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Effects of intramammary antibiotic therapy during the dry period on the performance of Lacaune dairy sheep under intensive management

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Often the only way to ensure profitability of Lacaune dairy sheep is intensive management, which requires appropriate dry-period treatment to ensure animal productivity and health. The present study aimed to investigate the effects of intramammary antibiotic dry therapy on the performance and health of Lacaune sheep under intensive management. We recorded data for 5981 complete lactation periods that followed a dry period. A total of 2402 lactation periods were preceded by a dry period involving intramammary administration of 300 mg of cephapirin benzathine (antibiotic group) and 3579 lactation periods were preceded by dry periods with no treatment (control group). The following on-farm yield data were collected for individual lactation periods: length of the subsequent lactation period; total milk yield per lactation period; daily milk yield and length of the subsequent dry period. Data on confounding factors that might affect productivity were also recorded, including the individual ewe, number of lactation periods and length of the previous dry period. Milk quality was assessed using data on somatic cell count (SCC) and content of protein and fat taken from the Spanish National Official Milk Yield Recording System. Antibiotic dry therapy significantly improved total yield per lactation period, which was 429 ± 151·1 l in the antibiotic group and 412 ± 165·5 l in the control group, as well as the daily milk yield, which was 1986 ± 497·0 and 1851 ± 543·2 ml/d, respectively (both $P < 0·0001$). The initial dry period was significantly longer in the antibiotic group than in the control group, and dry period length correlated inversely with yield variables such us total yield per lactation period ($r = -0·055$; $P < 0·0001$) and yield per day in milk ($r = -0·039$; $P < 0·0001$). As a result, milk yield records systematically underestimated the positive effects of antibiotic dry therapy. Antibiotic dry therapy also significantly improved milk quality. Milk from the antibiotic group showed 50% lower SCC (573 ± 1326 *vs.* 1022 ± 2126 cells/ml; $P < 0·0001$) and slightly higher content in fat (7·33 ± 0·91 *vs.* 7·15 ± 0·87%) and protein (5·63 ± 0·44 *vs.* 5·44 ± 0·4%). The results of this study suggest that cephalosporin dry therapy of Lacaune dairy sheep increases milk production and improves milk quality during subsequent lactation periods.

Keywords: Lacaune, dairy sheep, antibiotic dry therapy, cephalosporin, SCC, intensive management.

One of the most effective strategies to reduce intramammary infections is antibiotic dry therapy. This practice is widely used in dairy cows and has proven effective in keeping them healthy and enhancing milk production (Robert et al. 2006). Antibiotic dry therapy has also shown good results in meat sheep breeds, helping to increase weight gain in lambs relative to untreated animals (Watson & Buswell, 1984). The therapy has worked well in several breeds of dairy sheep (reviewed by Petridis & Fthenakis, 2014), including

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Israeli-Assaf sheep under intensive management (Chaffer et al. 2003), cross-bred dairy sheep in a semi-intensive system (Spanu et al. 2011), Churra sheep under traditional management (Gonzalo et al. 2004) or Spanish-Assaf sheep in mixed production systems (Gonzalo et al. 2009, 2010).

In addition, previous studies of this therapy in dairy sheep have not examined in detail the various factors that may influence its success, such as dry period length, which can be crucial for subsequent milk yield (Hernandez et al. 2012). These investigations are particularly important for optimising production while minimising antibiotic use. Therefore, the present study investigated the effects of intramammary cephapirin dry therapy on the performance and health of Lacaune sheep under intensive management.

Material and methods

Flock and management

This study included data on milk production from complete lactation periods of 4345 Lacaune sheep on a single farm between March 2009 and January 2012. Since June 2010, intramammary cephalosporin (cephapirin benzathine; CEFA-SAFE®, MSD Animal Health, Boxmeer, Netherlands) was administered to all sheep (300 mg/ewe) at the beginning of the dry period. Ewes belonged to a flock of approximately 4000 sheep on the Cerromonte Farm in Avila, Spain (continental climate, latitude 40.90°N, altitude 900 m). The original flock had been imported from the French Lacaune Association in the Upra Lacaune Region of Aveyron.

