MANAGEMENT AND NUTRITION FOR MILKING SHEEP IN SHORT AND FREQUENT LACTATIONS

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INTRODUCTION

Traditional sheep dairy production is seasonal. The lack of year-round availability of fresh product has deterred steady sales and buyers' markets of sheep milk and sheep milk products in the US. Research from Europe suggests seasonal income, as well as difficulties to coordinate lambing seasons (Sitzia et al., 2015), as interference to an even and reliable marketplace. The 30% rise in consumption of dairy sheep products in the past 20 years (Thomas, 2014) – the US imports 50 to 60% of the world's annual exports in sheep dairy products (Thomas, 2014) – indicates a dramatic increase in US demand for sheep milk products. Official FAO data from 2011 lists an import amount of 26 million kg of sheep milk cheese. With a cheese yield of ~18-25% that is equivalent to ~123 million kg of raw sheep milk.

A survey conducted prior to this research showed that 70% of the ~60 responding sheep dairy farmers with flock sizes ranging between 20 and 2,000 head in northeastern US indicated that they would consider a change in a current operation and begin to milk sheep year-round to meet this rising demand. Little new East-Friesian or Lacaune dairy sheep breed genetic material is available. Import restrictions from Europe are stringent. Additionally, the non-surgical artificial insemination traditionally used in sheep (Purdy et al., 2009) and a lack of a phenotypic data for a comprehensive genetic analyses limits the pace of selection to meet the rising demand. Hence, research into new management practices, aseasonal breeding ability, and nutritional strategies to boost year-round milk production in sheep is needed to provide dairy sheep farmers with techniques to produce at a price competitive with imports and to allow for consistent income and economically viable operations.

The main aims of an on-going two-year experiment (projected to end September 2018), at the Cornell Teaching barn are: 1) a comparison of published values for 180-day, yearly lactations of traditionally-milked dairy-breed ewes with yearly yields and components of Dorset and Finnsheep × Dorset ewes milked in short and frequent lactations; and 2) the determination of optimal dietary levels of fermentable fiber for maximum milk production, ewe body condition, fertility, fecundity, and flock health.

EXPERIMENTAL DESIGN

Dorset, Finnsheep and Dorset X Finnsheep crossbred ewes, not previously selected for dairy production, are being milked in short and frequent lactations on the STAR accelerated lambing system, developed by Brian Magee and Doug Hogue at Cornell in the 1980s (Lewis et al., 1996; Lewis et al., 1998; Posbergh et al., 2017). In the STAR system, any ewe with a perfect conception rate will lamb 5 times in 3 years or 1.67 times per year which results in short and frequent lactations when adapted to dairy production.

The experiment is a triply replicated 3 x 3 Latin square with 3 diets (30, 35, 40% pfNDF) and 3 lactations (1, 2, 3) within each of 3 STAR groups (STARR, STARB, STARG) of ewes. Each Latin Square includes 3 pens with a minimum of 4 ewes within STAR group as columns, lactations as rows and diets repeated orthogonally in each pen and lactation of each Latin Square. Ewes and squares will be the replicates for yield and components of milk with 44 df for error. Squares will be the replicates for feed intake and milk/feed with 18 df for error. The 2 df for diets will be split into linear and quadratic orthogonal contrasts. The error for all response variables will be small because the replicated Latin Square design efficiently removes the group, lactation, and pen sources of variation.

Each STAR group is lambing and lactating consecutively at 205 days intervals. Ewes will lactate in three 73- to 103-day lactation periods throughout this two-year study with rebreeding starting on day 73 of each lactation. Lambs are removed within 12 hours after birth and after receiving colostrum from their dams. They are reared artificially on the cold-milk, lambar system. Breeding is enhanced with teaser rams. Except for the autumn breeding season, CIDRs are used (Inskeep, 2011) to ensure that the maximum number of ewes are cycling at the time of breeding. Milk yields are recorded twice daily for each ewe. Feed and refusal weights are collected twice daily for each dietary group; samples are collected once weekly. Rumen fluid and fecal samples are collected biweekly. Fecal, feed, and refusal samples will be analyzed with the acid insoluble ash method for digestibility (Thonney, 1979). Rumen fluid pH is measured immediately after collection. Then, rumen fluid is acidified and frozen for later VFA determination. The milking ewes are weighed once weekly during lactation. AM and PM milk samples are collected once weekly and analyzed for total fat and protein, SCC, MUN and fatty acid composition with a novel infrared method developed for cow milk and adapted for sheep milk by Dr. Dave Barbano from the Cornell Food Science Department (Woolpert, 2016, 2017).

