



Milk composition and feeding in the Italian dairy sheep

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ABSTRACT

Milk production represents a relevant quota of the energy consumption of the dairy ewe. Studies on relationships among level of production, milk composition and metabolic aspects are the first fundamental step in the development of a feeding system aimed at satisfying nutritive requirements of the animals. This paper reviews the knowledge about the milk composition of main Italian dairy sheep breeds, the relationship among secretion kinetics of milk and protein and productive level of animals, the algorithms used for estimating fat (6.5%) and protein (5.8%) corrected milk yield, the evolution over time of milk production during lactation and the relationships between feeding and milk composition.

Key words: Milk composition, Feeding, Dairy ewes.

RIASSUNTO

COMPOSIZIONE DEL LATTE E ALIMENTAZIONE NELLE PECORE DA LATTE

La produzione del latte rappresenta una quota rilevante delle esigenze energetiche della pecora da latte. Lo studio delle relazioni che intercorrono fra livelli produttivi, composizione del latte e aspetti metabolici, costituisce il primo passo per lo sviluppo di un adeguato sistema di alimentazione. In questa rassegna sono presi in esame, relativamente alle principali razze ovine da latte italiane, le relazioni fra cinetiche di secrezione di grasso e proteine e livello produttivo degli animali, gli algoritmi per il calcolo del latte normalizzato per il contenuto in grasso (6,5%) e in proteine (5,8%), le curve di lattazione e le relazioni fra composizione del latte e alimentazione.

Parole chiave: Composizione del latte, Alimentazione, Pecore da latte.

Introduction

Milk production represents a relevant quota of the energy consumption of the dairy ewe. The average net energy expenditure for a sheep weighing kg 50 and producing kg 250 of fat and protein corrected milk (at 6.5% and 5.8% fat and protein contents, respectively) per lactation, including also maintenance, walking and pregnancy requirements, is about one third of the annual total ener-

gy balance of the animal. Moreover, the total dry matter secreted with milk can be estimated at 45 kg (16.5 kg of fat, 14.5 kg of protein, 12.0 kg of lactose and 2.5 kg of minerals), about 7% of the total annual feed intake of the dairy ewe.

Studies on relationships among level of production, milk composition and metabolic aspects are the first fundamental step in the development of a feeding system aimed at satisfying nutritive requirements of the animals. The aim of this paper

is to review the knowledge about: a) milk composition of principal Italian dairy sheep breeds; b) relationship among secretion kinetics of main milk constituents and productive level of animals; c) algorithms used for estimating fat and protein corrected milk yield; d) evolution over time of milk production during lactation; e) relationships between feeding and milk composition.

Ewe milk composition and secretion kinetics

Sheep milk consists of water, which represents the main constituent, and dry matter that can be further divided into: fat in emulsion, soluble proteins, protein and minerals linked to casein micelles, in suspension; soluble glucides, minerals, non protein nitrogen and, soluble vitamins.

The differences among breeds in average fat and protein (expressed as total nitrogen compounds) contents (Table 1), are due not only to genetic but also to environmental factors.

Lactose is the main osmotic component of milk, with a concentration ranging within 4.8-5.0% in sheep milk. The fat/lactose and protein/lactose ratios are on average 1.5 and 1.2, respectively, indicating higher daily secretion

Table 1. Fat and protein contents in some sheep breeds (Pulina and Nudda, 2001; Bencini and Pulina, 1997).

Breed	Fat (%)	Protein (%)
Aragat	5.70	5.49
Awassi	6.70	6.05
Chios	6.60	6.00
Comisana	7.5-10.6	5.9-10.4
Delle Langhe	6.75	5.95
East Friesian	6.64	6.21
Karagouniki	8.70	6.60
Lacaune	7.14	5.81
Leccese	7.9-8.4	5.8-6.3
Manchega	9.07	5.43
Massese	6.8-7.4	5.5-6.0
Merino	8.48	4.85
Sarda	6.69	5.82
Tsigai	7.41	5.45

rates for fat and protein than for lactose in sheep, whereas in cattle and goats they are lower (0.73 and 0.67, respectively, for cattle, 0.62 and 0.58 for goats).