The environmental conditions of the animals remained approximately the same over the entire study period. Flock management, described in detail by Elvira et al. (2013a, b), can be summarised as follows. Animals were housed indoors, and food was rationed according to the sheep's production level. Reproductive management included five mating periods per year; different groups of ewes were kept with males for 25 d to allow natural mating. Ewe lambs were mated for the first time between 8 and 10 months of age. Mean age at first lambing was 432 ± 77·4 d (14·4 months). Ewes were mated again approximately 100–140 d after lambing. From the day after lambing, ewes were milked twice a day, with no suckling period for lambs, and milking continued until production dropped below 0·5 l/d or until 30 d before the subsequent lambing, when they were dried off.

Experimental groups and endpoints

Data available from ewe lactation periods were analysed in two different ways, depending on the question we wanted to examine. In Experiment 1, we wanted to determine the effects of antibiotic dry therapy on on-farm milk yield and on ewe performance during 5981 lactation periods. All lactation periods included in our analysis were complete: they included a previous initial dry period as well as subsequent lambing. A total of 2152 lactation periods were second lactation periods; 1681, third; 1015, fourth; 667, fifth; 316, sixth; and 150, seventh or later lactation periods.

A total of 2402 lactation periods followed an initial dry period with antibiotic therapy (antibiotic group), while 3579 followed an initial dry period with no therapy (control group). Data on potential confounding factors known to influence performance, such as lactation period number (LN), length of initial dry period (I-DPL) and initial interlambing interval (I-ILI) were collected. ILI was defined as the time interval between two consecutive lambings.

To control for effects of antibiotic dry therapy at the level of individual ewes, we analysed a subset of 1951 animals for which data for two consecutive lactation periods were available. For these animals, data were compared for a lactation period after an initial dry period with no antibiotic treatment (control group) and for a subsequent lactation period after antibiotic dry therapy (antibiotic group).

The following on-farm yield data were collected for individual lactation periods: individual ewe; the initial interlambing interval (I-ILI), defined as the interval between the previous lambing and the lambing that gave rise to the lactation period under study; the number of the lactation period under study (LN); the length of the initial dry period before the lactation period under study (I-DP); the length of the lactation period under study (S-LL); total milk yield of the lactation period under study (TY), daily milk yield in ml during the lactation period under study (Y/DIM); the length of the subsequent dry period (S-DPL); and the length of the subsequent interlambing interval (S-ILI) (Fig. 1).

In Experiment 2, we wanted to study the effects of antibiotic dry therapy on milk quality parameters, i.e. somatic cell count (SCC) and content of fat and protein. Data on milk quality were taken from the Spanish National Official Milk Yield Recording System for Sheep Dairy Production Control Programme (http://www.uagcyl.es/). This part of the study included 3727 complete lactation periods with a previous dry period, of which 1620 followed a dry period with no antibiotic therapy (control group) and 2107 followed antibiotic dry therapy (antibiotic group). Ewe-level analysis was conducted on data from 1390 animals for which two consecutive lactation periods were compared, one after an untreated initial dry period (control group) and a subsequent lactation period after antibiotic dry therapy (antibiotic group). Data from the National Official Milk Yield Recording System were extracted on the following parameters of milk yield and quality during subsequent lactation periods: SCC (cells/ml × 10^{-3}), Y/DIM, total protein yield (TP, %) and total fat yield (TF, %). Sampling was performed once a month by farm workers, who tested every sheep that was lactating on the day of sampling.

During the study period, antibiotic residues in the milk of each bulk tank were assayed daily before collection. These legally mandated assays are designed to detect down to 4 parts per billion by volume (ppb) of amoxicillin, 4 ppb of ampicillin and 10 ppb of oxytetracycline. The assays were performed using an Eclipse 100ov screening test

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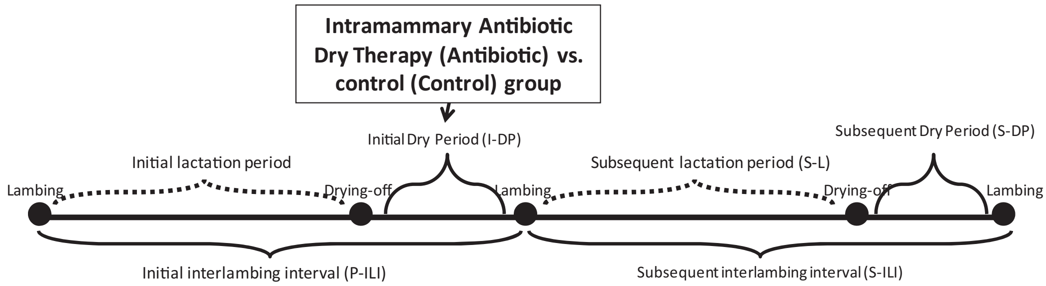

