

# Effect of weaning system on lamb growth, mammary gland development and ewe milk production in dairy sheep managed in an outdoor pasture-based commercial farming system

Susan McCOARD<sup>1</sup>, Shen -Y HEA<sup>1</sup>, Adrian MOLENAAR<sup>1</sup>, Katherine LOWE<sup>1</sup>, Marita BROADHURST<sup>2</sup>, Miles KING<sup>3</sup> and David STEVENS<sup>4</sup>

<sup>1</sup>AgResearch Limited, Grasslands Research Centre, Tennent Drive, 4442 Palmerston North, New Zealand

<sup>2</sup>AgResearch Ruakura, Hamilton, New Zealand 3214

<sup>3</sup>Kingsmeade Artisan Cheese, Masterton, New Zealand 5810

<sup>4</sup>AgResearch Invermay, Mosgiel, New Zealand 9092

sue.mccoard@agresearch.co.nz

## Abstract

The objective was to merge science and practice to determine the feasibility of a mixed suckling and milking system compared with a traditional exclusive suckling management system on the production performance of dairy sheep and their progeny in an outdoor pasture-based farming system at commercial scale. At 14 d postpartum, twin- and triplet-bearing mixed-age East Friesian ewes were randomly allocated to either a mixed system of once-a-day milking, suckling and early weaning (MS, n=61) or control with exclusive suckling and later weaning (Ctrl, n=57) using a randomised block design. MS lambs had lower live weight at weaning (14.6 vs. 16.7 kg;  $P<0.001$ ) but 3-5 weeks post-weaning average daily gain and mammary gland mass was similar between groups. Ewe lamb mammary mass was positively associated with post-weaning but not pre-weaning live weight gain ( $P<0.01$ ). Weaning system influenced the percentage of protein, total solids and fat (MS > Ctrl) while milk yield, somatic cell count and lactose levels were not different. This study highlighted that the MS compared with Ctrl system had no negative effects on dam or progeny performance.

**Keywords:** sheep, weaning, growth, milk yield, composition

## Introduction

In contrast to global dairy production systems, sheep milking is an emerging industry in New Zealand. To accelerate the development of dairy sheep enterprises in New Zealand, a co-innovation approach involving a partnership between science and industry was established (Stevens et al., 2018). For some producers, rearing lambs on the dam is a requirement to meet market expectations, while for others it is a lower-cost option.

Approximately one quarter of the total milk yield from a dairy ewe is produced in the first 30 d of lactation (Folman et al., 1966; Ricordeau and Denamur 1962).

Therefore, not milking dairy ewes during this period, to enable natural rearing of the lamb, limits the total harvestable commercial yield. Dairy ewes can produce more milk than required by their suckling lambs to support lamb growth (Bocquier et al., 1999), and mixed management systems that enable a combination of lamb suckling and machine milking have been described (Folman et al., 1966; Papachristoforou 1990; Gargouri et al., 1993; McKuisick et al., 2001; Dikmen et al., 2007). These mixed systems are widely used globally in dairy sheep production systems in traditional milking breeds, such as Awassi (Folman et al., 1966; Dikmen et al., 2007), Chios (Louca 1972) and East-Friesian (McKusick et al., 2001). In these systems, ewes are fully or partially housed indoors and both ewes and lambs are fed predominantly concentrates. Knight et al. (1993) reported that Poll Dorset lambs can be effectively reared with restricted access to their mothers (day or night separation) in a pasture-based system with only small reduction in the ewe's total milk yield. However, that study used a non-traditional dairy breed (Poll Dorset), and the ewes only raised a single lamb which is not characteristic of dairy sheep breeds where greater litter sizes are observed. The potential to optimise lamb rearing systems to support the growth of naturally reared lambs as replacements or for meat production, and simultaneously increase commercial milk harvest from ewes would be beneficial for outdoor pastoral-based farming systems.

Milk yield is a function of several factors including udder size, the amount and activity of secretory tissue (Capuco et al., 2003), and lactational demands on the udder such as increased suckling as litter size increases (Fernandez et al., 1995). Litter size can influence the development of the mammary gland in lambs (McCoard et al., 2018) and mammary growth in early life can influence future milk production (van der Linden et al., 2009). Ultrasonography is a non-invasive method to evaluate mammary development in young ruminants (Esselburn et al., 2015; McCoard et al., 2019) and milk storage capacity of the udder in sheep (Rovai and Caja

2008). The impact of litter size, pre- and post-weaning average daily gain on mammary development has not been established in sheep.

The objective of this experiment was to compare a mixed suckling and milking system with earlier weaning in a traditional rearing system on progeny growth, mammary development and ewe milk yield and composition on a commercial scale in an outdoor commercial pasture-based farming system.

## Materials and Methods

All animal manipulations in this study were reviewed and approved (AE13643) by the Animal Ethics Committee of AgResearch Grasslands, Palmerston North, New Zealand. The trial was conducted using 118 single-, twin- and triplet-bearing mixed age (2 to 6 years) East Friesian-cross 'Dairymeade' (Lopez-Villalobos et al., 2017) ewes bred naturally to four sires in the first reproductive cycle (17 d) of the 2016 breeding season. All ewes grazed ryegrass dominant pasture on Greytown silt loam soils on a 11-hectare dairy sheep farm in Wairarapa, New Zealand. They were managed under standard commercial farm management and grazing practices, with lambing from July 28<sup>th</sup> to August 21<sup>st</sup> 2016. The ewes were vaccinated against leptospirosis (Leptosshield®, Zoetis New Zealand), and *Campylobacter* (CampyVax4®, MSD Animal Health, New Zealand) and clostridial infections (Ultravac 5+1 B12®, Zoetis New Zealand) pre-lambing.

All ewes were given the opportunity to give birth and to rear their own lambs to meet consumer expectations for a natural rearing system from sheep milked for cheese manufacture on this farm. This was achieved using standard farming practices, which involved twice daily visual assessment of the ewes and lambs and assistance provided with lambing or feeding newborns when required and, if necessary, artificial rearing of any orphan lambs.

At 7 d *post-partum*, single-bearing ewes were milked once daily to minimise the risk of mastitis. At 14 d *post-partum*, ewes were randomly allocated to either the mixed system (MS, n=61 ewes, 11 single, 65 twin and 38 triplet lambs) or the control (Ctrl, n=57 ewes, 11 single, 54 twin and 40 triplet lambs) groups using a randomised block design, according to lambing date and litter size. Birth rearing rank (*i.e.*, combination of the number of lambs born and the number reared successfully to 14 d *post-partum*) was determined after allocation to treatment groups by matching the lamb tag to the ewe tag. Ewes and lambs were allocated to blocks (n=6) based on lambing (three to six day spread of lambing per block).