The data reported here are from the first lactations from each of the STAR groups, STARR, STARB, and STARG, as well as a comparison of 1st and 2nd STARR lactations. Milk yield for the first lactation curves was fitted in MINITAB 18 and R to a model that include the fixed effects of STAR group, diet, and the STAR group x diet interaction. Ewe was included a random effect nested within STAR group and diet. Linear, quadratic, and cubic polynomials for days in milk (DIM) were included as covariates, allowing for the possibility of different covariates for STAR groups and diets. Non-significant covariates were removed by a modified step-down procedure until the model included only effects with P-values < 0.05. The statistical analysis of milk yield for lactations 1 and 2 of STARR was similar.

Dry matter intake for pens was analyzed by analysis of covariance with the effect of STAR group, diet, and the STAR group x diet interaction in the model and linear and quadratic effects day of lactation as covariates. The effects of STAR group and diet on covariates were included when P-values were < 0.05.

Diets

Previous research at Cornell showed that feed intake is impacted by the source and concentration of dietary fiber (NDF) (Schotthofer et al., 2007; Thonney and Hogue, 2007). The effect source of NDF was mainly due to the proportion of potentially-fermentable NDF (pfNDF) compared with indigestible NDF (INDF) (Thonney and Hogue, 2013); where pfNDF is defined as NDF – 1X maintenance INDF, with 1X maintenance INDF being determined by the concentration of indigestible dry matter at 1X maintenance (Thonney, 2017), minus 10 to 15 percentage units of DM as metabolic fecal losses (Van Soest, 1994). The diets were balanced on their carbohydrate fractions, mainly the concentration of pfNDF, followed by crude protein, minerals, and vitamins (Thonney, 2017). Due to their high concentration of pfNDF and pectins (that are fermented similarly to NDF), soy hulls were substituted for corn to increase the dietary pfNDF concentrations (Table).

Table 1. Composition of initial experimental diets (% of DM). The three diets formulated for this experiment differ in their levels of pfNDF: 30, 35, or 40%, respectively and are fed ad libitum with about 500 g of hay per ewe per day.

Ingredient	30% pfNDF	35% pfNDF	40% pfNDF
Soy hulls	43.60	52.10	60.60
Corn	41.20	33.40	25.60
Soybean meal	10.30	9.91	9.42
Vegetable oil	2.22	2.23	2.23
Cornell sheep premix	1.06	1.06	1.06
Ammonium chloride	0.78	0.78	0.78
Calcium carbonate	0.56	0.33	0.11
Salt	0.22	0.22	0.22
Estimated components			
DM	89.93	89.85	89.77
DDM	79.97	79.95	79.22
CP	16.10	16.11	16.10
NDF	36.37	41.72	47.07
pfNDF	30.61	35.56	40.52
INDF	5.87	6.27	6.66
NSCHO	38.93	33.67	28.44
EE	4.95	4.80	4.65
Ash	4.15	4.19	4.23

RESULTS AND DISCUSSION

Our findings so far are concurrent with previous research that showed minimal levels of pfNDF are needed to maintain healthy rumen function (Schotthofer, 2007; Schotthofer et al., 2007; Hein et al., 2010). Zero occurrence of acidosis was recorded; measured pH levels for STARR-2 ranged from 6.13 to 7.05. Sheep don't seem to rely on physically effective fiber (Mertens, 1997) and small particle size in feed doesn't appear to prompt acidosis (Nudda et al., 2004). For STARR-1, STARB-1, and STARG-1, pfNDF content of the experimental diets was highly influential (P < 0.000) on intake, as well as on milk production (P < 0.000). NDF concentrations of 37% of the dry matter were suggested in diets for lactating dairy ewes by Pulina (2004), which is in accordance to our findings but only if the NDF is highly fermentable.