Fig. 1. Study design and nomenclature of lactation periods and relevant performance parameters.

according to the manufacturer's instructions (ZEU-Inmunotec, Zaragoza, Spain). This test is based on the ability of samples to inhibit the growth of spores of *Bacillus stearothermophilus* var. *calidolactis* C953. Milk in bulk tanks was also sampled monthly for the 12 months preceding this study in order to identify pathogens present on the farm. The pathogens most frequently isolated were coagulase-negative *Staphylococcus*, followed by *Staph. aureus* and least often *Streptococcus agalactiae*. These results were used to select the appropriate drug for antibiotic dry therapy during the present study. SCC was determined by spectrophotometry and flow cytometry.

Statistics

Performance records were collected at the farm, stored and validated on-farm using Alpro Windows software (DeLaval, Tumba, Sweden). Records from the National Official Milk Yield Recording System were collected from the publicly available database (www.uagcyl.es). Data were analysed using SPSS® 19.0 (IBM, NY, USA). Statistical significance of differences in continuous parameters was assessed using Student's *t* test. Relationships between continuous variables were assessed using Pearson correlation analysis. When data did not show a normal distribution, the significance of differences was assessed using the Kruskal-Wallis test. Only differences with $P<0{\cdot}001$ were considered significant; this restrictive threshold was chosen in light of the large size of the animal groups in this study.

Results

Experiment 1: on-farm parameters of yield and performance

Antibiotic dry therapy with cephalosporin significantly improved daily milk yield and total yield per lactation period in Lacaune dairy sheep under intensive conditions, based on analysis of 5981 complete lactation periods (Table 1, Fig. 2).

To verify that these results were likely to reflect the effects of antibiotic dry therapy, we compared the antibiotic and control groups in terms of several potential confounding factors. As expected, we found that the antibiotic group showed a similar number of lactation periods, similar initial interlambing interval but larger initial dry period length (Table 1).

Table 1. Performance and yield parameters associated with lactation periods of 1951 Lacaune dairy sheep under intensive management following an initial dry period with cephapirin therapy (Antibiotic) or no therapy (Control)

	Antibiotic lactation periods ($n=3579$)	Control lactation periods ($n=2402$)	
Parameter	Average ± SD	Average ± SD	*P*
TY, l	429 ± 151·1	412 ± 165·5	<0·0001
Y/DIM, ml/d	1986 ± 497·0	1851 ± 543·2	<0·0001
S-LL, d	212 ± 39·6	218 ± 50·2	<0·0001
S-DPL, d	66 ± 27·0	72 ± 43·1	<0·0001
N-ILL, d	278 ± 41·7	291 ± 59·1	<0·0001
NL	3·32 ± 1·49	3·29 ± 1·25	>0·05
I-DPL	72 ± 42·0	66 ± 50·2	<0·0001
I-ILI	300 ± 61·7	296 ± 65·8	>0·05

TY, total yield of subsequent lactation periods; Y/DIM, daily milk yield; S-LL, length of the subsequent lactation period; S-DPL, length of the subsequent dry period; N-ILL, subsequent interlambing interval; NL, number of lactation periods; I-DPL, length of the initial dry period; I-ILI, length of the initial interlambing interval

Analysis of variations in performance variables within and between the antibiotic and control groups revealed that initial dry period length correlated inversely with yield variables such us total yield ($r=-0{\cdot}055$, $P<0{\cdot}0001$), daily milk yield ($r=-0{\cdot}039$, $P<0{\cdot}0001$), and length of the subsequent lactation period ($r=-0{\cdot}048$, $P<0{\cdot}0001$). Initial dry period length correlated directly with subsequent dry period length ($r=0{\cdot}141$) and subsequent interlambing interval ($r=0{\cdot}058$; both $P<0{\cdot}0001$).

