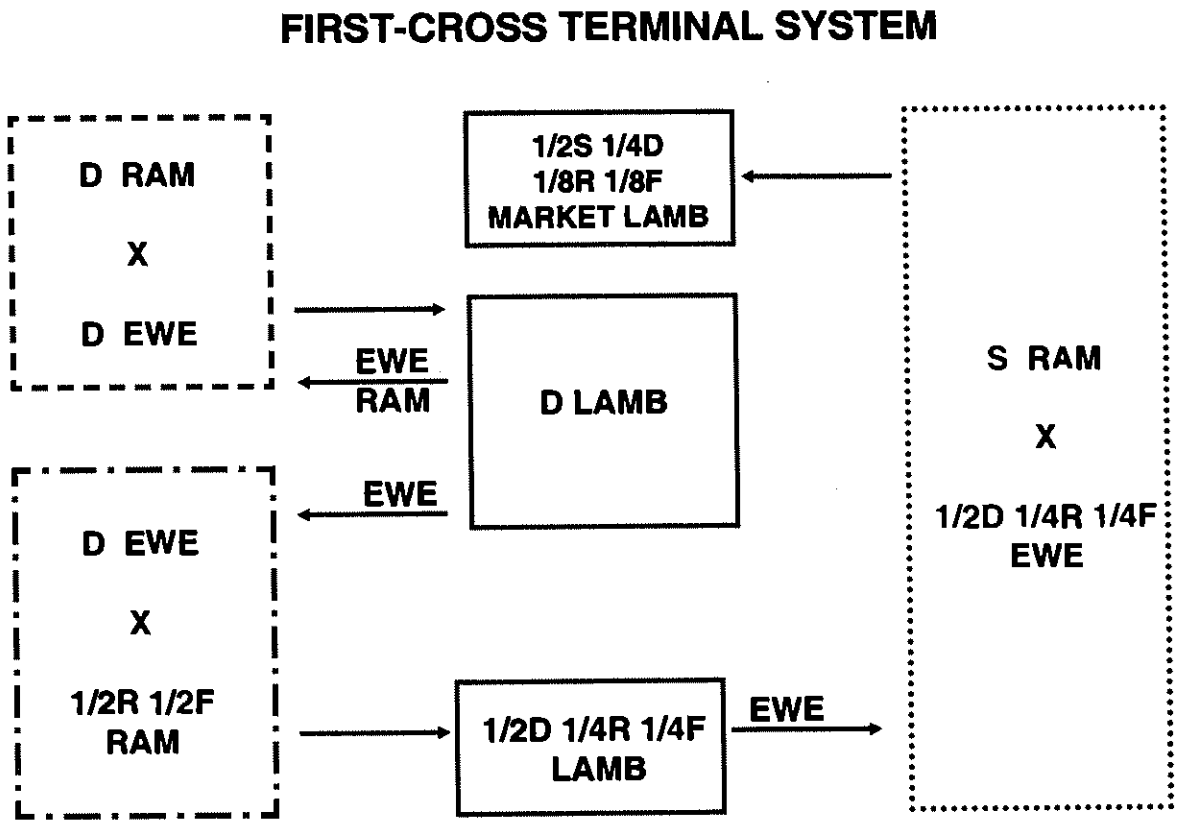

Figure 1. A first-cross terminal system using Dorset (D), Rambouillet (R), Finnsheep (F), and Suffolk (S). Matings to produce purebred replacements (⬚), first-cross replacement ewes (⬚), and terminally-sired market lambs (⬚) are indicated.

Use of Finnsheep Crosses in a Western Commercial Sheep Operation

Richard and Burrows Hamilton
Hamilton Brothers Ranch, Rio Vista, CA

The Hamilton family has been engaged in agriculture, including sheep production, in California for more than 130 years. The farming and ranching operation is diversified, and includes row crop farming, dry land grain and safflower farming and livestock which also includes cattle. The sheep flock today consists of about 3800 commercial whiteface ewes that are 3/8 Finn, and about 85 purebred Suffolk ewes.

The climate of the area is Mediterranean, with rain from October or November to March or April, and thus with a dry season of at least six months in most years. Sheep are an integral part of our cropping system, and particularly important to the dryland wheat and barley production, which is our largest cropping enterprise. Following harvest of the grain crop, the sheep graze the crop residues during the summer. The land is left fallow the following season or sometimes two seasons, but with the rains there is a substantial "volunteer" crop of grasses and forbs, which provide good grazing for the sheep. If not grazed, this growth would make crop preparation the following season more difficult, especially in better than average rainfall years. Sheep have an advantage over cattle in this system in that they cause much less compaction of the heavy clay soils. The ranch includes considerable areas of native grass range that are also grazed much of the year to complement the stubble and fallow grazing. The sheep are also used to enhance sensitive native California grasslands for the Nature Conservancy, Solano County Open Space and the California Fish and Game Department.