The MS ewes were moved into the milking flock with separation of the lambs from the ewes for 8 h during the day (08:00 to 16:00 h) with free access to

concentrate starter, fresh water and shelter, and ewes milked once daily at 16:00 h. Lambs in the MS group were abruptly weaned from the ewes if they met the weaning criteria by at least four weeks of age, with a minimum body weight of two times their birth weight for singles and twins and three times their birth weight for triplets (~12 to 13 kg live weight), body condition score >3.0 (BCS; Jefferies, 1961) and were consuming solid feed and ruminating and in good health based on individual observation by the same trained operator. These criteria were developed based on observations from previous studies where artificially reared lambs were weaned from 4-5 weeks of age (Carballo et al., 2019; McCoard et al., 2019).

The MS ewes were milked once daily if they continued to suckle one or more lambs, or twice daily when all lambs were weaned (ewes were managed in once-daily or twice-daily milking flocks). The Ctrl ewes were moved out of the lambing paddock into one of two flocks: 1) single bearing ewes which were milked once daily with lambs at foot to minimise the risk of mastitis (standard farm practice), or 2) twin- and triplet-bearing ewes were managed as one flock and naturally reared their lambs until at least five to six weeks of age (standard farm practice on-farm) followed by abrupt weaning of the lambs when they had met the weaning criteria of a minimum body weight of ~15 kg and were in good health and BCS > 3.0. Following the start of weaning (five to six weeks *post-partum*), the Ctrl ewes, suckling one or more lambs that did not meet the weaning criteria, were combined with the single-bearing ewe Ctrl group and milked once daily.

Following weaning for both groups, all ewes and lambs were managed outdoors separately on pasture according to commercial grazing practices. All lambs were treated with oral anthelmintic to control parasites as recommended by the flock veterinarian and according to commercial practice pre- and post-weaning. All ewes were managed outdoors in a rotational pasture grazing system with additional concentrate supplement offered in the paddock two weeks prior to lambing through to weaning (Vitec Nutrition Limited, Masterton, New Zealand). A grain-based diet supplement was formulated to complement the pasture diet for the ewes and lambs up to weaning (Supplement 1), post-weaning for the lambs (Supplement 2) and the ewes following entry into the milking flock (Supplement 3). The Ctrl ewes and lambs were offered Supplement 1 up to weaning (300 g/ewe+lamb/d), followed by Supplement 2 offered to the lambs post-weaning (300 g/h/d) and Supplement 3 offered to the ewes in the milking parlour following entry into the milking flock (300 g/h/d). The MS ewes and lambs were offered Supplement 1 prior to entry of the ewes into the milking flock at two weeks *post-partum* (300 g/ewe+lamb/d). After entry into the

milking flock, lambs were offered *ad libitum* access to Supplement 2 during the separation period from their dams in open feed troughs pre-weaning once daily with enough head space for all lambs to gain free access to the supplement. Post-weaning, the concentrate supplement was restricted to 300 g/h/d. The MS ewes were offered Supplement 3 in the milking parlour (300 g/h/d).

Three representative samples of the supplements were collected for composition analysis (Table 1) using wet chemistry methods for the following nutritional components (and their analytical method; AOAC, 2016): DM (945.15), ash (942.05), CP (992.15), crude fat (932.02), starch (920.40), NDF (2002.04), and ADF (973.18) by a commercial laboratory (Hill Laboratories Ltd., Hamilton, NZ). The samples were subjected to *in-vitro* organic matter digestibility (OMD) testing and digestibility of organic matter in DM (DOMD) was calculated from OMD using the Australian Fodder Industry Association standard equation. The metabolisable energy content was calculated using the equation:

$$ME = \text{DOMD}\% \times 0.16.$$

Pasture samples were collected from the paddocks grazed by the MS and Ctrl ewes prior to separation of the lambs or weaning respectively, by the lambs post-weaning, and the ewes in the milking flock (combination of the MS and Ctrl ewes). Samples were collected weekly for the first eight weeks of the study (two weeks pre-partum to six weeks post-partum; representative pluck per paddock), pooled into three representative samples, and composition analysed using NIR (Nutrition Laboratory, Massey University,

Palmerston North, New Zealand). Pasture nutritional composition is shown in Table 2.

All lambs were tagged within 12 h of birth and their body weight, birth rank and sex recorded. Ewe BCS at parturition was recorded. Lambs were weighed weekly immediately following separation from their dam to monitor growth pre- and post-weaning growth.

**Table 1** Nutritional composition (g/100 g dry matter unless specified) of the concentrate offered to the ewe and lambs pre-weaning (Supplement 1), the lambs post-weaning (Supplement 2) and the ewes following entry into the milking flock (Supplement 3).

	Supplement 1	Supplement 2	Supplement 3
DM %	87.9	88.1	83.4
Crude Protein	15.7	17.5	10.0
ADF <sup>1</sup>	8.3	7.8	2.7
NDF <sup>2</sup>	18.5	16.3	10.3
Ash	5.4	6.3	1.0
Soluble Sugars	5.8	5.6	1.1
Starch	43.4	41.4	70.6
Crude fat	3.0	3.1	3.4
DOMD <sup>3</sup>	83.2	83.7	95.3
ME (MJ/kg DM) <sup>4</sup>	13.3	13.4	15.2
NSC <sup>5</sup>	57.5	56.7	75.2
OMD <i>in vivo</i>	87.9	89.4	96.3

<sup>1</sup> ADF, acid detergent fibre;

<sup>2</sup> NDF, neutral detergent fibre;

<sup>3</sup> DOMD, digestibility of organic matter in DM;

<sup>4</sup> ME, metabolisable energy;

<sup>5</sup> NSC, non-structural carbohydrates.

**Table 2** NIRS chemical composition (g/100 g dry matter unless specified) of the ryegrass white clover pasture grazed by the mixed suckling (MS) and Control (Ctrl) ewes prior to separation of the lambs or weaning respectively, the lambs post-weaning, and the ewes in the milking flock.

	MS ewes pre-separation	Ctrl ewes pre-wean	Post-wean lambs	Milking flock
ADF <sup>1</sup>	20.1	19.7	18.8	18.7
Ash	9.8	10.4	10.4	10.9
CP <sup>2</sup>	20.8	23.9	25.9	26.5
Residual DM	95.6	96.2	97.0	96.0
OMD <sup>3</sup>	79.0	79.8	79.7	81.2
Lipid	4.4	4.4	4.4	4.7
NDF <sup>4</sup>	40.6	38.6	40.1	39.3
SSS <sup>5</sup>	13.6	11.5	9.3	10.1
ME <sup>6</sup> (MJ/kg DM)	11.1	11.4	11.2	11.4

<sup>1</sup> ADF, acid detergent fibre;

<sup>2</sup> CP, crude protein;

<sup>3</sup> OMD, organic matter digestibility;

<sup>4</sup> NDF, neutral detergent fibre;

<sup>5</sup> SSS, soluble starch and sugars;

<sup>6</sup> ME, metabolisable energy.