Phenotypic (and genetic) correlations among fat and protein percentages and milk yield are negative (Table 2). The negative sign of all correlation coefficients reflects the reduction of fat and protein contents as milk yield increases, i.e. the well-known dilution effect. On the other hand, correlations among fat and protein yields and milk yield are positive and of a higher magnitude than those reported in Table 2. Therefore, it could be reasonably hypothesized that as milk yield (and consequently the amount of lactose synthesized and secreted) increases, fat and protein synthesis show a slower rate of increase, according to an allometric process. In order to test this hypothesis, data used for the calculation of correlations reported in Table 2 were analysed with the following allometric model:

$$y = ax^b$$

where: y = fat or protein test day yield (g/d);

x = milk test day yield (kg/d);

a, b = equation parameters.

Parameter b represents a scaling factor describing the effect of milk yield variation on the secretion of its two main constituents. If $b = 0$, then $x^0 = 1$, $y = a$, fat or protein concentration in milk is a/y and therefore milk composition varies only according to a dilution effect; if $b = 1$, milk yield shows a linear relationship with fat and protein yield whose content in milk is equal to $= a$; finally, if $b > 1$, fat and protein yields tend to increment more proportionally than milk yield and therefore their concentration tends to increase as milk yield increases.

Some useful indications can be drawn from a further development of the allometric model and from the combination of its parameters. The first derivative $dy/dx = abx^{(b-1)}$ represents the ratio of fat (protein) yield variation to milk yield: in particular, the magnitude of the exponential (negative in sign and ranging between 0 and 1) shows its decrement as the milk yield increases. Moreover, the function $a_1/a_2 x^{(b_1-b_2)}$, where a_1, a_2, b_1 and b_2 are allometric parameters for fat and pro-

Table 2. Phenotypic correlation coefficients between milk yield and fat (r_1) and protein (r_2) concentrations in three Italian dairy sheep breeds. Correlations are calculated using experimental data supplied by G. Pulina, M. Avondo and M. Todaro.

Breed	n.	Milk (g/d)	Fat (%)	Protein (%)	r_1	r_2
Sarda	1065	1006	6.70	6.09	-0.418	-0.393
Comisana	441	658	7.31	6.14	-0.423	-0.323
Valle del Belice	5058	1584	7.32	5.69	-0.333	-0.536

tein respectively, allows for the comparison of the secretion rate of the two milk constituents when milk yield increases (if the exponential is negative, fat tends to decrease more rapidly than protein and vice versa).

The allometric model was applied to the three main Italian breeds of dairy sheep: Sarda, Comisana, Valle del Belice. The model fits experimental data well (better fits for protein than for fat) (Figure 1-3) with negative estimates of the b parameter, as expected from correlation values reported in Table 2. This result seems to indicate that the higher productive level of the animals is expressed in a

higher increase of lactose than fat and protein synthesis. Values of parameter b for fat were lower than those for protein in all the three breeds. The difference $b_1 - b_2$ was higher in the Comisana (-0.1053) than in Valle del Belice (-0.0537) and Sarda (0.0510), thus indicating that the reduction in fat synthesis compared to protein synthesis as milk yield increases is higher in the first breed. Similar estimates have been obtained by fitting the allometric model to data coming from other dairy species: 0.895 and 0.946 for fat and protein, respectively, in dairy cattle, 0.945 and 0.947 in buffaloes and 0.934 and 0.928 in goats (Pulina *et al.*, 2003).

Figure 1. Relationship between daily milk yield (kg/d) and fat (g/d), protein (g/d), Energy concentration (Mcal/d) and Energy density (NEm in Mcal/kg) of milk in Sarda dairy ewes.