Ewes are lambed in two seasons, a fall lambing from October 18 to December 15, when 75% or more of the mature ewes lamb, and a winter lambing from January 20 to March 15, when the ewe lambs and remainder of the mature ewes lamb. Ewes in each group are pregancy tested and separated by fetal count and estimated stage of gestation. Mature ewes with singles are generally field lambed, while those carrying multiples and all ewe lambs are barn lambed. A very successful fostering system is used to maximize the number of ewes raising twins and minimize the number of ewes that fail to raise a lamb.

Breeding Plan

The traditional plan for obtaining replacement ewes in nearly all California commercial sheep operations is to purchase yearling whiteface ewes, of predominantly Rambouillet and Targhee breeding, from the intermountain states, Texas, New Mexico and Arizona. While such ewes at maturity will have reasonably satisfactory fall lambing performance, there is no selection for that in the spring-lambing intermountain flocks. The yearling ewes, often little more than 12 months of age when put with the rams in California, often have a high percentage of dries (typically 10 to 15%) the first year. These ewes do not produce enough twins to reach a 100% lamb crop. California's average lamb crop is approximately 90%.

In the late 1960's, we realized that the traditional range ewe wasn't productive enough to meet the ever-changing demands of the sheep industry in our area. Our weaning rate per ewe in the flock was not much over 100%, typical for the area then and still for many flocks today. A decrease in the number of dry ewes and an increase in twinning rate seemed essential. In 1970, Dr. Eric Bradford of the University of California at Davis had acquired from USDA the first Finnsheep rams in the state, and had mated these to some Targhee ewes from a group selected for several years for increased weaning weights. Ken Ellis of UC Cooperative Extension organized a program with a few ranchers to evaluate the performance of ewes sired by these Finn-Targhee rams. We obtained rams from these first Finn crosses and used them on selected twin-bearing ewes in 1972.

The daughters of these rams weaned more lambs than any ewes we had had up to that time. Furthermore, as ewe lambs, mated at about 9 months of age, they had fewer dries than the purchased yearling ewes that had been our replacements in the past. With our 1/4 Finn cross ewe lambs, we typically would get 82 to 87% conception rate and turn out 1.15 lambs per ewe and today, with our 3/8 Finn cross, we typically get between 90 and 96% conception rate and turn out 1.20 to 1.30 lambs per ewe. We therefore obtained more 1/2 Finn rams, and converted the entire ewe flock to 1/4 Finn breeding. Our weaning percentage from mature 1/4 Finn ewes, lambing predominantly in the fall, rose to 135%. When we started selecting Finn cross ewes and rams, we instituted strict production and quality standards in our program. We tried to achieve standards in wool quality, conformation, and production that best utilizes our available resources and meets the needs of our markets. Our goal is to produce a ewe that at the minimum twins yearly during the fall, produces a wool clip between 22.05 to 23.49 microns, and produces Yield 2 market lambs weighing between 135 and 140 pounds. Concerns about size, conformation, and adaptability to Western sheep operations are reasons often stated by other producers for not being willing to try Finn crosses. What other producers often don't realize is the high lamb production potential of these sheep, which is so important to net returns, and thus the potential advantages from incorporating a percentage of Finn to meet production goals. Our results show thar the risk of loss in wool quality, conformation and adaptability can be overcome through selection.

With 1/2 Finn rams of the type we were using not readily available to purchase, and recognizing that we could probably raise better rams than we could buy, we started to raise our own rams, from the best of our 1/4 Finn ewes and rams, in 1981. We chose not to use Polypays, which were becoming available, because we felt our sheep were somewhat larger, and more consistent and finer in wool quality. Had the Polypay been available when we first started our own breeding program, we might have used that breed, but by the time it was available, we had our own program which was working well for us.

