In: New Research on Livestock Science and Dairy Farming ISBN: 978-1-60456-556-0
Editors: P. Di Alberto and C. Costa

Chapter 6

SUITABILITY OF SIMPLIFIED MILK RECORDING METHODS FOR GENETIC EVALUATIONS USING TEST-DAY MODELS IN DAIRY SHEEP

***B. Portolano**[*1]**, V. Riggio**[1]**, D.O. Maizon**[1,2]** and M. Tolone**[1]*

[1]Dipartimento Scienze Entomologiche, Fitopatologiche, Microbiologiche Agrarie e Zootecniche, Università di Palermo, Italy

[2]Instituto Nacional de Tecnología Agropecuaria, EEA Anguil, Argentina

ABSTRACT

Nowadays in dairy sheep, test-day records are collected monthly under an alternate morning/evening system. This alternate system was implemented because of the steady increase in recording cost per sheep observed in the last few decades. Furthermore, additional modifications to the testing schemes have been proposed to reduce the costs of milk recording. In dairy sheep, the cost for milk recording is indeed too high compared both with individual outputs and with other dairy species. Therefore, the purposes of the present study were: i) to compare estimated breeding values (EBVs) for milk yield using different simplified testing schemes with a test-day sire model; ii) to evaluate the effect of different testing schemes on the ranking of top rams; and iii) to evaluate the effect of different testing schemes on the genetic progress, based on sire selection. A total of 28,304 test-day records from 4,968 lactations of 2,429 Valle del Belice ewes, collected in 15 flocks between 1994 and 2006, were used for the analysis. To have the same ewes through different testing schemes, it was requested that a ewe have at least six test-day records included in the dataset. The pedigree file included a total of 206 sires. The response variable was the daily milk production. Four different recording schemes were used to estimate breeding values and to make comparisons. The reference scheme considered all data obtained from ewes in the present recording system in which ewes in lactation were tested every month. Three alternative schemes that used less information were considered. A random regression sire model that used a Legendre function of days

* *Corresponding Author:* Prof. Baldassare Portolano. Dipartimento Scienze Entomologiche, Fitopatologiche, Microbiologiche Agrarie e Zootecniche-Sezione Produzioni Animali. Viale delle Scienze-Parco d'Orleans, 90128 Palermo, Italy. Tel: +39 091 7028868; Fax: +39 091 7028869; Email: baldop@unipa.it.

in milk was fitted. EBVs obtained with alternative recording schemes and under different intensities of selection showed different degrees of Spearman correlation with EBVs obtained using the monthly recording scheme. These correlations ranged from 0.68 to 0.98. The consequence of moving the test-day schedule to one of these schemes will produce a decrease in genetic response to selection due to the associated loss of intensity and accuracy. Consequently, before given any recommendation in this regard, further research should be done to better elucidate the consequences of a change in the scheme of test-day collection.

Keywords: test-days, genetic evaluation, recording schemes, dairy sheep

Introduction

In Sicilian dairy sheep, the production period affects management decisions such as culling and mating, and strongly influences ranking of animals having different numbers of lactation and lambing in different seasons. Consequently, for genetic evaluation based on total lactation animal models, adjustment coefficients for environmental factors are needed. However, the estimation of these coefficients could be of poor exactitude; this might be overcome by using test-day models (TDM). These models have become the basic state-of-the-art in genetic evaluation, both in dairy sheep and dairy cattle. There are indeed several well-documented advantages of using a TDM compared with the traditional use of aggregated yields over lactation (e.g., Barillet, 1985; White et al., 1999; Samoré et al., 2001; Schaeffer, 2004; Misztal, 2006). By using test-days, records can be considered without any modification, i.e., records are considered directly in the analysis and no assumptions about the length of the lactation have to be made (Visscher and Goddard, 1995). Additionally, more precise adjustment for temporary environmental effects on the test-day, and the possibility of genetic evaluation for persistency of lactation, can be realized (Jensen, 2001).

Normal husbandry both in Sicily and in other Mediterranean countries for dairy sheep traditionally includes a lamb suckling period of approximately one month and a milking period that begins after lambs are weaned (i.e., Gonzalo et al., 2003). Estimation of daily milk yield as a basis for flock management decisions and estimation of lactation yield for use in ewe and ram evaluation are both objectives of milk recording (Carriedo et al., 1995).

