Analysis of Environmental Effects on Test Day Milk Yields of Sarda Dairy Ewes

N.P.P. MACCIOTTA, A. CAPPIO-BORLINO, and G. PULINA
Dipartimento di Scienze Zootecniche, Università degli Studi di Sassari,
Via De Nicola 9, 07100 Sassary, Italy

ABSTRACT

Temporal evolution of Sarda ewes milk production was analyzed with mixed linear models and factor analysis to investigate environmental effects on the shape of lactation curves and on milk yields during different lactation stages. Parity, year of production, level of altitude, and flock within altitude affected milk yield, whereas the effect of type of lambing was not significant. Lactation curves pertaining to the three altitudes were clearly different. Factor analysis suggested an independence among yields recorded during different phases of lactation and a specific behavior of (co)variances structure among test day yields obtained in mountains compared with hills and plains.
(**Key words:** sheep lactation curves, test day, factor analysis)

Abbreviation key: MSA = measure of sampling adequacy, **TDIM** = test day yields of the same DIM interval, **TDY** = test day yields.

INTRODUCTION

The Sarda breed, comprising approximately 4.5 million head (75% of which are on the Island of Sardegna, Italy) and producing 500,000 tonne of milk per year, can be considered one of the most important dairy sheep breeds in the world. Their milk is destined for the cheesemaking industry: Pecorino Romano cheese, largely exported in the US (20,000 tonne per year), is the most popular product (3). The husbandry system usually being semi-extensive, production is greatly influenced by environmental factors, similar to other dairy sheep breeds of Mediterranean countries.

Pluriparous ewes are mated in May to June, after shearing, and lambings occur in October to December. The breeding season of primiparous ewes occurs in fall, and lambings are concentrated at the end of the winter. All ewes are dried off in June to July, resulting in different lactation lengths for primiparous and pluriparous ewes. The productive cycle is synchronized with the availability of pastures; two periods of grass growth are concentrated in fall and spring. Furthermore, in Sardegna, spring is frequently dry and hot, causing a sudden drop of pastures quality that leads to a decline in milk yield and, in some cases, to an anticipated dry off of ewes. In some regions of the island the temperature in winter falls below 0°C for many weeks, restricting pasture availability for the ewes that, in this period, are at the beginning of lactation. Most farms have no sheep barns; feeding is based upon grazing natural pastures and upon annual and perennial forage crops; supplementation is given only in some periods of the year: hay in late summer to fall and concentrates in late fall to winter.

The environmental influence is enhanced by the different altitudes at which farms are located (5). Sheep farms on plains are usually characterized by better feeding conditions and management. Farms located on mountain regions often suffer from scarce management and insufficient feeding resources. As a consequence, serious problems arise for the genetic evaluation of animals. A recent study highlighted that genetic values of rams estimated by using all lactations of daughters available are different from genetic values obtained by using only lactations developed on high or on low production farms (31). From these considerations arise the need for more detailed studies on variation in sheep milk yield patterns under different conditions of production.

The peculiarity of the husbandry and the biological characteristics of the sheep make study of its milk production pattern rather complex. Studies have been carried out following the two main approaches originally conceived for dairy cattle. In the first approach, the regular and continuous component of milk yield (i.e., the lactation curve) is described by mathematical functions (16, 29, 40). In the second approach, test day yields (**TDY**) are analyzed by linear models that take into account a DIM factor whose estimates allow the construction of the lactation curve corrected for the effects of other factors (34). However, use of such methods with dairy sheep gives unsatisfactory results both in detecting main environmental effects (7, 9) and in identifying the shape of lactation curve (8). The frequent estimation of function parameters that clearly lack any biological meaning can be cited as an example (8, 24).

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In this study, the temporal evolution of ewe milk yield was analyzed by mixed linear models, in which TDY recorded at different DIM intervals (**TDIM**) were considered as repeated measures of the same variable, and by factor analysis, in which TDIM were regarded as different traits. Our aim was to attain a better understanding of the effects of environmental factors such as parity, prolificacy, production year, flock, and, above all, altitude at which sheep farms are located, both on the shape of lactation curves and on the (co)variances structure among TDIM.