All mortalities were recorded. Daily concentrate supplement intake for the MS lambs was recorded pre-weaning, and for all lambs post-weaning at a group level, which was measured as the difference between feed offered and refused. Animal health was monitored daily in all ewes and lambs. All animal health treatments were managed according to standard farm practice under the recommendations of the flock veterinarian.

Mammary gland growth in the lambs was measured at 122 d (range of 100-131 d) *post-partum* using ultrasonography using an approach previously described in calves (McCoard et al., 2019). Lambs were restrained on their rumps and images of both halves of the mammary gland perpendicular to the teat to capture the maximum depth of the gland using a SonoSite M-Turbo scanner with a 5MHz 65mm sectorial probe using vegetable oil to make a sonic contact. The images were captured and the depth of the mammary gland depth at the widest point recorded by two independent operators blinded by treatment.

Milk yield for a subset of animals in MS (n=6-10) and Ctrl (n=6-9 per timepoint) ewes was reported and analysed as repeated measures for each animal, but not all animals were represented at each timepoint. This was measured directly by collecting the total milk produced in the afternoon (PM) milking on the 21 September (42-54 DIM), 22 October (71-85 DIM), 2 December (112 – 126 DIM), 20 January (165-175), 24 February (197-204) and 21 March (211-236 DIM). Total milking volume for each ewe was collected in a separate milking bucket connected into the dairy vacuum line. After recording yield, milk from each animal was thoroughly mixed and a subsample collected for milk composition analysis as described previously (Teng et al., 2019).

Linear mixed models using restricted maximum likelihood (REML) were used to investigate the effect of variables (fixed effects) on the outcomes. Model random effects (random intercepts and random slopes) allowed the modelling of structured data by accounting for non-independent observations (*i.e.*, multiple measurements per animal, multiple lambs born to each ewe, and multiple lambs separated into groups by time). For weaning weight, weaning age and average daily gain (ADG) data, the variables used in the model were treatment, birth rank, sex, centred ewe age, centred lamb birth weight and sire. Ewe random intercepts nested within separation group were included in the model. The variables age, treatment, birth rank, sex, centred birth weight, centred ewe age and sire were used to model lamb weights over time. The random effects used in the model include random intercepts for lamb nested within ewe within separation group, and a random slope was created for lamb age to allow for different growth patterns for each lamb. An orthogonal polynomial term (degree 2) for lamb age was used to allow for a

curvilinear weight trend. For mammary gland depth, the variables used in the model were birth rearing rank, centred birth weight, centred ewe age, sire and treatment. Random intercepts for lamb nested within ewe, within separation group were included in the model.

For milk yield and composition outcomes (total afternoon daily milk yield; percentage of total solids, fat, protein, and lactose; fat:protein ratio and somatic cell count), the covariate days in milk (DIM), treatment and the age of the animal were included in the model. An interaction term between DIM and treatment group was included to allow for different slopes between treatment groups. An orthogonal polynomial term (degree=2) for DIM was used to allow for curvilinear trend. A random intercept for ewe was used in the model. Centred variables (birth weight and ewe age) were created by deducting each respective value by their grand mean. Model fit was assessed by viewing residual diagnostic plots (QQ plots, fitted vs. residuals plots and influence plots). The outcomes weaning age, mammary gland measurements and somatic cell counts were log transformed to stabilise residual variance (*i.e.*, to correct for residual heteroscedascity). No significant multicollinearity was detected amongst the fixed effects for all the models using a variance inflation factor of 3.0 as a cut-off (Zuur et al., 2010).

The R packages (R Core Team 2019) ‘lme4’ (Bates et al., 2015), ‘lmerTest’ (Kuznetsova et al., 2017) and ‘emmeans’ (length) were used for modelling, generation of P-values and marginal means, respectively. Significance was determined at  $P < 0.05$ , a trend at  $P < 0.10$  and non-significant at  $P > 0.10$ .

## Results

In the Ctrl group, one lamb was treated for pneumonia, three were treated for scald and two lambs died (~five weeks of age). In the MS group, three lambs had short-term scours that did not require treatment, one lamb was treated for pink eye with topical antibiotic cream and two ewes with mastitis were removed from milking flock following weaning of their lambs. Retrospective analysis of BCS at lambing indicated no differences between MS and Ctrl ewes (mean±SD:  $3.1 \pm 0.49$  vs.  $3.1 \pm 0.50$ ).

At birth, male lambs were heavier than females ( $4.9 \pm 0.13$  vs.  $4.8 \pm 0.16$ ;  $P = 0.03$ ) and singletons were heavier than twins which, in turn, were heavier than triplets ( $5.5 \pm 0.22$ ,  $4.9 \pm 0.13$ ,  $4.0 \pm 0.18$ ;  $P < 0.001$ ). Weaning system influenced lamb live weight during the trial period ( $P < 0.01$ ; Figure 1) with lower lamb live weight at weaning in the MS than the Ctrl group ( $14.6 \pm 0.43$  vs.  $16.7 \pm 0.43$ ;  $P < 0.001$ ). Weaning weight was positively affected by birth weight ( $P < 0.001$ ) but not affected by sex, birth rank or ewe age. Independent of treatment, males were a similar weight to females

at weaning ( $15.9 \pm 0.41$  vs.  $15.5 \pm 0.42$ ,  $P=0.12$ ). The average age at weaning was 35 d for MS (range 28-67 d) and 40 d for Ctrl lambs (range 28-72 d).

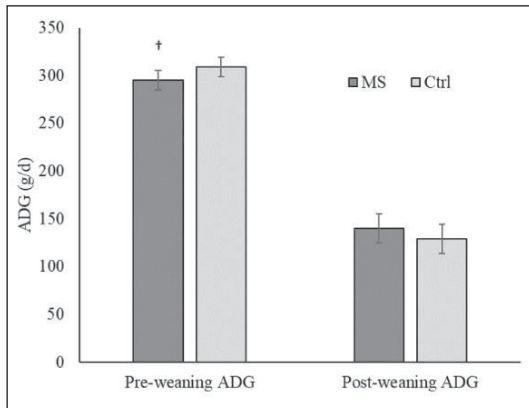
Pre-weaning ADG tended to be lower in MS than Ctrl lambs (Figure 1). Pre-weaning ADG was affected by birth rank (singletons,  $334 \pm 14.3$ , twins,  $295 \pm 10.1$ , triplets,  $277 \pm 11.4$ ;  $P < 0.001$ ), sex (males,  $309 \pm 10.1$ , females,  $296 \pm 10.2$ ,  $P=0.05$ ) and positively affected by birth weight ( $P < 0.001$ ). Post-weaning ADG did not differ between MS and Ctrl lambs (Figure 1). Post-weaning ADG was influenced by birth rank (singletons,

$100 \pm 19.8$ , twins,  $149 \pm 15.1$ , triplets,  $154 \pm 16.7$ ;  $P < 0.01$ ), but not sex ( $P=0.38$ ) or birth weight ( $P=0.22$ ). Overall, the live weight of MS compared with Ctrl lambs from 20 to 85 d of age was lower ( $P < 0.01$ ), but the difference in was small (on average  $< 1$  kg) and so was unlikely to have biological significance (Figure 2).