In order to identify which factors exerted the strongest influence on the length of subsequent lactation periods and therefore productivity, we simultaneously analysed all yield and performance variables for a possible relationship with the length of the subsequent lactation period. This decision-tree analysis, conducted simultaneously on data from both the antibiotic group and control group, revealed that the length of the initial dry period was the strongest determinant of the length of the subsequent lactation period ($P<0{\cdot}0001$). Initial dry periods lasting 48–52 d were associated with

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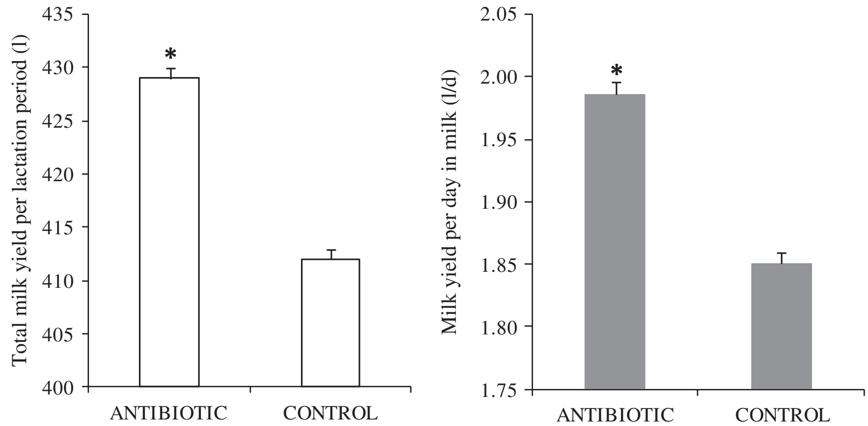

Fig. 2. Total yield per lactation period (left) and daily milk yield (right) of Lacaune dairy sheep under intensive management. Lactation periods were preceded either by cephapirin dry therapy ($n=3579$ lactation periods; Antibiotic) or by a dry period with no therapy ($n=2402$ lactation periods; Control). Asterisks show statistically significant differences between groups ($P<0{\cdot}001$).

Table 2. Comparison of milk yield parameters between a lactation period preceded by an untreated dry period (Control), followed by a lactation period after cephapirin dry therapy (Antibiotic) in the same in the same group of sheep as in Table 1

	Antibiotic	Control	
Parameter	Average ± SD	Average ± SD	*P*
TY, l	432 ± 157·0	432 ± 154·7	> 0·01
Y/DIM, ml/d	1985 ± 501·3	1804 ± 454·3	< 0·0001
S-LL, d	213 ± 40·3	237 ± 56·2	< 0·0001
S-DPL, d	67 ± 28·1	71 ± 42	< 0·0001
N-ILL, d	281 ± 43·5	308 ± 63·4	< 0·0001
I-DPL, d	77 ± 43·0	61 ± 44·8	< 0·0001
I-ILI, d	305 ± 58·2	288 ± 64·1	< 0·0001

TY, total yield of subsequent lactation periods; Y/DIM, daily milk yield; S-LL, length of the subsequent lactation period; S-DPL, length of the subsequent dry period; N-ILL, subsequent interlambing interval; NL, number of lactation periods; I-DPL, length of the initial dry period; I-ILI, length of the initial interlambing interval

longer lactation periods (mean, 226 d) than were initial dry periods outside this range. Antibiotic therapy affected the length of the lactation period only when the initial dry period was shorter than 48 d; in this case, antibiotic therapy during the dry period was associated with a shorter lactation period (mean, 210 d) than was a dry period without therapy (mean, 219 d; $P<0{\cdot}001$).

In order to analyse the effects of antibiotic dry therapy at the level of individual ewes, yield parameters were analysed for 1951 sheep with two consecutive complete lactation periods, the first following an initial dry period without antibiotic therapy, and the second following an initial dry period with antibiotic therapy. Antibiotic dry therapy was associated with greater milk production per lactation period (1985 ± 501·3 *vs.* 1804 ± 454·3 l; $P<0{\cdot}0001$) as well as shorter lactation periods (213 ± 40·3 *vs.* 237 ± 56·2 d; $P<0{\cdot}0001$; Table 2).