MATERIALS AND METHODS

Data

The data set comprised 8714 test day milk yield records of 1307 Sarda pluriparous ewes from 23 commercial flocks involved in a dairy recording program. The data were collected during 2 production yr (1990 and 1993), representative of two different climatic patterns (low and high rainfall, respectively), by the Provincial Breeders Association of Sassari, Sardegna, Italy. The average records per ewe was 6.5; lactations with less than five test day records were discarded. Lactation length was fixed at 260 d and was divided into 8 DIM intervals of 30 d each, starting from d 20 of lactation. Milk of the first period of lactation was suckled by the lamb. First and second lambing ewes were not considered in this study because lactations of primiparous ewes occur in a different season compared with older animals, and second lambing ewes are partially conditioned by this delay of the productive cycle. As a consequence, the effects of environmental factors on these two parity groups (first and second lambing ewes vs. older ewes) are not comparable, and each group should be treated independently. Less than 5% of ewes had lactations in both years of production; repeated lactations were assumed to be uncorrelated, as previously suggested by other authors (34).

All flocks were classified on the basis of their location as stated by the Italian Institute of Statistics (17): 7 flocks were located on mountains, (over 500 m above the sea level), 10 on hills (200 to 500 m), and 6 were on plains (0 to 200 m).

Data were classified according to the following factors: type of lambing (one lamb or two lambs), parity (third, fourth, fifth, sixth, seventh or greater); year of production (1990 or 1993); altitude of the flock (plain, hill, or mountain); flock (23 levels); and eight levels of DIM interval. Lambing season and month of production, the two main seasonal factors usually considered in analyzing milk yield, were not taken into account because all ewes lambed in November to December and, consequently, all lactations occured in the same period (from January to July).

Statistical Analysis

Mixed linear model. The TDY were analyzed with the following mixed linear model:

$$Y_{ijklmnopq} = \mu + T_i + bX_j + YE_k + P_l + DIM_m + ALT_n + F(ALT)_{on} + DIM \times ALT_{mn} + L_p + E_{ijklmnopq} \quad [1]$$

where $Y_{ijklmnopq}$ = test day milk yield q of ewe p, μ = overall mean, T_i = fixed effect of the type of lambing, bX_j = covariable represented by the DIM at which the first record occurred, YE_k = fixed effect of production year, P_l = fixed effect of parity, DIM_m = fixed effect of DIM interval, ALT_n = fixed effect of level of altitude, $F(ALT)_{on}$ = fixed effect of flock o nested within level of altitude n, L_p = random effect of individual lactation, and $E_{ijklmnopq}$ = random residual.

The random factor L (1307 levels of individual lactation) was considered to account for the variability associated with each lactation. This animal factor was not split into genetic and permanent environment components because pedigree information was limited because of the negligible impact of AI (less than 0.5% of the total population) on the Sarda breed, and data from flocks in which natural mating is used are not always reliable. As a consequence, covariance matrices of random effects are $\mathbf{I}\sigma^2_L$ and $\mathbf{I}\sigma^2_e$, respectively, and fixed effects were estimated by ordinary least squares. However, to account for a possible effect of the heterogeneity of the residual variances on the estimates of fixed factors already observed for dairy cattle (25, 38), fixed effects of Model [1] were also estimated by a weighted least squares method. Weights were proportional to the reciprocal of the error variances, whose structure was assumed to be a diagonal matrix in which the diagonal elements differed depending on the DIM for each test (25).

Solutions for fixed effects and estimates of variance components associated with random factors were obtained using SAS MIXED and VARCOMP procedures (32). Lactation curves pertaining to different levels of altitude were constructed by plotting estimated daily milk yields over time. Estimates were obtained by adding the overall mean to the solutions for ALT, DIM, and ALT × DIM effects.

Factor analysis. Factor analysis was carried out on raw data to find stages of lactation that contributed to the whole variability of milk yield and to show possible differences of such (co)variance structures among lactations obtained at different altitudes.