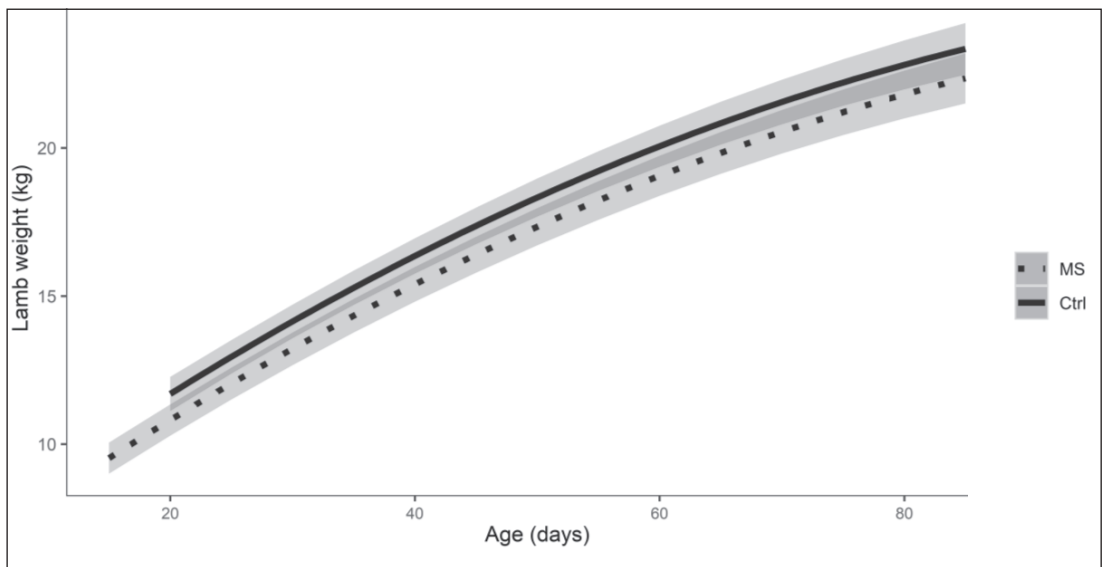
Mammary gland depth at 122 d *post-partum* did not differ between MS and Ctrl lambs ( $15.6 \pm 1.20$  vs.  $15.3 \pm 1.17$  mm;  $P=0.69$ ) after adjustment for variation in birth rank, birth weight, ewe age and sire. Birth rank, birth weight and sire had no effect on mammary gland depth. Mammary gland depth was positively associated with the weight of the lamb at scanning ( $P < 0.001$ ) after controlling for age and sire, with every 1 kg increase in weight at scanning increasing mammary gland depth by 0.37 mm.

Independent of treatment, pre-weaning ADG did not influence mammary gland depth ( $P=0.98$ ) but post-weaning ADG positively affected mammary gland depth ( $P=0.01$ ) with a 0.33 mm increase in mammary gland depth with every 20 g/d increase in ADG. Weaning weight, birth rank, ewe age, sire and birth weight did not influence mammary gland depth at scanning.

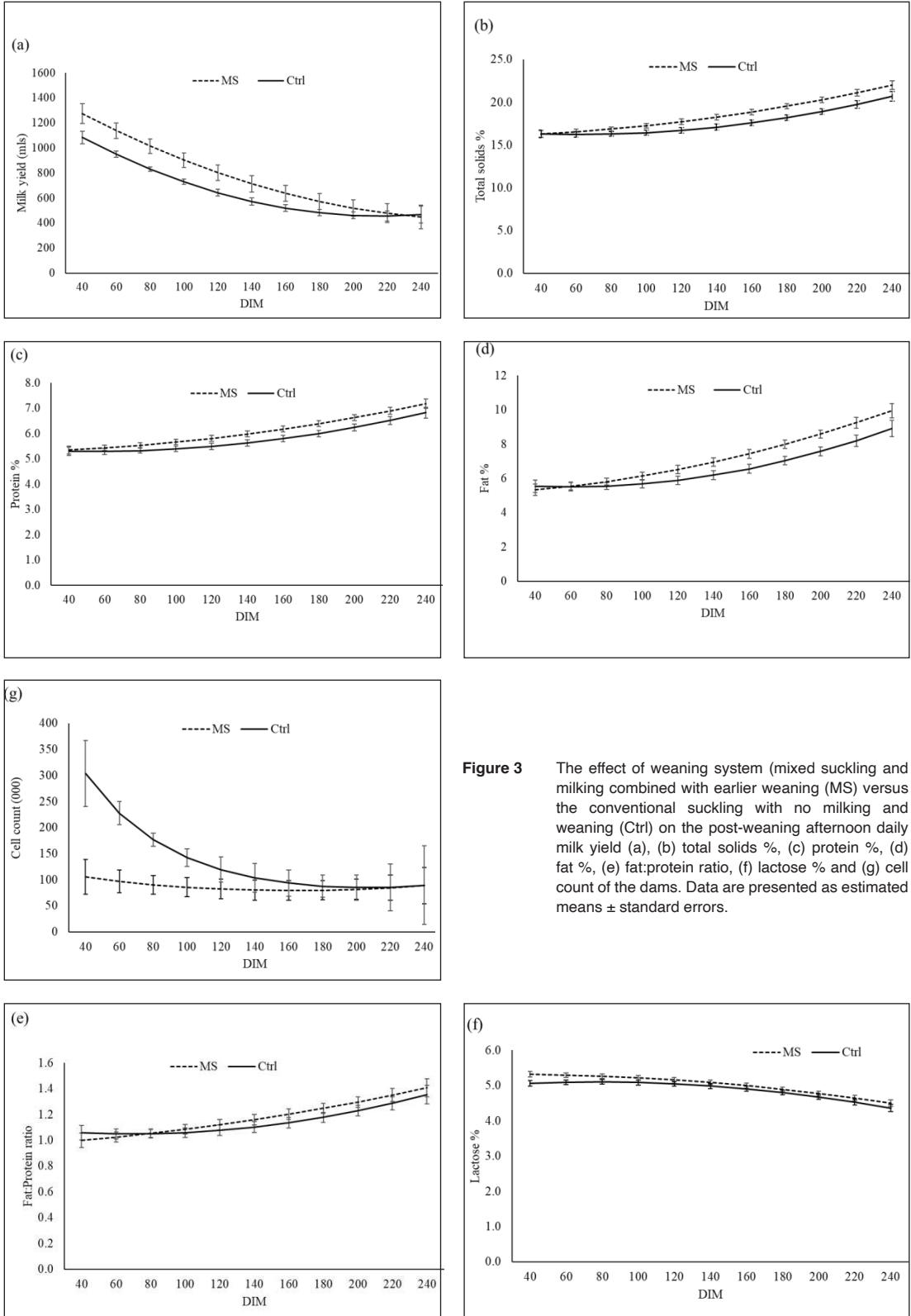
Afternoon dam daily milk yield and composition post-weaning (Figure 3) was affected by sampling date ( $P < 0.01$ ). Protein ( $P=0.05$ ), total solids ( $P=0.03$ ) and fat ( $P=0.05$ ) were greater in MS than Ctrl ewes. Numerically, afternoon milk yield ( $P=0.11$ ) was greater and log cell count ( $P=0.12$ ) was lower in MS than Ctrl ewes, but statistical significance was not achieved.