The International Committee for Animal Recording system (ICAR, 2003) has officially defined several milk recording methods for sheep. Twice-daily milking has been the most frequent milking schedule of dairy ewes for a long time, recording milk production approximately every 30 days (Barillet et al., 1987); whereas in Italy, standard testing plans were based on collecting milk twice within a 24 h period every four weeks (A4 methods). However, the costs of supervised recording of the two daily milkings are too high in dairy ewes compared both with individual outputs (Barillet et al., 1987) and with other dairy species (Othmane et al., 2007). For this reason, and according to a report on milk recording in sheep (Astruc et al., 2005), simplification of milk yield recording has spread widely among ICAR countries (Othmane et al., 2007). Potential benefits of simplified plans relative to the standard twice-a-day monthly recording plan (A4) are numerous, i.e., less disruption in milking routine caused by the supervisor's visit, less supervisor time leading to lower costs schemes, **S40** as RS but considering a 40-day interval; **S50**: 50-day interval; and finally **S60:** 60-day interval.

Statistical Analysis

The ASReml software (Gilmour et al., 2002) was used to carry out the statistical analyses. Several models were tested to explore the fitted factors and to optimize the analysis. The lactation curve and permanent environmental effects were modelled by a Legendre polynomial of degree 4, accordingly to Tolone et al. (2007) who found that this polynomial model had a better adjustment than other models for the lactation curve in Valle del Belice sheep.

In general, Legendre polynomials, have the benefit that 1) the functions are orthogonal, which is useful for analyzing patterns of genetic variation (Kirkpatrick et al., 1990), 2) missing records can be predicted more accurately than with other curves (e.g., Wilmink curve) (Pool and Meuwissen, 2000), and 3) higher orders were estimable when conventional polynomials failed (Pool and Meuwissen, 2000) because of better convergence.

The following model was used in the analysis:

$$y_{ijklst} = F_i + g(t)_j + FYS_k + r(pe,t,m)_l + sire_s + e_{ijklst}$$

where y_{ijklst} was the observation of milk yield on the l^{th} ewe, daughter of the s^{th} ram, recorded at DIM t in the k^{th} flock-year-season class, the j^{th} parity group, and the i^{th} group of fixed effects. F_i included all the fixed effects: overall mean, age at first lambing (AFL, with 4 classes, AFL = 1 when first lambing occurred between 12 and 15 months of age; AFL = 2, between 16 and 18; AFL = 3, between 19 and 21, and AFL = 4, between 22 and 24), and litter size (with 2 levels, single or multiple); $g(t)_j$ were Legendre polynomials of order 4 that accounted for the phenotypic trajectory of the average observations across ewes in the j^{th} parity group (where j has 6 levels: 1^{st}, …, 6^{th} or higher parity); FYS_k was the random effect of flock-year-season class (with a total of 167 levels; 15 flocks, 13 years of lambing, and 3 seasons of lambing). The lambing season was equal to 1 when lambing occurred from August to November; equal to 2, from December to March; and equal to 3, from April to July, as in Portolano et al. (2007); $r(pe,t,m)_l$ were Legendre polynomials of order m for the random permanent effects (pe) as function of DIM within parity; $sire_s$ was the random effect of the s^{th} sire; and e_{ijklst} was the residual effect.

Spearman correlations between EBVs for milk production of the different testing schemes were obtained with the RANK procedure of SAS (SAS Institute, 2004) using different hypothetical proportions of sires selected i.e. 5, 10, 20 and 100 percent.

For each alternative milk recording scheme, the expected response to selection (Δ_g) for sires was predicted according to the classical formula using estimated values from the fitted models:

$$\Delta_g = \frac{\bar{r}_{A,\hat{A}} i^*_p \hat{\sigma}_a}{L}$$

where: $\bar{r}_{A,\hat{A}}$ was the average of accuracies of predicted breeding values from candidate sires in each milk recording scheme; i^*_p was the selection intensity adjusted accordantly, since the candidates were only 206, with p being the top fraction, a 10% proportion selected based on $\hat{A}$, where $\hat{A}$ were the EBVs; $\hat{\sigma}_a$ was the estimated additive genetic standard deviation, and in this case, because we used a sire model, it was estimated from the estimated additive genetic variance of the sires $\hat{\sigma}^2_s$ as $4\hat{\sigma}^2_s$; and L was the generation interval for which we considered 3.5 years.

RESULTS

Means, standard deviations and number of the test-days for all milk recording schemes are given in Table 1. The daily average milk yield was 1,336g for the RS scheme and slightly lower for the other schemes. Small variations were observed in the standard deviation of milk yield for the four different schemes; whereas the number of test-days decreased from 5.7 to 3.5 across milk recording schemes.

Table 1. Means, standard deviations and number of test-days for each milk recording scheme

Milk recording scheme	Number of observations	Test-day milk production (g)		Number of test-days	
		Mean	SD	Mean	SD
RS	28,304	1,336	631	5.7	2.0
S40	23,767	1,310	632	4.8	1.5
S50	20,046	1,272	629	4.0	1.2
S60	17,341	1,246	626	3.5	1.0

Table 2 shows the estimates for variance components and the heritabilities for all milk recording schemes under study. The heritability estimates were similar among milk recording schemes and ranged from 0.11 to 0.16. The lowest estimate was obtained with the S60 scheme; whereas the milk recording RS gave the highest heritability.