Table 3. Comparison of milk yield parameters between a lactation period preceded by an untreated dry period (Control), followed by a lactation period after antibiotic dry therapy (Antibiotic) in Lacaune dairy sheep under intensive management, stratified by lactation order

	Antibiotic	Control	
	Average ± SD	Average ± SD	*P*
930 sheep (2nd *vs.* 1st lactation periods)			
TY, l	441 ± 152·9	418 ± 151	< 0·0001
Y/DIM, ml/d	1998 ± 490·2	1686 ± 40·2	< 0·0001
427 sheep (3rd *vs.* 2nd lactation periods)			
TY, l	446 ± 157·4	463 ± 152·9	> 0·01
Y/DIM, ml/d	2059 ± 500·1	1991 ± 453·2	< 0·0001
217 sheep (4th *vs.* 3rd lactation periods)			
TY, l	426 ± 175·7	453 ± 193·5	< 0·0001
Y/DIM, ml/d	1967 ± 572·2	1926 ± 524·8	> 0·01
206 sheep (5th *vs.* 4th lactation periods)			
TY, l	404 ± 130·1	427 ± 146·7	> 0·01
Y/DIM, ml/d	1916 ± 454·5	1847 ± 422·7	> 0·01

TY, total yield of subsequent lactation periods; Y/DIM, daily milk yield

To extend this individual-level analysis, we compared, for the same ewe, one lactation period after an untreated dry period with a lactation period after a treated dry period as a function of lactation order (Table 3). The results indicate that the positive effect of antibiotic treatment on yield is greater during earlier lactation periods.

Experiment 2: milk quality parameters

Antibiotic dry therapy significantly improved both the daily milk yield and milk quality during the subsequent lactation period. SCC was significantly lower, and fat and protein content slightly higher, in milk produced following antibiotic dry therapy than in milk produced after a control dry period (Fig. 3, Table 4).

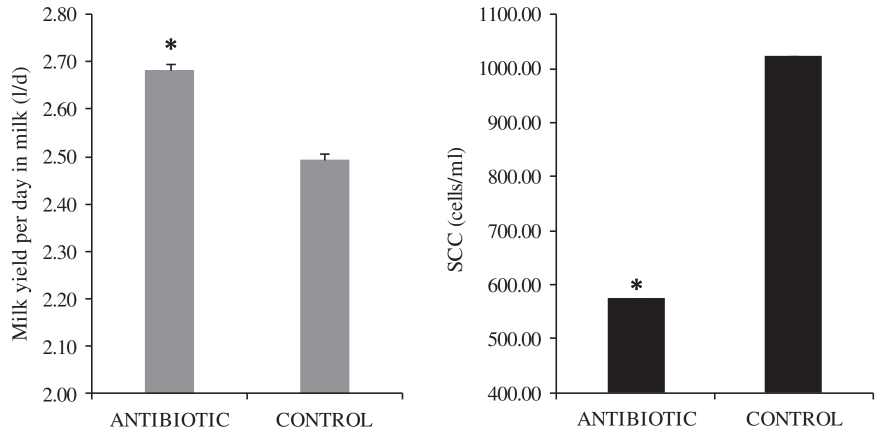

Fig. 3. Daily milk yield (left) and somatic cell count (SCC) of milk (right) produced by Lacaune dairy sheep under intensive management during lactation periods preceded either by cephapirin dry therapy ($n=2107$ lactation periods; Antibiotic) or by a dry period with no therapy ($n=1620$ lactation periods; Control). Asterisks show statistically significant differences between groups ($P<0{\cdot}001$).

Table 4. Daily milk yield (Y/DIM) and milk quality associated with lactation periods of Lacaune dairy sheep under intensive management following an initial dry period with cephapirin therapy (Antibiotic) or no therapy (Control)

	Antibiotic	Control	
	Average ± SD	Average ± SD	*P*
Y/DIM, ml/d	2682 ± 690·5	2492 ± 608·84	< 0·0001
Milk protein, %	5·63 ± 0·44	5·44 ± 0·4	< 0·0001
Milk fat, %	7·33 ± 0·91	7·15 ± 0·87	< 0·0001
Somatic cell count, cells/ml	573·7 ± 1326·8	1022 ± 2126·2	< 0·0001

Source: Spanish National Official Milk Yield Recording System for Sheep Dairy Production Control Programme

Table 5. Analysis of correlations between somatic cell count (cells/ml) and milk production and quality parameters of Lacaune dairy sheep under intensive management

Parameter	*r*	*P*
TY, l	− 0·162	< 0·0001
Y/DIM, ml/d	− 0·192	< 0·0001
PY, %		> 0·01
FY, %	− 0·079	< 0·0001
S-LL, d	− 0·069	< 0·0001
NL		> 0·01

TY, total yield of subsequent lactation periods; Y/DIM, daily milk yield; PY, protein yield in %; FY, fat yield in %; SCC, somatic cell count; S-LL, length of the subsequent lactation period; NL, number of lactation periods; I-DPL, length of the initial dry period

Given the importance of SCC as an index of milk quality, we examined whether SCC correlated with milk yield or quality parameters in our study. The results indicated that SCC correlated inversely with nearly all yield and quality parameters (Table 5). The exceptions were protein content in the milk and number of lactation periods, neither of which showed an association with SCC.