**Figure 1** The effect of weaning system (mixed suckling and milking combined with earlier weaning (MS) versus the conventional suckling with no milking and weaning (Ctrl)) on average daily gain (ADG) of the progeny pre- and postweaning. Data presented as means  $\pm$  standard errors. †,  $P < 0.10$ .



**Figure 2** The effect of weaning system (mixed suckling and milking combined with earlier weaning (MS) versus the conventional suckling with no milking and weaning (Ctrl)) on lamb live weight during the study period. Data presented as means  $\pm$  standard errors. Treatment effect  $P < 0.01$ .



**Figure 3** The effect of weaning system (mixed suckling and milking combined with earlier weaning (MS) versus the conventional suckling with no milking and weaning (Ctrl) on the post-weaning afternoon daily milk yield (a), (b) total solids %, (c) protein %, (d) fat %, (e) fat:protein ratio, (f) lactose % and (g) cell count of the dams. Data are presented as estimated means ± standard errors.

The fat:protein ratio ( $P=0.57$ ) did not differ between treatments and no treatment by time interactions were evident ( $P>0.10$ ).

## Discussion

Earlier weaning using the mixed system employed in this study had little effect on pre- or post-weaning lamb growth, which was consistent with prior studies in East Friesian (McKusick et al., 2001) and other Mediterranean breeds (Locua 1972; Lawlor et al., 1974; Dikmen et al., 2007). However, Hadjipanayiotu and Louca (1976) reported lower weight gain of lambs in mixed weaning systems compared with exclusively suckled controls. Similar to the observations of McKusick et al. (2001), supplementary feeding of MS lambs when separated from their dams compensated for the reduction in milk intake. There was potential for the lambs to have benefited from some milk remaining in the udder that the lamb accessed when reunited with its mother, which is common in mixed suckling and machine milking weaning systems (Folman et al., 1966; Papachristoforou 1990; McKusick et al., 2001). However, because milk retention in the udder was not measured pre-weaning, this cannot be confirmed in the present study. While pre-weaning ADG was similar to that observed by McKusick et al. (2001), post-weaning ADG in the present study was considerably lower independent of weaning method. This can be explained by the management system, *i.e.*, indoor housing with exclusive concentrate feeding in the study by McKusick et al. (2001) compared with outdoor pasture-feeding with limited allocation of supplementary concentrate post-weaning in the present study. The lower pre-weaning compared with post-weaning ADG in pasture-fed, early weaned lambs offered limited supplementary concentrates, was consistent with previous observations (Jensen et al., 2017).

Accelerated pre-weaning growth rate in dairy heifer calves has been related to increased future milk production (Soberon and van Amburgh 2013; Gelsinger et al., 2016) and was postulated to be a result of accelerated mammary development which is sensitive to early life nutrition (Meyer et al., 2006; Geiger et al., 2016). Therefore, understanding how early life factors can influence mammary development may have important implications for future milk production in sheep. The weaning method used in this study did not influence mammary gland mass post-weaning, and pre-weaning ADG was not correlated with post-weaning mammary gland mass. The lack of weaning method effects on mammary growth was consistent with the lack of substantial differences in growth performance between the treatment groups. These results indicated that pre-weaning growth rate was not a predictor of post-weaning mammary gland mass in the growing

ewe lamb. It has previously been reported that twinning affected *in utero* morphological development of the mammary gland in sheep (McCoard et al., 2018). The lack of effect of litter size on post-weaning mammary mass suggested that any potential developmental changes *in utero* may not translate into changes in mammary mass in the post-weaning lamb. In calves, nutrient intake has been reported to influence, but not consistently, parenchyma and/or fat pad mass (Brown et al., 2005; Meyer et al., 2006; Daniels et al., 2009; Geiger et al., 2016; Soberon and van Amburgh 2017). Potential impacts of pre-weaning growth rate and or *in utero* developmental differences resulting from litter size on growth of parenchymal and fat pad/stromal tissue independent of mammary mass could not be ascertained from this study, but warrant further investigation.

In contrast to pre-weaning, post-weaning ADG and live weight at scanning, but not birth rank, birth weight or weaning system, had a positive effect on mammary mass in the growing ewe lamb. Consistent with this effect, Villeneuve et al. (2010) reported that differing planes of nutrition achieved through a combination of feed allowance and diet composition (predominantly concentrate with varying forage quality) during the allometric phase of mammary development post-weaning (Johnsson and Hart 1985) influenced growth performance and mammary gland mass and composition in pre-pubertal Dorset lambs. Similar relationships have been observed in Manchega, but not Lacaune, ewe lambs fed a restricted plane of nutrition between 1 and 5.5 months of age (Zidi et al., 2005). The impact of the variation in post-weaning weight gain and/or weaning system on the composition of the mammary gland (*i.e.*, parenchyma vs. fat pad), and subsequent impact on milk production, was not possible to determine in the present study. Negative effects of rapid post-weaning weight gain in dairy heifers on future milk production have been reported (Sejrsen and Purup 1997). Commercial dairy sheep production systems mate adolescent lambs at 8 months of age to maximise lifetime milk production. Therefore, high growth rates of ewe replacements are required to meeting target mating weights to enable their first lactation at one year of age. Future studies to examine the effects of environment (*e.g.*, nutrition, litter size, weaning methods) on mammary gland development and the relationship with future milk production may provide insights into early life management approaches to improve future lactation performance. Furthermore, establishing a relationship between early life mammary development and future lactation performance may offer an opportunity to utilise ultrasonography as a tool to select ewe replacements that have high potential for future milk production.