The amount of variation explained by the FYS effect was large, showing that this factor plays an important role on daily milk production of Valle del Belice breed. The residual variance decreased among milk recording schemes, accordingly to the increased interval between test-day records in the different milk recording schemes, except for the S60 scheme that showed the highest residual variance estimate.

Table 2. Estimates of variance components and heritabilities for each milk recording scheme

	RS	S40	S50	S60
[1] $\hat{\sigma}^2_{FYS}$ (g/d)^2	78,150.0	76,614.2	74,781.9	81,157.1
[2] $\hat{\sigma}^2_S$ (g/d)^2	8,809.1	7,772.4	7,906.3	6,032.3
[3] $\hat{\sigma}^2_{pe}$ (g/d)^2	76,553.0	78,342.9	78,666.9	71,805.5
[4] $\hat{\sigma}^2_e$ (g/d)^2	63,154.1	61,035.6	60,883.6	68,509.7
[5] $\hat{\sigma}^2_P$ (g/d)^2	226,666.2	223,765.1	222,238.7	227,504.6
[6] h^2	0.16	0.14	0.14	0.11

[1]Flock-year-season variance. [2]Additive genetic variance of the sire. [3]Permanent environmental variance modeled with a Legendre polynomial of degree 4. [4]Residual variance component. [5]Phenotypic variance estimated as sum of the flock-year-season, additive genetic, permanent environmental and residual variances. [6]Heritability estimated as 4 times the genetic variance of the sire over the phenotypic variance.

For all milk recording schemes, means of milk yield across DIM within some parity classes (first, second, and sixth, respectively) are shown in Figures 1 to 3. As it can be seen, when more information (lower interval between test-days) was used, S40 and S50 relative to S60, the curves approached the one of RS; although this effect is more evident in primiparous (Figure 1) and in multiparous (sixth or higher parity) ewes (Figure 3).

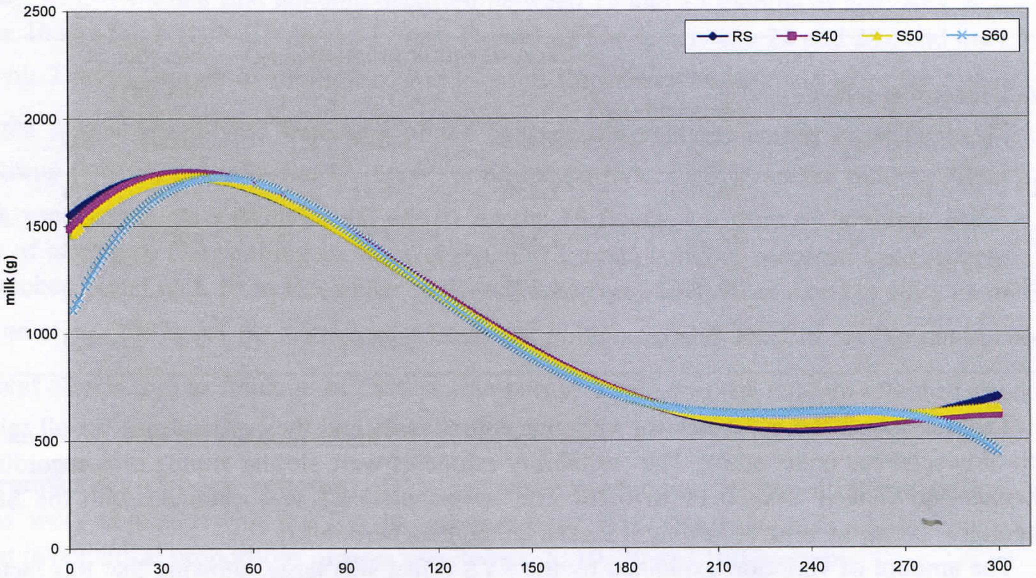

Figure 1. Means of milk yield across DIM for all the milking recording schemes in primiparous ewes.