Just as we did for milk yield parameters, we wanted to examine the effects of antibiotic dry therapy on milk quality at the level of individual ewes. Therefore, we analysed quality data for 1390 sheep with two consecutive complete lactation periods, the first following an initial dry period without antibiotic therapy, and the second following an initial dry period with antibiotic therapy. The results confirmed that antibiotic therapy improved yield per day in milk (2694 ± 672·1 *vs.* 2412 ± 527·3 ml/d; $P<0{\cdot}0001$) and reduced the SCC (614·4 ± 1362·1 *vs.* 773·2 ± 1672·2 cells/ml; $P<0{\cdot}001$) (Table 6).

To extend this individual-level analysis, we compared, for the same ewe, one lactation period after an untreated dry period with a lactation period after a treated dry period as a function of lactation order (Table 7). The results indicate that the positive effect of antibiotic treatment on yield was greater during earlier lactation periods, but that the reduction in SCC was more notable in the third lactation period than in the second one.

Discussion

The present study provides the first detailed insights into how antibiotic dry therapy affects the productive and milk quality parameters of Lacaune sheep under intensive management. Total yield per lactation period as well as daily milk yield were significantly greater during lactation periods following antibiotic dry therapy than during lactation periods without such therapy. In addition, milk produced after antibiotic dry therapy showed significantly lower SCC and slightly higher protein and fat content than milk in control lactations. These results suggest that antibiotic dry therapy with 300 mg intramammary cephapirin benzathine per ewe can increase the profitability and health of Lacaune dairy sheep under intensive management.

Table 6. Comparison of milk quality parameters between a lactation period preceded by an untreated dry period (Control) and a subsequent lactation period preceded by antibiotic dry therapy (Antibiotic) in the same group of 1390 Lacaune dairy sheep under intensive management

	Antibiotic	Control	
Parameter	Average ± SD	Average ± SD	*P*
Y/DIM, ml/d	2694 ± 672·1	2412 ± 527·3	< 0·0001
PY, %	5·61 ± 0·43	5·43 ± 0·41	< 0·0001
FY, %	7·3 ± 0·9	7·1 ± 0·87	< 0·0001
SCC, cells/ml	614·4 ± 1362·1	773·2 ± 1672·2	< 0·001

Y/DIM, daily milk yield; PY, protein yield in %; FY, fat yield in %; SCC, somatic cell count

Table 7. Comparison of milk quality parameters between a lactation period preceded by an untreated dry period (Control) and a subsequent lactation period preceded by antibiotic dry therapy (Antibiotic) in Lacaune dairy sheep under intensive management, stratified by lactation order

	Antibiotic	Control	
	Average ± SD	Average ± SD	*P*
514 sheep (2nd *vs.* 1st lactation periods)			
Y/DIM, ml/d	2750 ± 674	2234·5 ± 450·6	< 0·0001
PY, %	5·62 ± 0·86	5·31 ± 0·4	< 0·0001
FY, %	7·34 ± 0·9	6·82 ± 0·78	< 0·0001
SCC, cells/ml	590·8 ± 1354·8	679·9 ± 1510·3	> 0·001
384 sheep (3rd *vs.* 2nd lactation periods)			
Y/DIM, ml/d	2754 ± 664·8	2573·9 ± 499·4	< 0·0001
PY, %	5·66 ± 0·41	5·54 ± 0·4	< 0·0001
FY, %	7·24 ± 0·83	7·3 ± 0·9	> 0·001
SCC, cells/ml	470 ± 1000·6	710·3 ± 1505·3	< 0·0001

Y/DIM, daily milk yield; PY, protein yield in %; FY, fat yield in %; SCC, somatic cell count

Analysis of yield in individual ewes showed that during the second lactation period, antibiotic dry therapy was associated with enhancement in daily milk yield relative to lactation without antibiotic therapy, while during the third and subsequent lactation periods, yield was similar with or without antibiotic therapy. In contrast, Lacaune ewes under intensive management normally show the highest yield during the first lactation period and then gradually smaller yields during subsequent lactation periods despite a constant daily yield, as a result of the fact that lactation periods gradually shorten with age (Hernandez et al. 2011; Elvira et al. 2013a, b). This suggests that antibiotic dry therapy, by increasing daily yield, can substantially increase total yield per lactation period.