Feed intake

Dry matter intake in lactation 1 tended to increase slightly with day of lactation but the change depended upon STAR group and diet (Figure 1). The STAR group x diet interaction (P = 0.004) intakes adjusted to the mean of 41 days of lactation are shown in (Table). The ewes in STARG were yearlings lambing and lactating for the first time so their lighter weights resulted in lower dry matter intakes. Dry matter intake was lowest for ewes fed the 40% pfNDF diet, but the highest intake varied with STAR group between the 30 and 35% pfNDF diets.

Table 2. Effect of STAR group and diet on daily dry matter intake (kg/ewe) in lactation 1 (SEM = 0.06).

	Diet		
Group and Lactation	30% pfNDF	35% pfNDF	40% pfNDF
STARR-1	3.2	3.4	2.9
STARB-1	3.0	2.7	2.6
STARG-1	2.6	2.6	2.5

Milk yield

Previous studies measured milk yields of traditional meat sheep a few times during lactation, mainly using weigh-suckle-weigh methods with ewes nursing lambs or in mixed milking and nursing systems. Suffolk and Targhee ewes reached peaks up to 3,744 g/d (Ramsey et al., 1998), and crossbred ewes peaked at 3,680 g/d (Cardellino and Benson, 2002).

The milk production results from the first lactation are summarized in Table 3. The 3rd degree polynomial was significant with both STAR group and diet affecting (P < 0.001) the equations that described the lactation curves. The first differentials of the average lactation curves for each diet within each STAR group were used to find peak lactation day and yield (Table). The integrals of the equations were used to calculate 73-day yield (Table). Previous research with nursing ewes (Schotthofer et al., 2007; Thonney and Hogue, 2007), indicated that ewes fed diets with levels of pfNDF higher than 30% would produce more milk. In line with the feed intake data (Table), however, peak milk yield day was later and higher and 73-day yield was highest for ewes fed the diet containing 30% pfNDF (Table 3). These results and the relatively high ruminal pH values for all three diets from a one-time sample during the second lactation of the STARR, suggests that 30% pfNDF is sufficient to maintain excellent ruminal function. Therefore, the more highly digestible 30% pfNDF diet allowed for higher milk production.