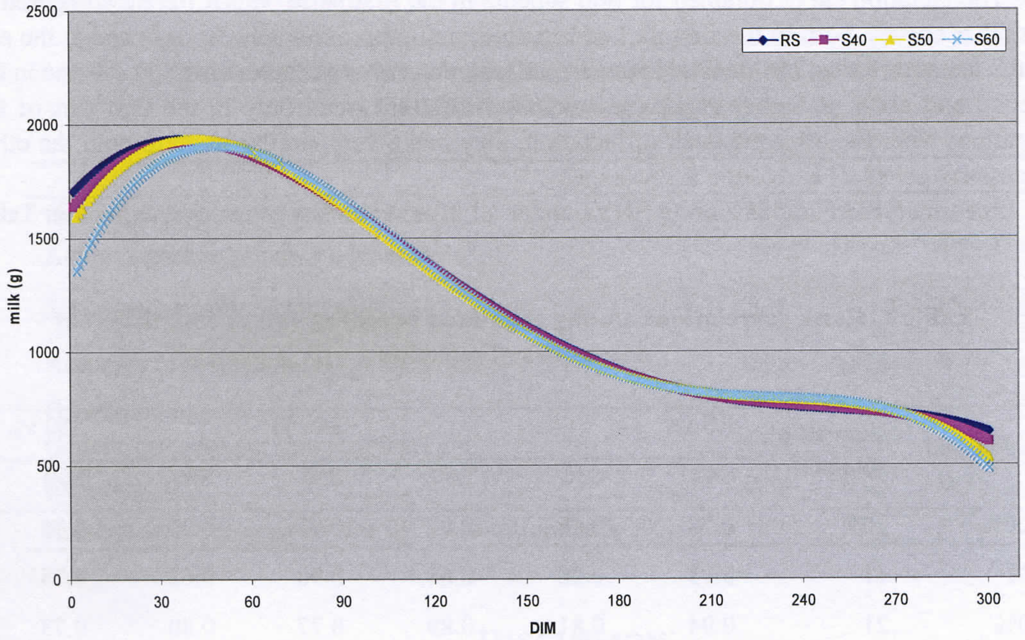

Figure 2. Means of milk yield across DIM for all the milking recording schemes in second parity ewes.

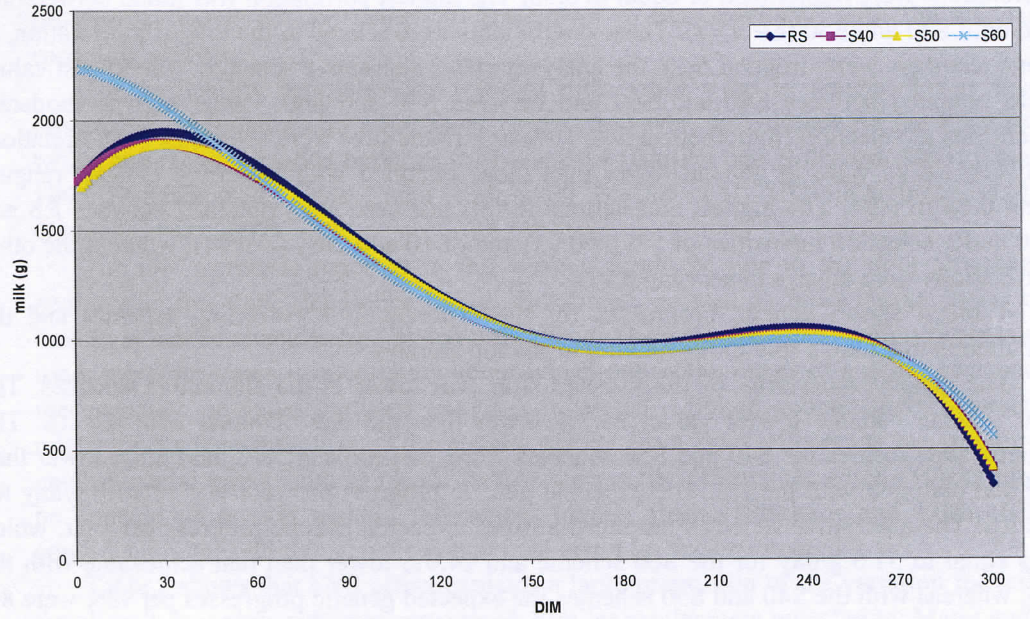

Figure 3. Means of milk yield across DIM for all the milking recording schemes in multiparous (sixth or higher parity) ewes.

The lactation curve obtained for S60 scheme in the first parity was different compared to the other curves, both in the first part of lactation, until approximately 50 days and at the end of the lactation (after 200 days). However, the lactation curves obtained for S60 scheme in the second and sixth or higher parity classes had a different trend only in the first part of the lactation; whereas, after the peak of lactation, they had a very similar trend to both the other alternative schemes and to the RS scheme.

Spearman correlations among EBVs under all milk recording schemes are given in Table 3.