Antibiotic dry therapy was also associated with significantly higher milk quality, reflected in a 50% lower SCC than milk from untreated lactation periods (1022 ± 2126 *vs.* 573 ± 1326 cells/ml). In fact, SCC in milk from treated lactation periods remained lower than SCC in untreated milk through at least the third lactation period. This is despite the fact that ewes are more likely to suffer intramammary infection and therefore higher SCC with increasing lactation order (Gonzalo et al. 2002, 2004). We found that lower SCC correlated with higher yield per day in milk, as reported for dairy cows (Hand et al. 2012) and for Churra and crossbreed dairy sheep (Gonzalo et al. 2004; Spanu et al. 2011). Presumably antibiotic dry therapy prevents and eliminates intramammary infections, maximising the number of healthy, milk-producing cells in the udder.

The association between antibiotic dry therapy and both higher daily yield and higher total yield per lactation period is slightly surprising given that the therapy was associated with a significantly longer initial dry period. Longer initial dry periods have been shown to reduce yield and length of subsequent lactation periods as well as leading to poor health in cows, Chilean sheep and Lacaune sheep (Natzke et al. 1975; Pinedo et al. 2011; Hernandez et al. 2012). However, we did not observe such effects in the present study, suggesting that the positive effects of antibiotic dry therapy can outweigh the potential negative effects due to longer initial dry periods. Such extended dry periods are necessary to ensure adequate time for the antibiotic to clear from the animals and not enter the milk. Indeed, daily testing of milk batches on the study farm failed to detect antibiotic levels in excess of legal limits for Spain (data not shown). This is consistent with previous results suggesting that antibiotic contamination of milk depends more on general farm conditions than on the use of antibiotic dry therapy (Gonzalo et al. 2010).

Antibiotic dry therapy was associated with one negative effect in our study: lactations following therapy were shorter than lactations following control dry periods. Our decision-tree analysis of all performance variables suggests that this negative effect was due not to the therapy itself but to the longer length of the initial dry period. This is similar to the conclusions of a study of antibiotic dry therapy in Lacaune sheep without antibiotic dry therapy (Hernandez et al. 2012). All these studies are consistent with similar work in dairy cows (Bernier-Dodier et al. 2011).

The fact that antibiotic dry therapy was associated with minimal problems in the present study probably reflects the rigorously controlled hygienic conditions on the study farm. Less rigorous control may help explain why such therapy by itself was found to be insufficient for reducing SCC in milk and therefore for enhancing yield in Israeli-Assaf dairy sheep after procaine-benzylpenicillin-nafcillin-dihydrostreptomycin dry therapy; additional measures were needed to prevent intramammary infections and maintain healthy udders in the herd (Chaffer et al. 2003). Failure to ensure adequate hygiene control may also help explain why antibiotic dry therapy failed to improve milk yield in Spanish Assaf milk ewes (Gonzalo et al. 2009).

We observed an inverse relationship between fat content in milk and SCC, as reported for dairy goats (Revilla et al. 2009; Rupp et al. 2011). In contrast, we observed no association between protein content of milk and SCC.

Management practices on the study farm can be considered representative of other Lacaune farms outside the Roquefort Designation of Origin and they are similar to management practices for many other dairy sheep breeds under intensive management. Therefore, we expect our results to be relevant to most intensive dairy sheep farms around the world.

Conclusion

This study indicates that antibiotic dry therapy with cephapirin is associated with both greater total milk yield and daily milk yield during subsequent lactation periods in Lacaune dairy sheep under intensive conditions. It is also associated with significantly lower SCC and slightly higher protein and fat content of milk produced in subsequent lactation periods. These findings suggest that antibiotic dry therapy may be effective for improving the health and productivity of Lacaune sheep as well as potentially other dairy sheep breeds under intensive management.