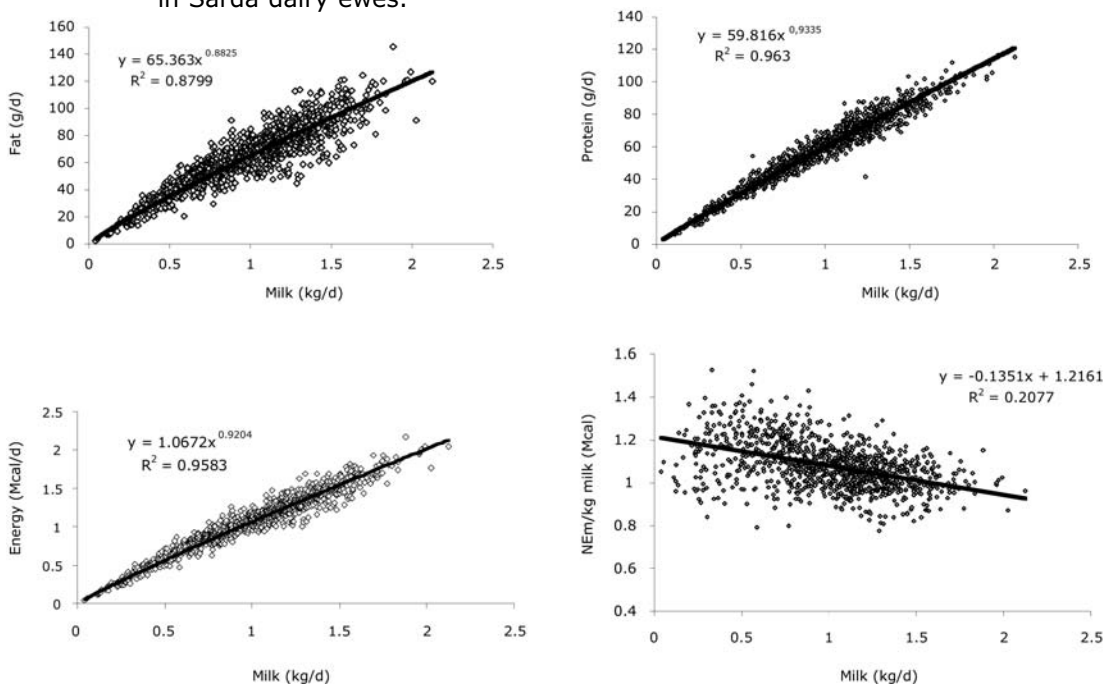


Figure 2. Relationship between daily milk yield (kg/d) and fat (g/d), protein (g/d), Energy concentration (Mcal/d) and Energy density (NEm in Mcal/kg) of milk in Comisana dairy ewes.

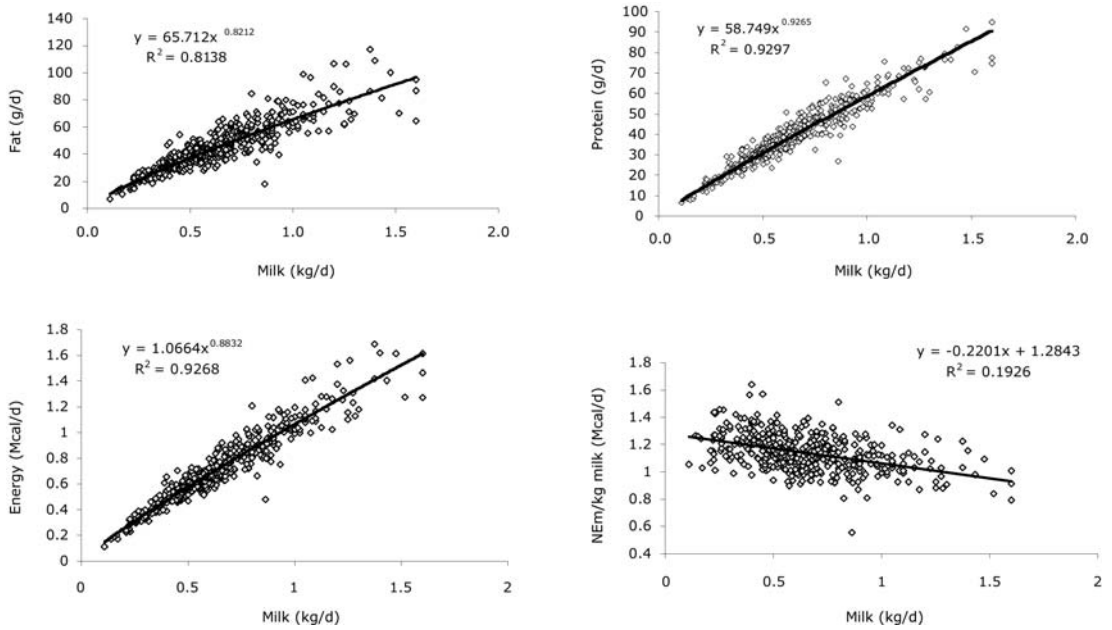
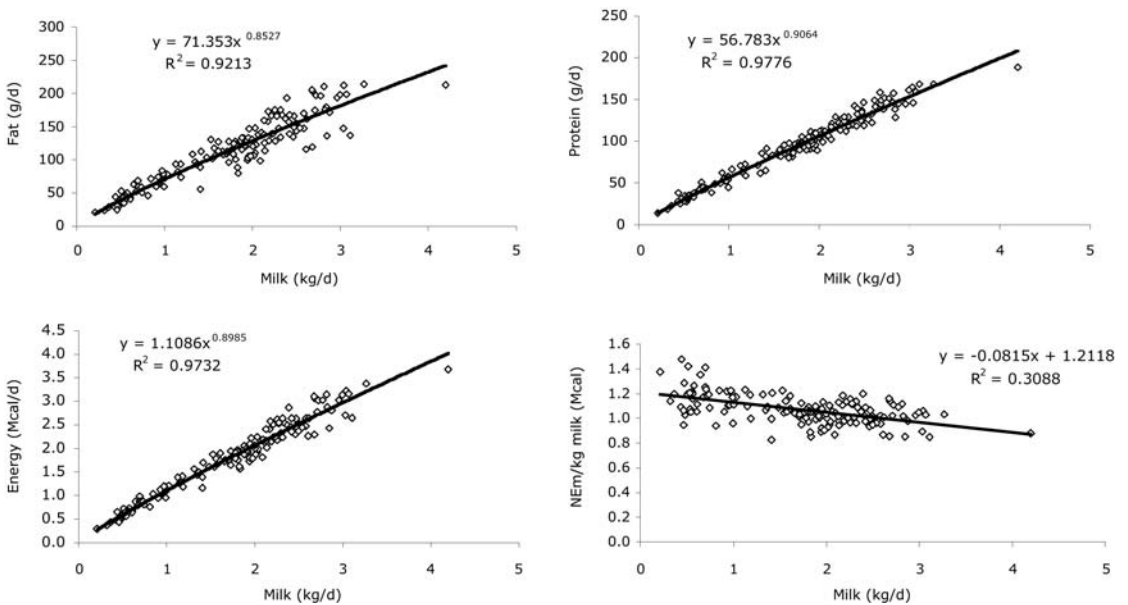