Table 3. Rank correlations among estimated breeding values with different intensities of selection

% selected	Number of animals	RS vs.			S40 vs.		S50 vs.
		S40	S50	S60	S50	S60	S60
100%	206	0.98	0.98	0.97	0.97	0.95	0.95
5%	11	0.93	0.90	0.68	0.90	0.68	0.75
10%	21	0.94	0.81	0.89	0.77	0.80	0.73
20%	41	0.94	0.86	0.87	0.91	0.89	0.83

Considering the whole dataset (with a proportion of sires selected equal to 100%), all correlations were higher than or equal to 0.95. The highest correlation was found between RS and both S40 and S50 ($r = 0.98$). These coefficients were related to the loss of information, as some test-days were dropped from the analyses under alternative schemes. The lowest values were obtained between S40 and S60 and between S50 and S60. Under high to moderate intensities of selection (hypothetical 5%, 10% or 20% of sires were selected), the correlations between EBVs were in general lower than those obtained with the entire dataset, ranging from 0.68 to 0.94. The highest correlations in this last case were obtained between RS and S40 under selection intensities of 5% ($r=0.93$) and of 10 and 20% ($r=0.94$); whereas the other correlations were always lower than 0.91.

Table 4 shows genetic progresses for the different milk recording schemes and the parameters that play a role in the ranking of the top animals.

The genetic superiority of the selected sires was lower in the alternative schemes. The S60 scheme had the lowest value, 24.7% lower than the one obtained with the RS. The genetic superiorities for S40 and S50 schemes were, respectively, 11.5 and 8.8% lower than the one obtained with the RS. The expected genetic progress per year was of 67.9 g/day for the RS. The alternative schemes produced a lower expected genetic progress per year, which was equal to 51.6 g/day for the S60 scheme and 24.0% lower than that achievable with the RS; whereas with the S40 and S50 schemes the expected genetic progresses per year were 8.7 and 8.4% lower than the one that could be obtained with the RS. In percentage of the mean, the genetic progress per year was equal to 5.1% for RS. The smallest value (4.1%) was obtained for the S60 scheme; whereas the S40 and S50 milk recording schemes showed genetic progresses per year equal, respectively, to 4.7% and 4.9%. Moreover, the expected genetic progress that could be obtained by selecting on S40 or S50 schemes would represent

97% of that achievable by selection on RS; on the other hand, it would be only 92% when selection were on S60 scheme.

Table 4. Prediction of genetic progress and comparison between RS and alternative schemes

	RS	S40	S50	S60
Genetic superiority of selected sires	127.3	112.7	116.1	95.8
Additive genetic standard deviation $(\hat{\sigma}_a)$	187.7	176.3	177.8	155.3
Selection intensity factor (i_p^*)		1.7425		
Accuracy of prediction $(\bar{r}_{A,\hat{A}})$	0.73	0.71	0.70	0.67
Generation interval *(L)*		3.5		
Genetic progress per year (Δ_g/year) g/d	67.9	62.0	62.2	51.6
(Δ_g/year)/ $\hat{\sigma}_a$	0.36	0.35	0.35	0.33
Relative selection progress for RS by selection for S_n (%)	100	97	97	92

DISCUSSION

This paper has compared the EBVs for milk yield using different simplified testing schemes; it has evaluated the effect of these different testing schemes on the ranking of top rams; and it has found that some alternative milk recording schemes might lead to genetic progresses (based on sire selection) equivalent to that reachable with the standard milk recording scheme.

The heritability estimates for test-day milk yield were in general lower than those reported in the literature for other sheep breeds; however, the estimate for the RS scheme was within the range, which is between 0.15 and 0.24 (Barillet and Boichard, 1987; Sanna et al., 1997; El-Saied et al., 1998; Ligda et al., 2000; Barillet et al., 2001; Kominakis et al., 2001; Othmane at al., 2002).

The low estimates reported in this chapter might be due to the poor structure of the pedigree in the Valle del Belice breed. This breed, as well as most Italian sheep and goat breeds, is indeed characterized by natural mating. The artificial insemination is not commonly used, therefore, there is uncertainty about which ram is the father of a given ewe. Moreover, the exchange of males between flocks is restricted. Limited genetic links between flocks might hinder the separation of the genetic effects from flock effects, as the genetic and the environmental effects aim to blend. Part of the genetic differences among flocks might then be considered as non genetic differences among flocks (Pirchner and Lush, 1959) and consequently the additive genetic component could be underestimated.