In factor analysis, each original variable, Y_i, is represented as a linear function of a certain number of unobserved variables, X_j, named as factors:

$$Y_1 = b_{11}X_1 + \ldots + b_{1m}X_m + e_1$$
$$\cdots\cdots\cdots\cdots\cdots\cdots$$
$$Y_p = b_{p1}X_1 + \ldots + b_{pm}X_m + e_p$$

where b_{ij} = parameter, usually named as loading, that measures the relative importance of factor j in the original variable i, and e_i = error term. By defining **B** as the matrix of the parameters and **S** as the variance-covariance matrix of original variables, it can be demonstrated that

$$\mathbf{S} = \mathbf{BB'} + \mathbf{E}.$$

Therefore, a major result of the factor analysis was the separation of the original (co)variances (**S**) into a (**BB′**) component, explained by the common factors, and a residual (**E**) unexplained component (19, 20). The derived common factors were the largest, statistically independent patterns of relationships among the variables (13), and were defined by their loadings, which measured the correlation between each original variable and each factor. An essential point was interpretation of factors, which was to recognize their specific role in predicting each of the observed variables. Interpretation can be made less subjective by rotating factors to make loadings closest to 0 or 1. Factor analysis must be preceded by a preliminary check of the suitability of data structure, which could be evaluated by the Kaiser measure of sampling adequacy (MSA) (11). The MSA that compares Pearson and partial correlations, the latter measuring relationships among each pair of variables controlling for possible effects of other variables. In this study, factor analysis was performed within each altitude by using an iterative maximum likelihood procedure (32). The eighth TDIM was not considered because of the constraint of factor analysis to work with balanced data.

RESULTS AND DISCUSSION

Linear Mixed Models

Table 1 shows raw means and standard deviations of TDIM for the three levels of altitude. On hill and especially on plain, the variability of yield tended to decrease gradually from the beginning to the end of lactation. These findings are different from what is observed in dairy cattle for which yields at the beginning and at end of lactation tend to be more variable than in the middle (25, 35, 38). However, it must be remembered that the TDIM considered in this study were taken after 20 DIM (i.e., after the suckling period) and, therefore, no inference could be made about the pattern of variability of yields in the first 20 d of lactation. On the mountain, the variability tended to be higher at around 90 d after parturition.

Table 2 shows the least squares means of the main environmental effects included in Models [1] and [2]. All factors, except type of lambing, affected milk yield, and no relevant differences between estimates of ordinary least squares and weighted least squares were observed.

The year of production resulted in a difference of about 60 g in daily milk yield. In 1993 the more frequent rainfalls resulted in a greater availability of pasture in early winter and in spring.

Ewes at fourth lambing showed the highest milk yield, confirming previous results obtained from dairy sheep (9, 12) and indicating that milk yield tends to increase till the fourth lactation. Older ewes produced more than expected because the best animals, which had been selected in previous years, are present in this age class.

The nonsignificant influence of the type of lambing contrasted previous work that reported a higher yield from ewes with multiple births. Actually, an effect of prolificacy along the whole curve has been detected only in meat and wool sheep (33, 36), whereas in dairy breeds the higher production of ewes raising twins is usually evident only during the first part of lactation (2, 4, 14, 15, 26, 27). Furthermore, this effect can be hidden or

TABLE 1. Raw means and standard deviations (kilograms) of test day yields (TDY) from three altitudes.

		Plain			Hill			Mountain		
DIM	Interval[1]	DD[2]	Mean	SD	DD[2]	Mean	SD	DD[2]	Mean	SD
1	20–50	40	2.15	0.53	41	1.78	0.40	34	1.19	0.29
2	51–80	65	1.97	0.55	65	1.69	0.39	64	1.38	0.37
3	81–110	95	1.67	0.46	95	1.60	0.38	92	1.40	0.45
4	110–140	126	1.50	0.43	125	1.53	0.38	122	1.36	0.35
5	141–170	156	1.28	0.35	155	1.37	0.34	152	1.29	0.29
6	170–200	186	1.05	0.33	184	1.15	0.31	182	1.11	0.38
7	201–230	215	0.75	0.31	213	0.84	0.25	212	0.73	0.35
8	231–260	237	0.61	0.22	238	0.70	0.22	241	0.62	0.28

[1]DIM interval of the TDY considered.

[2]DD = Mean DIM at which the test day occurred.

TABLE 2. Least squares means (kilograms per day) of main effects for the ordinary least squares (OLS) and weighted least squares (WLS) methods.