Figure 3. Relationship between daily milk yield (kg/d) and fat (g/d), protein (g/d), Energy concentration (Mcal/d) and Energy density (NEm in Mcal/kg) of milk in Valle del Belice dairy ewes.



The biological explanation of the dilution effect can be found in the need of the lactating ewe to keep as constant as possible the amount of energy (fat) and protein supplied with milk to its offspring. Actually, the regression of milk yield on energy output (kcal of NEL) (see calorimetric equation of the following paragraph) highlights an allometric pattern (Figure 1-3), but with intermediate coefficient estimates that fall between those obtained for fat and protein. Milk energy content (Mcal of NEL/kg) decreases on average of Mcal 0.14, 0.22 and 0.08 per kilogram of increase in milk yield in the Sarda, Comisana and Valle del Belice breeds, respectively. Finally, milk energy content differs among the three breeds according to the level of milk production, with average decreasing rates of 0.920, 0.883 and of 0.898 Mcal of NEL/kg milk for the Sarda, the Comisana and the Valle del Belice, respectively.

The correction of yields

The energy content of milk depends on the level of production but also on other genetic and environmental factors. In order to standardize the expression of animal energy requirements (and also net energy content of feeds), a fundamental step is represented by the correction of milk yield for predefined fat and protein contents. Such a correction is based on the determination of milk energy content, performed directly with the calorimetric bomb or indirectly from the chemical composition of milk. The following equations represent relationships among the energy content of the milk, fat and protein concentrations in Sarda dairy sheep milk (Pulina *et al.*, 1989).

$$CE = 376.3 + 99.15F \quad (R^2 = 0.81; \text{RSD} = 61)$$

$$CE = 251.7 + 89.6F + 37.8P \quad (R^2 = 0.86; \text{RSD} = 53)$$

where:

CE = Energy Content (kcal/kg)

F = Fat content (% of weight)

P = Protein content (% of weight)

RSD = Residual standard deviation of the regression (in kcal/kg)

Moreover, the relationship between direct and indirect measurements of milk energy value has

also been estimated by the same authors:

$$y = 0.984x - 15 \quad (R^2 = 0.82; \text{RSD} = 58)$$

where:

y = Milk energy value measured directly by using the calorimetric bomb;

x = Milk energy value content calculated from its fat and protein contents by using standard calorimetric coefficients.