Table 2 shows that FYS effect explains a large proportion of the variation for milk yield, for all milk recording schemes considered. Similar results were reported by Maria and Gabiña (1993) for the Latxa breed and by Carriedo et al. (1995) for the Churra breed. Management of the Valle del Belice breed is indeed characterized by enormous variability. Part of this variability is due to the fact that most of the farmers milk ewes by hand, whereas a few others use a milking machine (Riggio et al., 2007). Furthermore, the lambing season of the Valle del Belice breed is all year long, and different from the lambing system adopted in other Mediterranean regions (e.g., Carta et al., 1995; Ligda et al., 2000). Moreover, sheep are fed natural pastures and fodder crops; supplementation, consisting of hay and sometimes concentrates, is occasionally supplied, for example at the end of gestation (Cappio-Borlino et al., 1997). The grazing possibilities, the chemical and nutritional composition of the feed, change annually and also differ between areas.

Figures 1 to 3 report some lactation curves across DIM. The reduced number of information of the alternative schemes mainly affected the first part of the lactation. Dairy sheep show indeed a negative balance in this part of lactation. This is principally caused by a nutritive deficit due to the non-synchronization of the lactation and feed intake curves. The former curve reaches a peak after 4 to 5 weeks, whereas the latter does so after about 10-15 weeks (Cannas et al., 2004). For this reason, the medium phase of the lactation is more representative of the productive capacity of the animals (Di Mauro et al., 2007). Another difficulty with sheep and goats is that the lambs are often allowed to suckle during the first four week or more, so that the test-day records in the first part of lactation are not available and can be critical fitting the phenotypic trajectories for milk production (Schaeffer, 2004). After the peak, between 60 and about 240 days, all milk recording schemes had a similar trend. These results could suggest, when a test-day approach for the genetic evaluation is used, to give a different weight to the test-days at the beginning, in the middle and at end of the lactation.

The rank correlations reported in Table 3 shows that the highest value, when considering a proportion of sires selected equal to 100%, was equal to 0.98, and was found between the EBVs obtained with the RS scheme and those obtained with the milk recording schemes with shorter intervals between test-days (S40 and S50). The rank correlations between RS and S60 were slightly lower, reflecting a higher re-ranking in the population of rams when this scheme was used. However, under high to moderate intensities of selection, correlations between RS and the other alternative schemes were lower, ranging from 0.68 to 0.94. Therefore, a way of thinking about these Spearman correlation coefficients is to observe the dispersion that the highest ranked individuals will suffer if less information is taken to estimate their breeding values. The regressions on rankings of rams between RS scheme and the other schemes showed that the best value (near intercept = 0 and slope = 1) was obtained for RS scheme *vs.* S40 scheme, indicating that these criteria give very similar ranking of the rams. Higher values for intercept and slope were obtained for RS *vs.* S60 scheme, confirming that these two milk recording schemes would lead to a different ranking. For example, the first ten rams ranked in RS were spread among the first 14, 16, and 16 rams ranked in S40, S50, and S60, respectively.

Table 4 shows that only the S60 scheme achieved different results, suggesting that this alternative milk recording scheme would lead to a lower genetic progress compared to the other schemes. These results were mainly due to the loss of information, as some test-days were dropped from the analysis. However, from a genetic point of view, the eventual repercussion of simplified recording plans on precision of genetic estimates is considered to be low, and it may be easily countered by increasing the number of daughters per sire (Poly and Poutous, 1968). The required increase of daughters, so as to maintain the same genetic gain, was estimated as 0.6–3% (0.1–0.5 daughters per ram) in ewes (Gabiña et al., 1986) and 2.7% (1–2 daughters per buck) in goats (Bouloc et al., 1991).

The two alternative milk recording schemes with shorter interval between test-days (S40 and S50) gave similar results, suggesting that both might be an alternative to the RS scheme, as they allow a correlated response for the RS scheme equal to 97% of the one achievable directly using the reference milk recording scheme.

CONCLUSION

The rank correlations reported in this chapter showed that S40 and S50 schemes could be considered equivalent to RS in measuring milk production, whereas the correlations between RS and S60 scheme did not recommend the use of this last as a milk recording scheme. Correlations of EBVs between the four milk recording schemes considered were, in general, high, but shuffling in the order of the highest-ranked sires was observed, demonstrating that practical differences can be observed depending on the milk recording scheme adopted. This study showed that both S40 and S50 schemes might be used in the genetic evaluation of the Valle del Belice dairy sheep as an alternative to RS, reaching a genetic progress per year based on sire selection, equal to 97% of the one achievable by using the standard milk recording RS. However, before making any recommendation in this regard, further research should be done, in particular using simulation and an economic approach to better elucidate the consequences of a change in the scheme of test-day collection.

ACKNOWLEDGMENTS

D.O. Maizon was supported by a Marie Curie Transfer of Knowledge Grant of the European Community programme "Quality of Life," contract number MTKD/I-CT-2004-14412.

REFERENCES

Anderson, S. M., Mao, I. L., & Gill, J. L. (1989). Effect of frequency and spacing of sampling on accuracy and precision of estimating total lactation milk yield and characteristics of the lactation curve. *Journal of Dairy Science*, 72, 2387–2394.