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References

Bernier-Dodier P, Girard CL, Talbot BG & Lacasse P 2011 Effect of dry period management on mammary gland function and its endocrine regulation in dairy cows. *Journal of Dairy Science* **94** 4922–4936

Chaffer M, Leitner G, Zamir S, Winkler M, Glickman A, Ziv N & Saran A 2003 Efficacy of dry-off treatment in sheep. *Small Ruminant Research* **47** 11–16

Elvira L, Hernandez F, Cuesta P, Cano S, Gonzalez-Martin JV & Astiz S 2013a Factors affecting the lactation periods curves of intensively managed sheep based on a clustering approach. *Journal of Dairy Research* **80** 439–447

Elvira L, Hernandez F, Cuesta P, Cano S, Gonzalez-Martin JV & Astiz S 2013b Accurate mathematical models to describe the lactation periods curve of Lacaune dairy sheep under intensive management. *Animal* **7** 1044–1052

Gonzalo C, Ariznabarreta A, Carriedo JA & San Primitivo F 2002 Mammary Pathogens and their relationship with somatic cell count and milk yield losses in dairy ewes. *Journal of Dairy Science* **85** 1460–1467

Gonzalo C, Tardaguila JA, De la Fuente LF & San Primitivo F 2004 Effects of selective and complete dry therapy on prevalence of intramammary infection and on milk yield in the subsequent lactation periods in dairy ewes. *Journal of Dairy Research* **71** 33–38

Gonzalo C, Linage B, Carriedo JA, Juarez MT, Beneitez E, Martinez A & De la Fuente LF 2009 Effect of dry therapy using an intramammary infusion on bulk tank somatic cell count in sheep. *Journal of Dairy Science* **92** 156–159

Gonzalo C, Carriedo JA, Garcia-Jimeno MC, Perez-Bilbao M & De la Fuente LF 2010 Factors influencing variation of bulk milk antibiotic residue occurrence, somatic cell count, and total bacterial count in dairy sheep flocks. *Journal of Dairy Science* **93** 1587–1595

Hand KJ, Godkin A & Kelton DF 2012 Milk production and somatic cell counts: a cow-level analysis. *Journal of Dairy Science* **95** 1358–1362

Hernandez F, Elvira L, Gonzalez-Martin JV, Gonzalez-Bulnes A & Astiz S 2011 Influence of age at first lambing on reproductive and productive performance of Lacaune dairy sheep under an intensive management system. *Journal of Dairy Research* **78** 160–167

Hernandez F, Elvira L, Gonzalez-Martin JV & Astiz S 2012 Influence of dry period length on reproductive performance and productivity of Lacaune dairy sheep under an intensive management system. *Journal of Dairy Research* **79** 352–360

Natzke RP, Everett RW & Bray DR 1975 Effect of drying off practices on mastitis infection. *Journal of Dairy Science* **58** 1828–1835

Petridis IG & Fthenakis GC 2014 Administration of antibiotics to ewes at the beginning ofthe dry-period. *Journal of Dairy Research* **81** 9–15

Pinedo P, Risco C & Melendez P 2011 A retrospective study on the association between different lengths of the dry period and subclinical mastitis, milk yield, reproductive performance, and culling in Chilean dairy cows. *Journal of Dairy Science* **94** 106–115

Revilla I, Lurueña-Martínez MA & Vivar-Quintana AM 2009 Influence of somatic cell counts and breed on physico-chemical and sensory characteristics of hard ewes'-milk cheeses. *Journal of Dairy Research* **76** 283–289

Robert A, Seegers H & Bareille N 2006 Incidence of intramammary infections during the dry period without or with antibiotic treatment in dairy cows – a quantitative analysis of published data. *Veterinary Research* **37** 25–48

Rupp R, Clément V, Piacere A, Robert-Granié C & Manfredi E 2011 Genetic parameters for milk somatic cell score and relationship with production and udder type traits in dairy Alpine and Saanen primiparous goats. *Journal of Dairy Science* **85** 3629–3634

Spanu C, Berger YM, Thomas DL & Ruegg PL 2011 Impact of intramammary antimicrobial dry treatment and teat sanitation on somatic cell count and intramammary infection in dairy ewes. *Small Ruminant Research* **97** 139–145

Watson DL & Buswell JF 1984 Modern aspects of sheep mastitis. *British Veterinary Journal* **140** 529–534