This equation can be used to correct the energy content of milk obtained indirectly from its composition. Finally, the equations above reported have been used to develop algorithms for the calculation of milk yield corrected at 6.5% of fat and 5.8% of protein contents (considered average values for the most widespread dairy breed):

$$FCM_{(6.5)} = M(0.37 + 0.097F) \\ (\text{reference value kcal/kg} = 1.020)$$

$$FPCM_{(6.5; 5.8)} = L(0.25 + 0.085F + 0.035P) \\ (\text{reference value kcal/kg} = 1.047)$$

where:

FCM, FPCM = fat (and protein) corrected milk

M = Milk yield (kg);

F = Milk fat content (%);

P = Milk protein content (%).

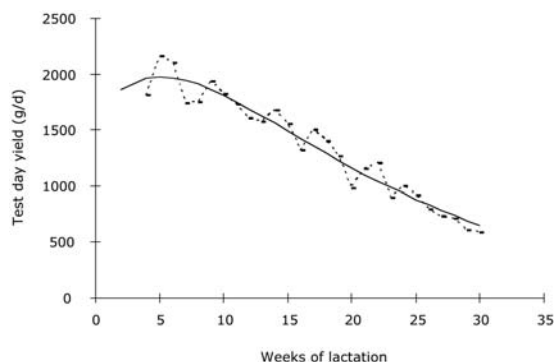
The lactation curve

Over time the evolution of milk production traits is the most relevant factor affecting dairy sheep nutritive requirements during lactation. The mathematical modelling of milk production allows, therefore, the estimation of feeding requirements for lactating ewes both at an individual and flock scale (feeding plans). Several analytical functions of time, originally proposed to model the lactation curve of dairy cattle, have also been applied to dairy sheep. The most widely used equation is the Wood's incomplete gamma function (Wood, 1967):

$$y(t) = a t^b \exp(-ct)$$

where $y(t)$ is the average daily production at time (t) and a , b and c are parameters with positive values which describe the shape of the lactation curve.

Figure 4. Wood's model fit to Sarda sheep lactation curve.



Lactation curves usually give good results when fitted to average lactation patterns of homogeneous groups of animals (i.e. of the same flock or parity) (Figure 4).

The Wood model has also been widely used to fit lactation curves of fat and protein contents. Obviously, the sign of the parameter c is negative, as it is the pattern of the two components that mirrors that of milk yield.

Values of Wood parameters estimated for aver-

age lactation curves of Sarda, Comisana, Valle del Belice and Massese breeds are reported in Tables 3, 4, 5 and 6, respectively. If compared with the official statistics of the breeds, total lactation yields obtained by integrating Wood function are lower for the Sarda and higher for the other breeds. However, it must be remembered that it is quite difficult to find in literature experimental works in which Wood function has been fitted to data collected for the entire length of lactation. Actually, as these differences are mainly due to the scale parameter (a), b and c values have been included in a simulation software (Fertisoft) for the estimation of flock feeding requirements evolution during the year (Pulina *et al.*, 1995).

The estimated curve of FPCM can then be obtained by combining coefficients of milk production traits (milk yield, fat and protein content) (Table 7).

As previously said, the Wood equation fits average lactation curves of homogeneous groups of animals well whereas the individual fitting gave conflicting results. Several studies report a relevant occurrence in sheep (up to 50% of the cases) of Wood model estimates that are out of the

Table 3. Estimates of Wood parameters for the average lactation curve (t in weeks) of a flock of Sarda ewes (Pulina and Nudda, 2001).

Trait		Wood parameters		
		a	b	c
Milk yield	g/d	934	0.181	-0.041
Fat	%	7.51	-0.186	0.028
Protein	"	5.19	-0.035	0.013

Table 4. Estimates of Wood parameters for the average lactation curve (t in weeks) of a flock of Comisana ewes (Portolano *et al.*, 1999, for milk yield, and first 15 weeks of lactation data supplied by Lutri, for fat and protein).