Astruc, J. M., Barillet, F., Fioretti, M., Gabiña, D., Gootwine, E., Mavrogenis, A. P., Romberg, F. J., Sanna, S. R., & Stefanake, E. (2005). Report of the working group on milk recording of sheep. In Performance Recording of Animals, State of the Art, European Association for Animal Production Publication 113, p.315.

Barillet, F. (1985). Amélioration génétique de la composition du lait des brebis: l'exemple de la race Lacaune. PhD Thesis, INA-PG/INRA Paris-Grignon.

Barillet, F., & Boichard, D. (1987). Studies on dairy production of milking ewes: Part I. Estimates of genetic parameters for total milk composition and yield. *Genetics Selection Evolution*, 19, 459-474.

Barillet, F., Boichard, D., Bouloc, N., Gabiña, D., Piacere, A., Roussely, M., & Sigwald, J. P. (1987). Accuracy and development of simplified sampling procedures with regard to the aim of milk recording in dairy sheep and goats. Books of Abstracts of the 38th Annual Meeting European Association for Animal Production, 27 September-1 October 1987, Lisbon, Portugal, p. 104.

Barillet, F., Rupp, R., Mignon-Grasteau, S., Astruc, J. M., & Jacquin, M. (2001). Genetic analysis of mastitis resistance and somatic cell score in French Lacaune dairy sheep. *Genetics Selection Evolution*, 33, 397–415.

Bouloc, N., Barillet, F., Boichard, D., Sigwald, J. P., & Bridoux, G. (1991). Etudes des possibilities d'allegement des controle laitier official chez les caprins. *Annales de Zootechnie*, 40, 125–139.

Cannas, A., Tedeschi, L. O., Fox, D. G., Pell, A. N., & Van Soest, P. J. (2004). A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. *Journal of Animal Science*, 82, 149-169.

Cappio-Borlino, A., Portolano, B., Todaro, M., Macciotta, N. P. P., Giaccone, P., & Pulina, G. (1997). Lactation curves of Valle del Belice dairy ewes for yields of milk, fat and protein estimated with test day models. *Journal of Dairy Science*, 80, 3023-3029.

Carriedo, J. A., Baro, J. A., De La Fuente, L. F., & San Primitivo, F. (1995). Genetic parameters for milk yield in dairy sheep. *Journal of Animal Breeding and Genetics*, 112, 59-63.

Carta, A., Sanna, S. R., & Casu, S. (1995). Estimating lactation curves and seasonal effects for milk, fat and protein in Sarda dairy sheep with a test day model. *Livestock Production Science*, 44, 37-44.

Delorenzo, M. A., & Wiggans, G. R. (1986). Factors for estimating daily yield of milk, fat, and protein from a single milking for herds milked twice a day. *Journal of Dairy Science*, 69, 2386–2394.

Di Mauro, C., Cappio-Borlino, A., Macciotta, N. P. P., & Pulina G. (2007). Use of a computer-aided design to develop a stress simulation model for lactating dairy sheep. *Livestock Science*, 106, 200-209.

El-Saied, U. M., Carriedo, J. A., De La Fuente, L. F., & San Primitivo, F. (1998). Genetic and environmental estimation for test day and standardized milk yield of dairy sheep. *Small Ruminant Research*, 27, 209-215.

Gabiña, D., Urarte, E., & Arranz, J. (1986). Métodos de simplificatión de control lechero cuantitativo. Aplicatión a las razas ovinas del Pais Vasco. *Investigación Agraria: Producción y Sanidad Animales*, 1, 159–170.

Gilmour, A. R., Gogel, B. J., Cullis, B. R., Welham, S. J., & Thompson, R. (2002). ASReml Guide Release 1.0, VSN International Ltd, Hemel Hempstead, HP1 1ES, UK.

Gonzalo, C., Othmane, M. H., Fuertes, J. A., De La Fuente, L. F., & San Primitivo, F. (2003). Losses of precision associated with simplified designs of milk recording for dairy ewes. *Journal of Dairy Research*, 70, 441-444.

Hargrove, G. L., & Gilbert, G. R. (1984). Differences in morning and evening sample milkings and adjustment to daily weights and percents. *Journal of Dairy Science*, 67, 194-200.

Henderson, C. R. (1975). Inverse of a matrix of relationships due to sires and maternal grandsires. *Journal of Dairy Science*, 58, 1917–1921.

ICAR (2003). International Committee for Animal Recording. International Regulations for milk recording in sheep. Institut de l'élevage, Department Génétique et Contrôle des Performances, Paris.