Factor	Levels	OLS		WLS	
		Mean (kg)	SE	Mean (kg)	SE
Type of lambing	One lamb	1.297	0.014	1.285	0.014
	Two lambs	1.312	0.014	1.296	0.014
Parity	Third	1.341^{A}	0.019	1.328^{A}	0.019
	Fourth	1.343^{AD}	0.017	1.331^{AD}	0.017
	Fifth	1.312	0.018	$1.298^{AD,a}$	0.018
	Sixth	$1.267^{BF,ab}$	0.019	$1.255^{BEF,b}$	0.018
	Seventh or greater	1.259^{CF}	0.018	1.242^{CF}	0.018
Year of production	1990	1.287^{A}	0.015	1.277	0.015
	1993	1.322^{B}	0.013	1.305	0.013
Altitude	Plain	1.352^{A}	0.018	1.354	0.018
	Hill	1.362^{A}	0.016	1.361	0.016
	Mountain	1.160^{B}	0.014	1.158	0.014

[A,B,C,D,E,F]Means within columns with different superscripts differ ($P < 0.01$).

[a,b]Means within columns with different superscripts differ ($P < 0.05$).

inverted (21) by undernutrition of the ewe before and after parturition.

The effect of level of altitude is particularly important in comparing TDY obtained in mountain flocks to those of hill and plain flocks (about 200 g of milk/d). Lactation curves are clearly separated for all three levels of altitude (Figure 1), especially in the first phase, because of the specific effect of the DIM factor for each level of altitude. Such interaction can be explained with differences in the climate and, mainly, in the quanti-qualitative evolution of pastures.

None of the lactation curves showed the presence of a lactation peak, because the first TDY occured, on average, at 40 DIM, and the peak of production in dairy sheep was expected around the third to fourth week after parturition (24). Similar results have been obtained in several studies on sheep by using both linear and nonlinear models (6, 10, 24, 28, 30). The slightly increasing phase in the lactation curve of mountain ewes must be interpreted as an effect of the improvement of conditions of production as lactation proceeds rather than as the physiological rise to the peak yield. In early lactation, occurring in December to January, environmental conditions are particularly adverse, mainly because of low temperatures and scarce availability of pastures. Actually, estimates of DIM include a seasonal effect on production that can not be considered separately because all ewes had lambings in the same period.

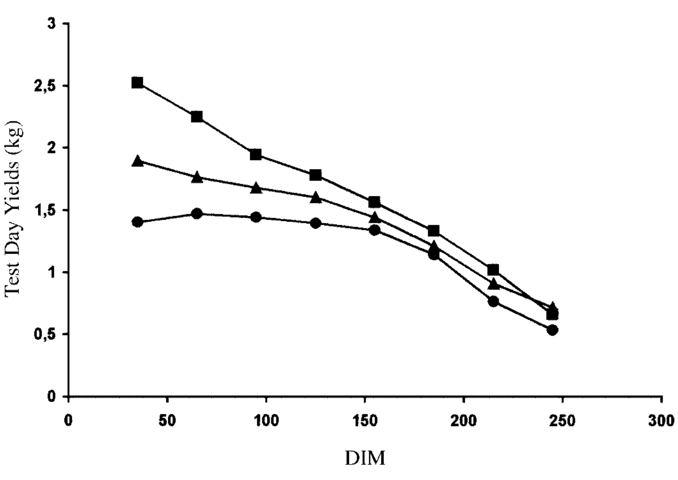

Figure 1. Estimates of lactation curves for ewes producing at different altitudes (■ = plain; ▲ = hill; ● = mountain).

The repeatability, as a ratio between the variance component associated with the individual lactation factor to the total phenotypic variance ($\sigma^2_L/(\sigma^2_L + \sigma^2_e)$) is 0.48, in agreement with observations on commercial sheep farms (7). This value was lower than that observed in dairy cattle (34), emphasizing a major incidence of environmental variability in sheep. Moreover, repeatability is influenced by the level of altitude (0.38 ± 0.046, 0.40 ± 0.036, and 0.29 ± 0.040, respectively, for plain, hill and mountain), confirming the increasing incidence of casual perturbative factors in flocks that are characterized by limited management and feeding resources.