There was no significant difference in afternoon daily milk yield observed post-weaning between MS and Ctrl ewes indicating no carryover effect (positive or negative) on milk production in the ewes in either group. These results were in contrast to those reported by McKusick et al., (2001) where an increase in milk yield was reported in ewes from a mixed weaning system compared with exclusive suckling. This difference may reflect insufficient statistical power in the current study, due to a numerical, but not significant, trend being observed that was consistent with the observations of McKusick et al. (2001). Alternatively, the difference may have been due to different methods used to measure milk yield. In the study by McKusick et al. (2001) milk yield was reported as a total lactation milk yield which included the milk collected prior to weaning of the lambs in the mixed suckling group. In contrast, the data reported in this study was from ewes after weaning their lambs, and so the milk harvested prior to weaning of the lambs in the MS group was not included. It was not possible to measure total milk yield in each group due to infrastructure limitations on the commercial farm where this project was undertaken. However, the ability to harvest milk from MS ewes for an average of 24 d prior to weaning of the lambs (*i.e.*, two weeks *post-partum* when lambs were separated to the average weaning age of 38 d) would provide an opportunity to increase the harvest of commercial milk during lactation from the MS ewes. Based on the milk yield of the subset of ewes measured in this study, there was potential to harvest an additional 25-30 l of milk per ewe if early weaning methods are adopted using this system. These observations suggested that, in addition to greater milk harvest prior to the conventional weaning date, ewes in the MS system may have increased post-weaning daily milk yield, which could increase the harvest of commercial milk. However, statistical significance was not achieved with the milk yield data, and measurements were only undertaken on a small number of ewes and these results require verification in a larger scale study. Greater harvest of total commercial milk from ewes milked either once or twice a day in addition to suckling compared with ewes not milked prior to weaning of the lambs has been reported in other breeds of dairy sheep (Folman et al., 1966; Louca 1972; Gargouri et al., 1993).

The percentage of protein, fat and total solids was greater in MS than Ctrl ewes. These observations contrast those of McKusick et al. (2001) where no differences in milk composition were observed. Greater total solids content of milk is important to for cheese yields and milk powder production. Mixed weaning systems of suckling and machine milking in early lactation can reduce SCC and mastitis in high yielding dairy cows (Krohn 1999). High SCC have also been

reported in exclusively suckled compared with machine milked ewes in early lactation (McKusick et al., 2001). No ewes in the present study were exclusively milked in early lactation, therefore direct comparison was not possible. However, while not statistically significant, MS ewes had numerically lower SCC at the first sampling point after weaning compared with Ctrl ewes which was consistent with previous reports (McKusick et al., 2000; 2001). Importantly, SCC greater than 500,000 cells/ml in dairy ewes (Pellegrini et al., 1997) and cows (Everson 1984) negatively impact cheese manufacture. The SCC observed in the present study were well below these levels (5.3 log units corresponds to 200,000 cells/ml). Therefore, the weaning systems used in this study may be suitable for systems where milk is harvested for commercial sale or cheese production.

These results highlighted the importance of early lactation management of ewes on overall production. Furthermore, it showed that a mixed weaning system can be successfully employed as a strategy to increase collection of commercial milk without compromising subsequent milk yield and composition, nor lamb growth, in an outdoor, pasture-based system. It is important to note that the pasture quality offered to the ewes and lambs in this study was high (> 11 MJ ME and CP content >20 g/100 g DM) and additional supplementary feeding of the lambs and of the ewes in the milking parlour likely supported this level of performance. Pasture quality can vary considerably with advancing gestation because of dry conditions over the Summer and early Autumn periods (December to March). On the farm where this study was conducted, irrigation was used to maintain pasture quality. Therefore, caution should be applied in extrapolation of the results to other pastoral farming environments and/or different years, where pasture quality and quantity may not be maintained during summer and early autumn to meet the nutritional requirements of high yielding dairy ewes.

Implementation of a mixed suckling and once-a-day milking system as an alternative to either artificial rearing of lambs or exclusive suckling prior to weaning is more challenging in outdoor farming systems. This is because the animals are not always near housing facilities to manage the lambs during the separation period, and mis-mothering can be problematic when reuniting ewes with lambs due to longer walking distances and lower stocking density. Due to these challenges, to minimise the risk of mis-mothering and enable closer monitoring of the animals, a mixed system was employed where lambs were separated from the ewes for 8 h during the day and reunited with ewes after afternoon milking. This approach contrasted other studies evaluating mixed weaning systems where lambs

were separated from their dams for 15 h overnight (e.g., McKusick et al., 2001; Dikmen et al., 2007).

From a feasibility perspective, the modified MS weaning protocol was successfully implemented in an outdoor pasture-based farming system within the scale of the farming system used. While not directly assessed in this study, additional labour was required to separate the lambs from the dams, but, based on feedback from the manager, the benefit outweighed the cost, as existing staff were able to manage this additional task. One adverse effect of this system was observed where a small proportion of ewes (<10% based on farmer feedback) exhibited teat damage in the mixed weaning group which may have been due to chewing of the teat by lambs after being reunited with their dams. Based on feedback from the farm manager, this issue has been avoided in subsequent seasons by reuniting lambs with their dams 1 h post-milking to enable sufficient intake to satisfy the lambs. This approach eliminated this issue.

It is important to highlight that this study was implemented in a season with good pasture growth and quality to maintain ewe BCS and support lamb growth. If insufficient feed resources are available (e.g., due to poor winter pasture growth or drought conditions), implementation of the mixed weaning system is not recommended. Within an outdoor pasture-based farming system, the MS system could be an option to increase commercial milk yield if feed resources are sufficient within any given season. Furthermore, the scale of the farming system needs to be considered when determining the feasibility of adopting this modified weaning system.

In conclusion, this study showed that a mixed system of suckling and once-a-day milking from 14 d *post-partum* had no major negative effects on lamb growth, health, weaning age and post-weaning mammary development to approximately nine weeks of age, compared with lambs exclusively suckled prior to weaning. No post-weaning negative impacts on dam milk yield and composition were observed, but the mixed suckling and milking system supported potential capture of commercial milk in early lactation and possibly improved milk yield and solids. Ultrasonography was useful as a non-invasive tool to evaluate mammary gland development in lambs. Post-weaning, but not pre-weaning, growth rate was positively associated with mammary development which may have implications for future milk production. The integration of science and commercial farm practice knowledge and experience enabled robust assessment of the weaning system change on animal performance (ewes and lambs) with simultaneous on-farm early adoption of the new approaches. This approach accelerated adoption and practice change

on-farm and provided proof-of-principle to other farm operations.