Jensen, J. (2001). Genetic evaluation of dairy cattle using test-day models. *Journal of Dairy Science,* 84, 2803-2812.

Kirkpatrick, M., Lofsvold, D., & Bulmer, M. (1990). Analysis of the inheritance, selection and evolution of growth trajectories. *Genetics*, 124, 979–993.

Kominakis, A., Volanis, M., & Rogdakis, E. (2001). Genetic modelling of test day records in dairy sheep using orthogonal Legendre polynomials. *Small Ruminant Research*, 39, 209-217.

Lee, A. J., & Wardrop, J. (1984). Predicting daily milk yield, fat percent and protein percent from morning or afternoon tests. *Journal of Dairy Science*, 67, 351–360.

Ligda, Ch., Gabriilidis, G., Papadopoulos, Th., & Georgoudis, A. (2000). Estimation of genetic parameters for production traits of Chios sheep using a multitrait animal model. *Livestock Production Science,* 66, 217-221.

Maria, G., & Gabiña, D. (1993). Non genetic effects on milk production of Latxa ewes. *Small Ruminant Research*, 12, 61-67.

Misztal, I. (2006). Properties of random regression models using linear splines. *Journal of Animal Breeding and Genetics*, 123, 74-80.

Othmane, M. H., De La Fuente, L. F., Carriedo, J. A., & San Primitivo, F. (2002). Heritability and genetic correlations of test day milk yield and composition, individual laboratory cheese yield, and somatic cell count for dairy ewes. *Journal of Dairy Science*, 85, 2692-2698.

Othmane, M. H., Fuertes, J. A., Gonzalo, C., De La Fuente, L. F., & San Primitivo, F. (2006). Accuracy of simplified sampling procedures for estimating milk composition in dairy ewes. *Journal of Dairy Research*, 73, 109-114.

Othmane, M. H., & Trabelsi, L. (2007). Suitability of simplified methods for monthly and twice-monthly milk recording, and new prediction factors for the alternate a.m./p.m. method in dairy ewes under a low-input production system. *Journal of Dairy Research*, doi:10.1017/S0022029907002634.

Pirchner, F., & Lush, J. L. (1959). Genetic and environmental portions of the variations among herds in butterfat production. *Journal of Dairy Science*, 42, 115-122.

Poly, J., & Poutous, M. (1968). Alternate monthly milk recording. I. Accuracy of recording monthly and every second month, for 305-day milk period. *Dairy Science Abstracts*, 30, 454.

Pool, M. H., & Meuwissen, T. H. E. (2000). Prediction of daily milk yields from a limited number of test days using test day models. *Journal of Dairy Science*, 82, 1555–1564.

Portolano, B., Finocchiaro, R., van Kaam, J. B. C. H. M., Riggio, V., & Maizon, D. O. (2007). Time-to-event analysis of mastitis at first-lactation in Valle del Belice ewes. *Livestock Science*, 110, 273-279.

Riggio, V., Finocchiaro, R., van Kaam, J. B. C. H. M., Portolano, B., & Bovenhuis, H. (2007). Genetic parameters for milk somatic cell score and relationships with production traits in primiparous dairy sheep. *Journal of Dairy Science*, 90, 1998-2003.

Samoré, A. B., van Arendonk, J. A. M., & Groen, A. F. (2001). Impact of area and sire by herd interaction on heritability estimates for somatic cell count in Italian Holstein Friesian cows. *Journal of Dairy Science*, 84, 2555-2559.

Sanna, S. R., Carta, A., & Casu, S. (1997). (Co)variance component estimates for milk composition traits in Sarda dairy sheep using a bivariate animal model. *Small Ruminant Research*, 25, 77-82.

SAS (2004). User Installation Guide for the SAS System Version 9.1, (SAS Institute Inc., Cary, NC).

Schaeffer, L. R., & Rennie, J. C. (1976). AM–PM testing for estimating lactation yield. *Canadian Journal of Animal Science*, 56, 9–15.

Schaeffer, L. R. (2004). Application of random regression models in animal breeding. *Livestock Production Science*, 86, 35-45.

Visscher, P. M., & Goddard, M. E. (1995). Genetic parameters for milk yield, survival, workability, and type traits for Australian dairy cattle. *Journal of Dairy Science*, 78, 205-220.

Tolone, M., Maizon, D. O., Riggio, V., & Portolano, B. (2007). Lactation curves in Valle del Belice sheep using random regression models. Book of Abstracts of the 58th Annual Meeting of the European Association for Animal Production, 26-29 August 2007, Dublin, Ireland, p. 267.

White, I. M. S., Thompson, R., & Brotherstone, S. (1999). Genetic and environmental smoothing of lactation curves with cubic splines. *Journal of Dairy Science*, 82, 632-638.