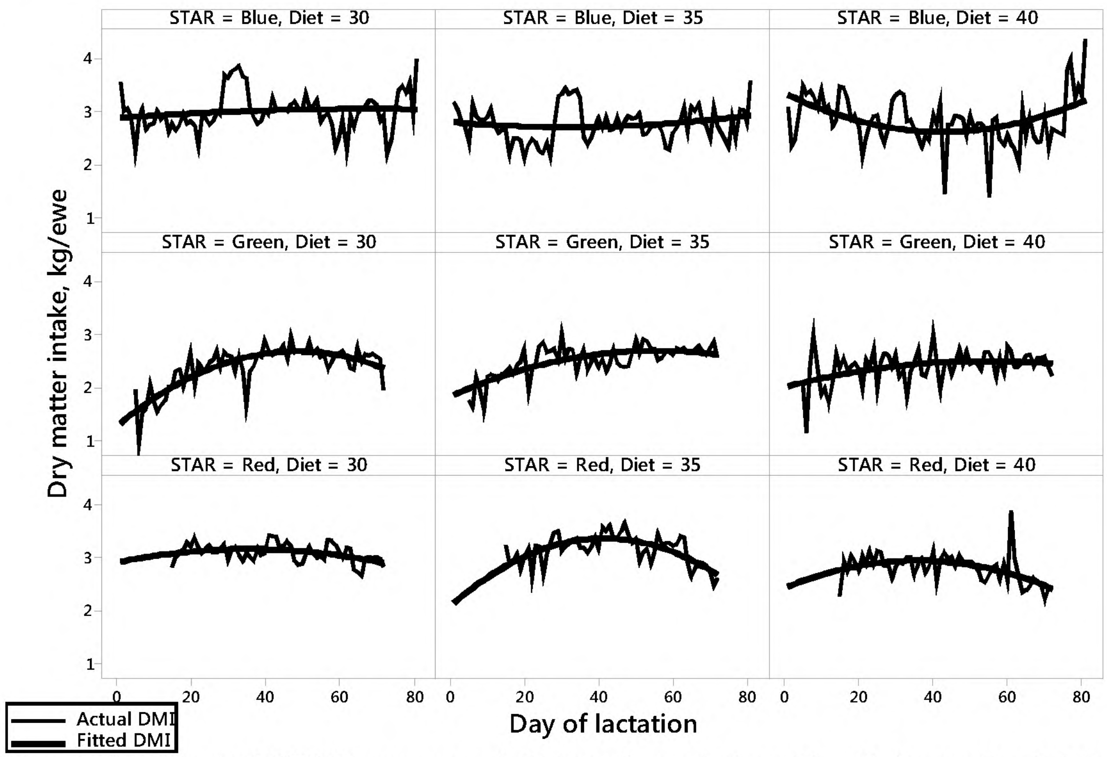

Figure 1. Effect of STAR group and diet on the relationship of dry matter intake to day of lactation 1.

The highest yielding Cornell ewes in our management system, so far, produced 2,722 g/d (STARR-1), 4,544 g/d (STARB-1), 2,903 g/d (STARG-1), and 4,082 g/d (STARR-2). In longer dairy sheep lactations, 25% of the milk yield achieved throughout lactation occurs within the first 30 DIM (Folman et al., 1966). Milking sheep in short and frequent lactations provides the opportunity to skim the lactation curves around their peaks, ranging between 7 and 30 days (Cardellino, 2002; Peterson, 2005) and makes use of high peak yields from the first part of lactation. Total milk yields of dairy sheep are compared with Cornell Finnsheep x Dorset crossbred ewes in Table . Overall through this stage of the experiment, the 30% pfNDF diet resulted in the highest response in milk production. All ewes fed this diet are listed in Table as Finnsheep x Dorset diet 30 with high producing ewes potentially selected for breeding listed as Finnsheep x Dorset High 30. Lactation lengths for the Finnsheep x Dorset diet 30 ewes are a multiple of 1.67, the maximum possible per year on the STAR system.

Table 3. Effect of STAR group and diet on milk production in lactation 1.

Group		Diets		
		30% pfNDF	35% pfNDF	40% pfNDF
STARR-1				
	Peak day	26	17	0
	Peak yield, kg/ewe	1.27	1.03	0.95
	73-d yield, kg/ewe	86	69	46
STARB-1				
	Peak day	12	14	1
	Peak yield, kg/ewe	2.59	2.11	2.05
	73-d yield, kg/ewe	144	116	103
STARG-1				
	Peak day	28	25	2
	Peak yield, kg/ewe	2.09	1.62	1.28
	73-d yield, kg/ewe	138	102	63

Although diets had a substantial influence ($P < 0.001$) on lactation curves throughout all STAR groups and lactation periods (Table), there was considerable variation among ewes within all groups and between STARR-1, and STARR-2. Example lactation curves for STARR-1 (24 October 2016 – 11 January 2017), and STARR-2 (3 June 2017 – 17 August 2017) groups are shown in Figure 2. The prominent differences between the milk yields of lactation 1 and 2 within all diets likely stem from the different management the ewes underwent prior to entering this study.

Table 4. Milk yield comparison among dairy and meat breeds.

Sheep breeds	Lactation length d/year	Milk yield kg/year	Literature
East Friesian	189	359	(Thomas, 2014)
Lacaune	180	345	(Thomas, 2014)
Finnsheep x Dorset Diet 30	125	225	Current experiment
Finnsheep x Dorset High 30	115	246	Current experiment

Ewe weight

The ewes in all groups gained weight after parturition and maintained excellent body condition and health while achieving high levels of milk production, even in the first part of lactation. For STARR-1, weight gain was significantly high ($P < 0.001$) throughout lactation. As can be observed in Figure 2, STARR ewes produced dramatically less milk in their first lactation compared with their second lactation. This might be related to the diet (pasture, no concentrate) during breeding and gestation prior to enrollment in this study and their first lactation. Body weight and condition during breeding are very influential on milk production in the successive lactation period (Reynolds, 1991). Combined with our results, this suggests that ewes during breeding need well-balanced, highly digestible diets.