Factor Analysis

Matrices of Pearson and partial correlations are reported in Table 3. Pearson correlations decreased as temporal distance among TDY increased, in agreement with previous findings in dairy cows (1, 22), although with a higher rate. Partial correlations showed the same trend, but with lower values, indicating that relationships between each pair of TDY were partially controlled by the intermediate TDY. Kaiser measure of sampling adequacy, both for the whole data set and within each level of altitude, exceeded the threshold of 0.80, which is usu-

TABLE 3. Pearson (above the diagonal) and partial (below the diagonal) correlations among test day milk yields of the same DIM interval (TDIM).

	TDIM1	TDIM2	TDIM3	TDIM4	TDIM5	TDIM6	TDIM7
TDIM1	. . .	0.710	0.626	0.499	0.305	0.406	0.301
TDIM2	0.458	. . .	0.792	0.686	0.516	0.481	0.255
TDIM3	0.133	0.420	. . .	0.784	0.592	0.538	0.310
TDIM4	0.052	0.096	0.435	. . .	0.747	0.555	0.233
TDIM5	–0.197	0.067	–0.007	0.509	. . .	0.609	0.310
TDIM6	0.044	0.045	0.037	0.104	0.299	. . .	0.646
TDIM7	0.128	–0.083	0.086	–0.176	0.009	0.588	. . .

ally considered a good index of the suitability of the data set for the factor analysis (11).

The ability of the two common factors corresponding to the greatest two eigenvalues of the original correlation matrix to represent about 75% of the original variability at all levels of altitude was shown by Bartlett's chi-square test ($P \leq 0.0001$). Interesting conclusions could be drawn from the interpretation of the pattern of rotated factor loadings (Table 4). The loadings representing correlations between original variables and common factors were particularly informative in defining lactation stages that contributed more to the variability of milk yield, as suggested by Wilmink (39). On plain and hill, the largest loadings were for TDIM 2 to 5 in the first common factor and for the last two TDIM in the second common factor. On mountain, the largest loadings were for TDIM 4 and 5 in the first common factor and for TDIM 1, 3, and 7 in the second common factor. Factor patterns of plain and hill were similar to those found in dairy cattle by several authors (37) (39) who suggested that the first factor could be associated with level of production and the second factor could be associated with persistency. Comparable results have been obtained for dairy sheep (23). More difficult is the interpretation of the two factors controlling the whole variability in mountain, because the loading did not show any defined pattern.

CONCLUSIONS

Results of this study confirm expected relevant differences among lactation curves obtained at different altitudes. Both mixed linear models and factor analysis were able to detect such differences. The part of the lactation curve that goes from 30 to 150 DIM seemed to be more sensitive to different environmental conditions. The great influence of environmental variability on yield is a peculiar feature of dairy animals managed under extreme conditions and is commonly regarded as a negative aspect related to environmental perturbation. However, in the specific case of the Sarda dairy ewe, it can also be interpreted in terms of the ability of the ewe to adapt to adverse conditions during production. This can be seen as the result of the selection developed empirically by shepherds before the starting of structured selection programs. The flexibility of the ewe to fit sudden variations in the conditions of production (mainly feeding and climate) were considered rather than its level of production obtained under good conditions. Furthermore, although the analysis was limited to phenotypic data, this different incidence of environmental variance could be read in terms of different values of heritability along the curve, also observed in dairy cattle (18).

Altitude of the flocks was a relevant discriminating factor because it included main environmental effects such as management level and climate. The clear distinction of mountain from the other two levels of altitude, highlighted by both the shape of the lactation curve and the results of factor analysis, was not sufficient evidence that milk yields obtained in different altitudes could be considered different traits. However, because all of these ewes were involved in the same selection scheme, results of this study suggest careful attention to the genotype × environment interaction.

TABLE 4. Rotated common factor loadings for the three different altitudes.

	Plain		Hill		Mountain	
Variable	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
TDIM1	0.613	0.282	0.547	–0.071	0.232	0.675
TDIM2	0.730	0.253	0.873	0.035	0.569	0.494
TDIM3	0.943	0.220	0.918	0.009	0.440	0.651
TDIM4	0.782	0.320	0.907	0.190	0.963	0.187
TDIM5	0.510	0.550	0.766	0.406	0.794	0.156
TDIM6	0.380	0.817	0.324	0.886	0.369	0.656
TDIM7	0.134	0.642	–0.139	0.740	–0.013	0.736

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