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## REFERENCES

- AFRC. 1993. Energy and Protein Requirements of Ruminants. Agricultural and Food Research Council. Publisher: CAB International, Wallingford, UK, pp. 159.
- Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67(1): 1-48. <https://doi.org/10.48550/arXiv.1406.5823>
- Bocquier F, Auel MR, Barillet F, Jacquin M, Lagriffoul G, Marie C. 1999. Effects of partial-milking during the suckling period on milk production of Lacaune dairy ewes. In: Barillet F & Zervas NP. Eds. *Milking and Milk Production of Dairy Sheep and Goats. Proceedings of the 6th International Symposium on the Milking of Small Ruminants*, Athens, Greece. Wageningen Pers, Wageningen, The Netherlands, pp. 257-262. <https://hal.inrae.fr/hal-02840880>
- Brown EG, VandeHaar MJ, Daniels KM, Liesman JS, Chapin LT, Forrest JW, Akers RM, Pearson RE, Weber Nielsen MS. 2005. Effect of increasing energy and protein intake on mammary development in heifer calves. *Journal of Dairy Science* 88: 595-603. [https://doi.org/10.3168/jds.S0022-0302\(05\)72723-5](https://doi.org/10.3168/jds.S0022-0302(05)72723-5)
- Capuco A, Ellis SE, Hale SA, Long E, Erdman RA, Zhao X, Paape MJ. 2003. Lactation persistency: insights from mammary cell proliferation studies. *Journal of Animal Science* 81(3): 18-31. [https://doi.org/10.2527/2003.81suppl\\_318x](https://doi.org/10.2527/2003.81suppl_318x)
- Carballo OC, Khan MA, Knol FW, Lewis SJ, Stevens DR, Laven RA, McCoard SA. 2019. Impact of weaning age on rumen development in artificially-reared lambs. *Journal of Animal Science* 97(8): 3498-3510. <https://doi.org/10.1093/jas/skz148>
- Daniels KM, Capuco AV, McGilliard ML, James RE, Akers RM. 2009 Effects of milk replacer formulation on measures of mammary growth and composition in Holstein heifers. *Journal of Dairy Science* 92: 5937-5950. <https://doi.org/10.3168/jds.2008-1959>
- Dikmen S, Turkmen II, Ustuner H, Alpaya F, Balci F, Petek M, Ogan M. 2007. Effect of weaning system on lamb growth and commercial milk production of Awassi dairy sheep. *Czech Journal of Animal Science*

- 52(3): 70-76. [https://www.researchgate.net/profile/Serdal\\_Dikmen/publication/242259875](https://www.researchgate.net/profile/Serdal_Dikmen/publication/242259875)
- Esselburn KM, Hill TM, Bateman HG, Fluharty FL, Moeller SJ, O'Diam KM, Daniels KM. 2015. Examination of weekly mammary parenchymal area by ultrasound, mammary mass, and composition in Holstein heifers reared on 1 of 3 diets from birth to 2 months of age. *Journal of Dairy Science* 98: 5280-5293. <https://doi.org/10.3168/jds.2014-9061>
- Everson TC. 1984. Concerns and problems of processing and manufacturing I super plants. *Journal of Dairy Science* 67: 2095-2099. [https://doi.org/10.3168/jds.S0022-0302\(84\)81551-9](https://doi.org/10.3168/jds.S0022-0302(84)81551-9)
- Fernandez G, Alvarez P, San Primitivo F, de la Fuente LF. 1995. Factors affecting variation of udder traits of dairy ewes. *Journal of Dairy Science* 78: 842-849. [https://doi.org/10.3168/jds.S0022-0302\(95\)76696-6](https://doi.org/10.3168/jds.S0022-0302(95)76696-6)
- Folman Y, Volcani R, Eyal E. 1966. Mother-offspring relationships in Awassi sheep. I: The effect of different suckling regimes and time of weaning on the lactation curve and milk yield in dairy flocks. *Journal of Agricultural Science (Cambridge)* 67: 359-368. <https://doi.org/10.1017/S0021859600017366>
- Gargouri A, Caja G, Such X, Ferret A, Casals R, Peris S. 1993. Evaluation of a mixed system of milking and suckling in Manchega dairy ewes. *Proceedings of the 5th International Symposium on Machine Milking of Small Ruminants. Hungarian Journal of Animal Production Supplement 1*: 484-499. <https://portalrecerca.uab.cat/en/publications/evaluation-of-a-mixed-system-of-milking-and-suckling-in-manchega->
- Geiger AJ, Parsons CLM, Akers RM. 2016. Feeding a higher plane of nutrition and providing exogenous estrogen increases mammary gland development in Holstein heifer calves. *Journal of Dairy Science* 99: 7642-7653. <https://doi.org/10.3168/jds.2016-11283>
- Gelsinger SL, Heinrichs AJ, Jones CM. 2016. A meta-analysis of the effects of preweaned calf nutrition and growth on first-lactation performance. *Journal of Dairy Science* 99: 6206-6214. <https://doi.org/10.3168/jds.2015-10744>
- Hadjipanayiotou M & Louca A. 1976. The effects of partial suckling on the lactation performance of Chios sheep and Damascus goats and the growth rate of the lambs and kids. *Journal of Agricultural Science (Cambridge)* 80: 15-20. <https://doi.org/10.1017/S0021859600026526>
- Jefferies BC. 1961. Body condition scoring and its use in management. *Tasman Journal of Agriculture* 32: 19-21. <https://cir.nii.ac.jp/crid/1572261550761504000>
- Jensen AC, Khan MA, Knol FW, Peterson SW, Morel PCH, McKenzie C, Stevens DR, McCoard SA. 2017. How does feeding meal affect growth of artificially-reared East Friesian-cross dairy lambs? *Proceedings of the New Zealand Society of Animal Production* 77: 13-17. <https://www.cabdirect.org/cabdirect/abstract/20183132582>
- Johnsson ID, Hart IC. 1985. Pre-pubertal mammogenesis in the sheep 1. The effects of level of nutrition on growth and mammary development in female lambs. *Animal Science* 41(3): 323-332. <https://doi.org/10.1017/S0003356100036370>
- Knight TW, Atkinson DS, Haack NA, Palmer CR, Rowland KH. 1993. Effects of suckling regime on lamb growth rates and milk yields of Dorset ewes. *New Zealand Journal of Agricultural Research* 36(2): 215-222. <https://doi.org/10.1080/00288233.1993.10417756>
- Krohn CC. 1999. A review: Consequences of different suckling systems in high producing dairy cows. *Proceedings of the International Symposium Suckling*, Swedish University of Agricultural Science, Stockholm, Sweden, pp 1-8.
- Kuznetsova A, Brockhoff PB, Christensen RHB. 2017. "lmerTest Package: Tests in linear mixed effects models. *Journal of Statistical Software* 82(13): 1-26. <https://www.https://doi.org/10.18637/jss.v082.i13>
- Lawlor MJ, Louca A, Mavrogenis A. 1974. The effect of three suckling regimes on the lactation performance of Cyprus fatted, Chios and Awassi sheep and the growth rate of lambs. *Animal Production* 18: 293-299. <https://doi.org/10.1017/S0003356100022467>
- Length RV. emmeans: Estimated Marginal Means, aka Least-Squares means. R package version 1.5.4. <https://CRAN.R-project.org/package=emmeans>
- Lopez-Villalobos N, King M, King J, Morris RS. 2017. Estimates of genetic parameters for direct and maternal genetic effects on weaning weights in Dairymeade sheep. *Proceedings of the New Zealand Society of Animal Production* 77: 129-132. <https://www.cabdirect.org/cabdirect/abstract/20183132611>
- Louca A. 1972. The effect of suckling regime on growth rate and lactation performance of the Cyprus fat-tailed and Chios sheep. *Animal Production* 15: 53-59. <https://doi.org/10.1017/S0003356100011211>
- McCoard SA, Adiletta AM, Jenkinson CMC, Peterson SW, Kenyon PR, Blair H. 2018. BRIEF COMMUNICATION: Impact of maternal plane of nutrition, ewe weight and twinning on fetal mammary gland development in sheep. *New Zealand Journal of Animal Science and Production* 78: 183-185. <https://www.cabdirect.org/cabdirect/abstract/20193148648>
- McCoard SA, Heiser A, Lowe K, Molenaar A, Maclean P, Johnstone P, Leath S, Hoskin SO, Khan MA. 2019. Effect of weaning age on growth, mammary gland development, and immune function in Holstein Friesian calves fed conserved alfalfa (FiberStart). *Journal of Dairy Science* 102(7): 6076-6087. <https://doi.org/10.3168/jds.2018-15615>