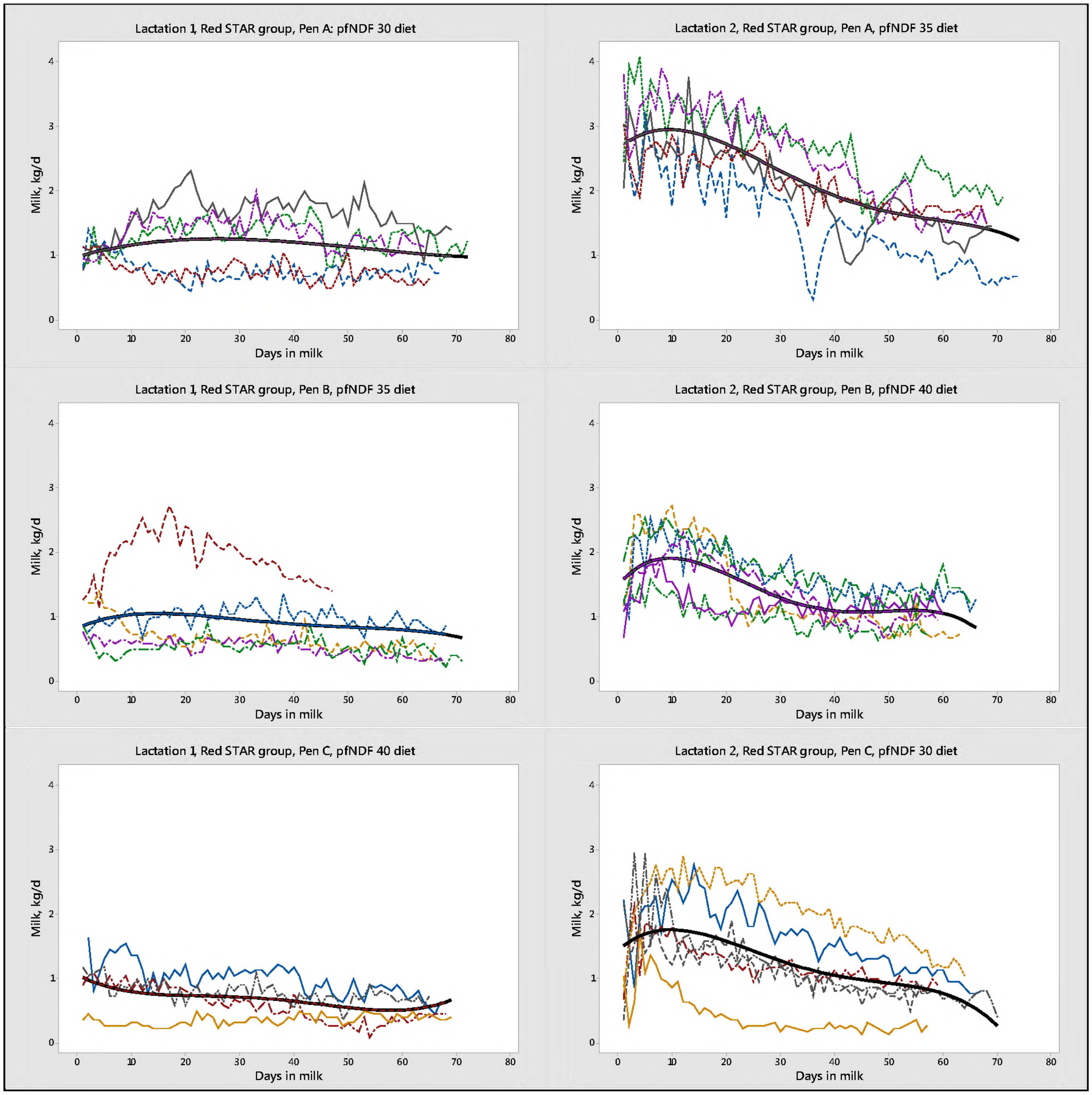

Figure 2. Individual ewe milk yields and fitted curves for diets with 30, 35, or 40% pfNDF in Red STAR group lactations 1 and 2.