By 1985, our management and success in raising twins had improved to the point that we felt we were ready to move to a higher level of prolificacy. After discussing some possibilities with Dr. Bradford, we decided to evaluate 3/8 Finns, and in 1986 purchased several large, heavy-boned 1/2 Finn x Targhee rams from Art Christiansen of Montana. These were mated to our best 500 1/4 Finn ewes, and their daughters evaluated before proceeding further. The first year, 96% of the 3/8 Finn ewe lambs lambed at 14-15 months of age (vs. 88% for 1/4 Finns). When the performance of these ewes at older ages showed that they regularly outperformed the 1/4 Finns, we made the decision to convert the entire flock to 3/8 Finn. Our philosophy in trying any new genetics is to compare the new cross with the control, in this case our established 1/4 Finn flock. We evaluate all of the potential benefits and problems of the new cross during a lifetime production cycle, with enough numbers to be confident of the results. This takes about five years and it is at that time we decide if the new cross is going to become the established cross.

Identification, Flock Management and Selection

With the exception of rams and of our purebred Suffolks, our sheep are not individually identified, but we do use a system of types and shapes of ear tags, ear notches, ear tattoos and type and color of paint brand to keep information needed in facilitating our selection process. The pertinent information is year of birth, type of birth and rearing, wool quality and lambing history (being dry their first year, what breeding group they are in, time of year they lamb - fall or spring - and what type of lambing they have had).

A potential replacement ewe lamb is given an All Flex ear tag in her left ear at docking. The male part of the tag is a sheep type tag and the color of the tag represents the birth year. The colors are rotated and we mix in white also. All our livestock, which includes cattle, have the same color tag each year. The female or bottom part of the tag is either black, meaning twin or triplet raised, or white, meaning single raised. The shape of the female tag represents the type of cross of the ewe. In our 1/4 Finn cross, we used a sheep type tag and in our 3/8 Finn cross, we use a hog type tag. If we are testing a new cross, the females of that cross are also given an ear tattoo in their right ear. We will ear tattoo until the new cross becomes the only cross we are raising. Currently, we are testing a Friesian cross and we are back using the sheep type tag as a bottom tag since there are no 1/4 Finn ewes left in the flock. There is no question that singles grafted as twins are identified as twins and twins born and raised as singles are identified singles. We do not feel that this has had a serious effect on our success in selection. We do try to graft only male lambs as twins to help reduce the effect of any misidentification on replacement ewe selection.

When a ewe reaches 12 to 14 months of age and before she is sheared as a yearling, we visually fleece each ewe and look for wool quality and consistency from shoulder to breech. Ewes that are off in quality are given a black All Flex medium ear tag in their right ear. This means that these ewes can only be used with terminal sires and not used to raise replacements.

We do individually identify ram lambs, since we keep individual wool production and breeding group records on rams. Since we keep only twin born and raised rams out of twin raised ewes, we identify the potential ram lambs before they leave the lambing facilities. Since the lambs and ewes are number branded for twin ID at birth, we can find a potential ram lamb's mother and twin and see their visual qualities. We do note the mother's ID with the potential ram. The ram lambs are given a numbered ear tag that matches the shape of the ewe's left ear tag, and also an identifying ear notch number. Since we are in the voluntary scrapie program, the rams are given a permanent scrapie ear tag in their right ear that matches the number and color of the ear tag in their left ear.

If a ewe at 14 months of age fails to raise a lamb, she receives a metal ear tag in her right ear. If this ewe with a metal tag shows up again open at preg testing or fails to raise a lamb, she is automatically culled. Normally, only first time lambing ewes get a second chance. We do not supplement ewe lambs before breeding so their conception rate is highly correlated to feed conditions.

Ewes are segregated into "single" and "twin" bands (and now in some cases into a triplet band) after lambing, and these are usually kept separate at weaning so that those raising multiples are known when mating bands are made up for the next season.

To maintain our sheep-stocking rate for our available resources and balance with our cattle operation, we need to retain 800 to 900 ewe lambs a year. To achieve our replacement numbers, we breed 1700 ewes to our 3/8 Finn rams. These ewes are selected in terms of size, conformation, fleece quality, history of twinning and fall lambing and are divided into 3 equal size groups. These replacement groups lamb between October 20 and December 15. These groups are known as a Purple group, Green group and Orange group. Once a ewe gets into one of the three groups, she is given an All Flex medium ear tag of the same color as the tag in her right ear. We also put a color ownership (HR) brand to match the color of the group ear tag. The earliest a ewe can get into this group is usually at 3 to 4 years of age, when her performance history has been established. As stated earlier, ewes with black tags in their right ear are not eligible for this group. A ewe will stay in this group as long as she meets the production standards. All the other mature ewes, which include the black tag ewes, are branded with a blue ownership (HR) brand and they are bred to Suffolk rams.