- McKusick BC, Marnet P-G, Combaud J-F, Dano Y, Aubry J-M. 2000. A half-udder comparison of suckling or machine milking on local modification of the teat and udder during early lactation of dairy ewes. *Proceedings of the International Dairy Federation Symposium of Immunology of the Ruminant Mammary Gland*. Zecconi A (Ed) Stresa, Italy, pp 124-130. <https://www.researchgate.net/profile/Pierre-Marnet/publication/26694466>
- McKusick BC, Thomas DL, Berger YM. 2001. Effect of weaning system on commercial milk production and lamb growth of East Friesian dairy sheep. *Journal of Dairy Science* 84: 1660-1668. [https://doi.org/10.3168/jds.S0022-0302\(01\)74601-2](https://doi.org/10.3168/jds.S0022-0302(01)74601-2)
- Meyer MJ, Capuco AV, Ross DA, Lintault LM, Van Amburgh ME. 2006. Developmental and nutritional regulation of the prepubertal heifer mammary gland: I. Parenchyma and fat pad mass and composition. *Journal of Dairy Science* 89: 4289-4297. [https://doi.org/10.3168/jds.S0022-0302\(06\)72475-4](https://doi.org/10.3168/jds.S0022-0302(06)72475-4)
- Papachristoforou C. 1990. The effects of milking method and postmilking suckling on ewe milk production and lamb growth. *Annales de zootechnie* 39: 1-8. <https://hal.archives-ouvertes.fr/hal-00888713>
- Pellegrini O, Remeuf F, Rivemale M, Barillet F. 1997. Renneting properties of milk from individual ewes: Influences of genetic and non-genetic variables, and relationship with physicochemical characteristics. *Journal of Dairy Research* 64: 355-366. <https://doi.org/10.1017/S0022029997002203>
- R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
- Ricordeau G, Denamur R. 1962. Production laitière des brebis Pré-alpes du Sud pendant les phases d'allaitement, de sevrage et de traite. *Annales de zootechnie* 11: 5-38. <https://hal.archives-ouvertes.fr/hal-00886765/document>
- Rovai M, Caja G, Such X. 2008. Evaluation of udder cisterns and effects on milk yield of dairy ewes. *Journal of Dairy Science* 91: 4622-4629. <https://doi.org/10.3168/jds.2008-1298>
- Sejrsen K & Purup S. 1997. Influence of prepubertal feeding level on milk yield potential of dairy heifers: a review. *Journal of Animal Science* 75(3):828-35. <https://doi.org/10.2527/1997.753828x>
- Soberon F & Van Amburgh ME. 2017. Effects of preweaning nutrient intake in the developing mammary parenchymal tissue. *Journal of Dairy Science* 100: 4996-5004. <https://doi.org/10.3168/jds.2016-11826>
- Soberon F & Van Amburgh ME. 2013. LACTATION BIOLOGY SYMPOSIUM: The effect of nutrient intake from milk or milk replacer of preweaned dairy calves on lactation milk yield as adults: A meta-analysis of current data. *Journal of Dairy Science* 91: 706-712. <https://doi.org/10.2527/jas.2012-5834>
- Stevens D, Samuelsson L, McCoard S, Day L, Young W, Bartlett N, Konui W, Gatley P, Hammond N, Macdonald T, King M, Hewittson J. 2018. Using a co-innovation approach to accelerate the development of dairy sheep enterprises in New Zealand. Presented at the 13th European IFSA Symposium, *Farming systems: facing uncertainties and enhancing opportunities; Theme 3 – Integrating science, technology, policy and practice*, Chania, Greece 1-5 July, pp. 1-13. [www.itsa.boku.ac.at/cms/fileadmin/Proceeding2018/Theme3\\_Stevens.pdf](http://www.itsa.boku.ac.at/cms/fileadmin/Proceeding2018/Theme3_Stevens.pdf)
- Teng F, Reis MG, Broadhurst M, Lagutin K, Samuelsson L, Ma Y, Stevens D, Day L. 2019. Factors affecting levels of volatile 4-alkyl branched-chain fatty acids in sheep milk from 2 contrasting farming systems in New Zealand. *Journal of Dairy Science* 103: 2419-2433. <https://doi.org/10.3168/jds.2019-17192>
- van der Linden DS, Kenyon PR, Blair HT, Lopez-Villalobos N, Jenkinson CMC, Peterson SW, Mackenzie DDS. 2009. Effects of ewe size and nutrition on fetal mammary gland development and lactational performance of offspring at their first lactation. *Journal of Animal Science* 87: 3944-3954. <https://doi.org/10.2527/jas.2009-2125>
- Villeneuve L, Cinq-Mars D, Lacasse P. 2010. Effects of restricted feeding of prepubertal ewe lambs on reproduction and lactation performances over two breeding seasons. *Animal* 4(12): 1997-2003. <https://doi.org/10.1017/S1751731110000170>
- Zidi A, Ayadi M, Caja G, Such X, Ghirardi JJ, Albanell E. 2005. Efectos de la alimentación antes de la pubertad sobre la vida productiva de ovejas lecheras de raza Manchega y Lacaune. *Informacion Tecnica Economica Agraria: Production Animals* 26: 249-251. [https://aida-itea.org/aida-itea/files/jornadas/2005/comunicaciones/2005\\_SGEG\\_25.pdf](https://aida-itea.org/aida-itea/files/jornadas/2005/comunicaciones/2005_SGEG_25.pdf)
- Zuur AF, Ieno EN, Elphick CS. 2010. A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution* 1(1): 3-14. <https://doi.org/10.1111/j.2041-210X.2009.00001.x>