Conception, breeding

Successfully synchronized breeding allows for shortened lambing times. Of the 72-total lambings so far, an average of 82% occurred within the first half of the 30-day lambing season. This has substantial implications on labor and management because lambing periods could be limited to five 14-day periods per year. Further research is needed to investigate ideal dry and transition times for sheep milked on an accelerated lambing system. Noteworthy is that rebreeding during lactation is feasible. This will have an impact on future management considerations.

Table 5. Conception rates.

Group and lactation	Ewes	Breeding start	Method	Scanned positive	Lambed	Parturition in first half of lambing period
Red STAR-1	18	6 Jun 2016	Teaser rams, CIDRs	14 (78%)	14	13 (93%)
Blue STAR-1	16	20 Aug 2016	Teaser rams, sponges	16 (100%)	16	11 (69%)
Green STAR-1	16	30 Oct 2016	Teaser rams	12 (75%)	12	11 (92%)
Red STAR-2	18	11 Jan 2017	Natural	17 (94%)	17	13 (76%)
Blue STAR-2	17	25 Mar 2017	Teaser rams, CIDRs in 13	13 (76%)	13	11 (85%)
Green STAR-2	18	6 June 2017	Teaser rams, CIDRs	17 (94%)	Lambing in October	

Lambs

Lactation is highly impacted by fecundity (Peterson, 2005), with an increased potential of up to 63% for twin vs single lambs (Snowder and Glimp, 1991) and another 20% for triplets vs twins. The Cornell ewes achieved 3.43 delivered lambs per ewe within this experiment, allowing these ewes to make use of their fecundity potential. In comparison, 1.85 lambs per year for East Frisian, and 1.69 per year for Lacaune (Thomas, 2014) were recorded. This level of prolificacy has substantial impact on the economic viability of a sheep dairy farm. In addition to high milk yields, higher numbers of lambs can be sold for meat and breeding stock.

Literature suggests a lower body weight at 120 days for lambs reared artificially (McKusick et al., 2001), yet the lambs in this study have grown well (Table). The death loss rate for lambs born alive has been very low at 1.4%. Further research might clarify the influence of dietary fiber levels on lamb vigor and growth potential.

Table 6. Growth of lambs.

STAR group and lactation	Number of lambs	Age, days	ADG, g/d
STARR-1	28	~50	263
STARB-1	34	~65	336
STARG-1	20	~45	269
STARR-2	36	~80	263
STARB-2	27	~20	290

Conclusions and outlook

Milking sheep in short and frequent lactations has an impact on yearly milk yield and lactation length. Intensive selection and breeding is needed to make full use of the high milking potential of many ewes observed in this experiment. It is possible to breed sheep during lactation without a decline in fertility. This can be used to further investigate ideal dry and transition times to expand lactation length. It's necessary to supply ewes with high levels of nutrients during breeding. Dairy sheep genetics might be used to generate crossbreds to increase lactation persistency alongside lactation length for sheep milked in frequent lactations. The high lamb crop suggests possibilities to use crossbreed ewes not previously selected for dairy production for both lamb and milk production.

Traditional lambing times may need to be reevaluated. Ewes bred in March and lambing in August (STARB-2, n=13, results not shown) have a higher lactation yield than ewes bred in August and lambing in January (STARB-1, n=14). This concurs with European research (Sitzia et al., 2015), where ewes bred in June reached higher total lactation yields than ewes bred in autumn.

Future analyses will report measured dry matter and NDF digestibility and determine the inference of varying levels of pfNDF on VFA production in the rumen (Araujo, 2008) and on milk composition.

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