Each year with our three replacement groups (Purple, Green, & Orange), we designate two groups as ewe replacement groups and one as the ram replacement group (ewe replacements are also selected from this group). Since we have a cross of sheep that is very hard to find outside of our own program, we try to avoid inbreeding through a system of rotation of the group providing replacement rams. Rams never breed ewes from the group in which they were born. Also, rams are used for no more than 3 years, and ewes do not enter a replacement breeding group until 3 or 4 years of age, so sib matings are also avoided. The ram producing group is always the group bred to the new crop yearling rams. Example: In 2000 fall lambing, our 1998 born yearling rams out of the Orange group are the sires of lambs in the Green group, which is the designated ram sire group. These 2000 fall born Green group ram lambs will be used as yearling sires on the Purple group for the fall lambing of 2002. This system has worked well. We have not brought in an outside ram since 1990. We do keep rams out of the ewe replacement groups, but they are sold to other breeders.

In California, with our green grass period starting in late December and ending in April, we have to have lambs old enough to take advantage of these grasses. This is why we lamb so early in the fall; we can lamb or run ewes and lambs on alfalfa and then move to the native grasses when the feed is strong for lambs. Since we are trying to breed at a time of year when ewes aren't cycling as regularly or have lower ovulation rate compared to fall breeding, we can overcome a lot of the difference with genetics (ex. Finn), and also using other tools such as flushing and teaser rams. In our operation, we do flush ewes on native grass fields that were not grazed in the months of March and April, and we also use teaser rams. From past history, we know we get a tremendous "ram effect" on our ewes when we put the rams in. If the ewes breed on the first cycle their ovulation rate is lower, especially in May. To help overcome the lower ovulation rates, we expose the ewes, including the ewe lambs, to teaser rams for one month before the breeding rams go in. This way we hope to get one or two estrous cycles before introducing the breeding rams. We feel it has helped our twinning percentage and also helped even out the peaks of lambing. We make teasers out of single born 3/8 Finn ram lambs.

Ewe lambs are mated beginning August 12, at an average of 9 months of age, until October 23, at the same time as the cleanup mating of the mature ewes. Ewe lambs are bred to 3/8 Finn rams, but no replacements are kept from them, although some of their lambs are sold as replacements for other flocks if there is demand.

Mature ewes are ultrasounded for pregnancy and fetal count in late August, and those with singles and with multiples, and early and later pregnancy, separated, for more efficient use of any supplemental feed and to facilitate management at lambing. Accuracy of counts has been good, about 95%. All the open ewes are run together and continue to be exposed to both Suffolk and 3/8 Finn rams. We continue to keep a couple of 3/8 rams with the pregnant ewes, so we have ram coverage for any ewes reabsorbing fetuses. All rams are removed on October 23. Ewes from later breeding are pregnancy checked approximately 35 days after the rams are removed.

Selection of rams occurs at several stages. As indicated, rams for use in our flock come from the designated ram replacement group, and other ram lambs for potential sales come also from the two ewe replacement groups. As stated earlier, promising individuals from dams raising twins or triplets are identified before hauling to the alfalfa or native pasture fields, so when docked they don't get castrated. We will identify about 125 to 140 potential rams. We wean the ram lambs at about 70 to 80 days of age to avoid possible mother to son breedings. At weaning, we castrate any "off" or below average ram lambs based on weight for age. After weaning, we take a side and breech wool sample for each ram lamb, and cull some based on wool evaluation. From approximately one month after weaning until they are evaluated as yearlings, the ram lambs are raised strictly on native rangeland and their further evaluation for size, conformation, condition and hardiness is based on these growing conditions. At yearling shearing their fleeces are weighed and graded, and this information, along with size and conformation, is used in selecting rams needed for the flock. Fleece grade is emphasized, in the interests of maintaining a uniform clip for the whole flock. Once we select our replacement yearling rams, we will cull the older rams from the flock. Normally, we turn over 3/8 Finn rams every three years. These older rams and the yearling rams from our ewe replacement groups are popular, and we are finding a more consistent demand than for replacement ewes. We sell on average 40 to 45 rams a year to other producers.

2000/2001 performance levels of the flock are approximately as follows:

	Replacement groups, rams in May 18	Terminal sire groups, rams in June*.	Ewe lambs
%preg : by late Aug. preg test	87%	53%	-0-
%preg : end of season preg test	12%	43%	93%
% open : end of season preg test	1%	4%	7%
Lambs/ preg ewe @ late Aug. preg test	1.57 lambs/ewe	1.45 lambs/ewe	-0-
Lambs/ ewe @ Docking (3.5 wks of age)	1.48 lambs/ewe	1.38 lambs/ewe	-0-
Lambs/ preg ewe @ last preg	1.64 lambs/ewe	1.64 lambs/ewe	1.51lambs/ewe
Lambs/ ewe @ Docking (3.5 wks of age)	1.51 lambs/ewe	1.51 lambs/ewe	1.20 lambs/ewe
Weaning wt.			
Twin lambs (note: 2000 ave. wt)	89 lbs.	85 lbs.	65 lbs.
Single lambs (note: 2000 ave. wt)	102 lbs.	98 lbs.	77 lbs.
Ewe Fleece wt.	8.2 lbs	8.2 lbs.	8 lbs.

*Rams are turned in two different dates. Group includes all yearling ewes

The wool clip sells under the term "original bag". "Original bag" means that we produce enough wool that it doesn't need to be pooled with other producers' wool, so our wool sells as Hamilton Bros. Ranch wool and how it sells depends on the quality and consistency of our micron reports. We belong to the Cal Wool Marketing Assn., a cooperative, which acts as our selling agent. We skirt and class our wool and it is marketed in two lines. Our A line is approximately 85% of the clip grading 62's, 22.0-23.5 microns, and our A1 line is a 60's clip, which is 23.5-24.9 microns. To help us evaluate our program of selecting for wool quality, we look at the standard deviation and coefficient of variation of our wool. On average, the standard deviation of our A line wool has been 4.6 to 4.9 and the maximum standard deviation for 62s grade wool is 5.89. On average, the coefficient of variation of our A line is between 19 and 20.4%.

As these figures show, the reproductive performance of the flock is much above the average, particularly for large flocks, for California or for the US. The fleece weights and fleece quality, and in fact the size and conformation of the sheep, are much superior to what many producers would expect from 3/8 Finn sheep. The increased prolificacy has no doubt come mainly from the introduction of Finn breeding. The growth rate, conformation and fleece traits we believe come from the selection we have practiced, in choosing the 1/2 Finn rams used to upgrade the flock to 3/8, and the ewe and ram selection practiced within the flock, on the ewe side now for more than 25 years.

Today, when people come to see our 3/8 Finn cross sheep, they can't believe that they have that much Finn in them based on their size, conformation, and wool quality. What we tell people when they visit our ranch is that we developed our Finn cross to work for our operation and that it might not work for you. If you are going to take something from our experience, take the idea that there are a lot of tools available to help you make improvements to your operation to be successful in the sheep industry.

The single most important factor in the success of our sheep operation has been the Finnsheep. Without the benefits of the Finn, we couldn't have made the changes that we needed to make to have a chance to survive in a global market.

Comments added by G. E. Bradford, University of California, Davis

The Hamilton ranch flock represents an exceptionally successful breeding and production operation, and it may be worthwhile to include an interested observer's comments on factors that appear to have contributed to this success.

1. Clear goals. The Hamiltons recognized that they needed to increase the number of lambs weaned per ewe to maintain a profitable operation, and have focussed on that goal throughout. Emphasis on secondary goals followed achievement of an increase in fertility and prolificacy.

2. Systematic evaluation based on performance. Lambing performance of the first 1/4 Finn crosses was compared with that of their traditional sheep before a decision was made to convert the flock to 1/4 Finn breeding, and the same step was followed before the decision to convert to 3/8 Finn. (A similar approach is currently under way in the flock to test the progeny of East Friesian x Targhee rams, to see if they can improve milk production and/or growth rates). In each case, by maintaining identity of the animals in the test group, the owners retain the option to eliminate all animals from that group if their performance is not better on average than that of the group they would replace.

3. Identification of all animals by breed group, year of birth, type of birth and current prolificacy level. Thus, even without individual identification, much is known about the pedigree and performance of each animal. Combining this with stratification into flocks to produce replacements and to be bred to terminal sires permits quite intense selection on performance, without individual performance records on the ewes.

4. Management has improved to take advantage of the increased genetic potential for prolificacy. This has included more jugs in the lambing barn, pregnancy checking and separation of single- and multiple-bearing ewes, improved supplemental feeding strategies, and more fostering.

The combination of higher genetic potential for prolificacy from the Finnsheep breed, consistent selection of rams and ewes under commercial production conditions, and improved management, has resulted in a flock production level estimated at 30 to 40% above that of average flocks in the state.

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