Trait		Wood parameters		
		a	b	c
Milk yield	g/d	1146	0.197	-0.011
Fat	%	6.75	-0.045	0.013
Protein	"	4.39	-0.045	0.053

Table 5. Estimates of Wood parameters for the average lactation curve (t in weeks) of a flock of Valle del Belice ewes (Portolano *et al.*, 1999; Todaro *et al.*, 1999).

		Wood parameters		
Trait		a	b	c
Milk yield	g/d	2599	0.034	-0.0045
Fat	%	4.71	0.082	0.00019
Protein	"	3.47	0.069	0.0009

Table 6. Estimates of Wood parameters for the average lactation curve (t in weeks) of a flock of Massese ewes (Franci *et al.*, 1999).

		Wood parameters		
Trait		a	b	c
Milk yield	g/d	1116	0.29	-0.0147
Fat	%	4.65	0.0039	0.00121
Protein	"	5.04	0.033	0.00153

Table 7. Estimates of Wood parameters for FPCM (6.5% fat and 5.8% protein) obtained from parameter values reported in tables 3-6.

		Wood parameters		
Breed		a	b	c
Sarda		928	0.0385	-0.0028
Comisana		1123	0.150	0.0095
Valle del Belice		1998	0.09030	-0.0045
Massese		917	0.3096	-0.0137

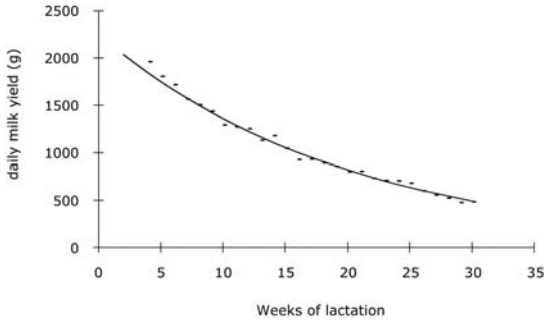
parameter space: for example, a negative value of the b parameter implies a negative time at which lactation peak occurs (calculated as the ratio b/c), which is obviously meaningless (Figure 5) (Cappio-Borlino *et al.*, 1995; Franci *et al.*, 1999; Portolano *et al.*, 1996).

A common explanation is that curves showing a negative estimate of b parameter are those that lack the lactation peak, the so-called atypical curves (Shanks *et al.*, 1981). However, even if there are sometimes curves that show only the decreasing phase, in other cases the production peak is

present, but it is characterised by a sudden occurrence that makes it no longer detectable by the Wood function. As a general conclusion, it can be said that the Wood function, as other empirical models of the lactation curve, is expected to give poor performances in 30 to 50% of cases when it is fitted to individual sheep lactation patterns. However, it must be remembered again that the Wood curve is an efficient tool for estimating the over time evolution of milk yield of the whole flock for management and feeding purposes.

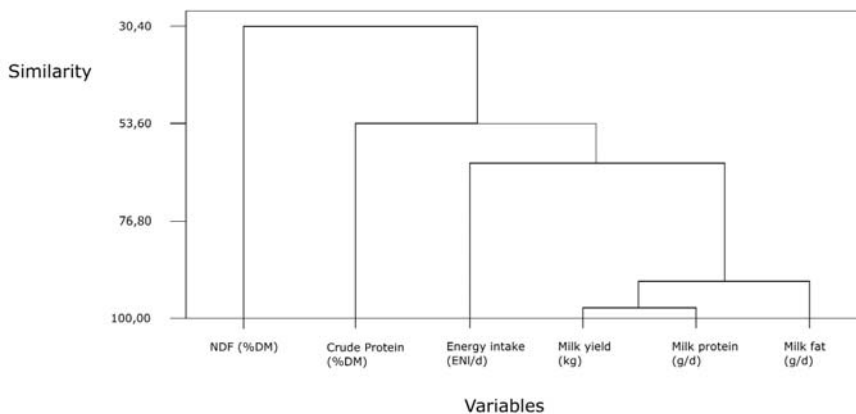
Lactation curve functions are able to estimate

Figure 5. Example of a lactation curve that can not be fitted by the Wood model it (apparently) lacks of the lactation peak.



the continuous and regular component of milk yield patterns from lambing to dry-off. However, individual variations still exist around mean curves mainly due to genetic and environmental factors and they can be evidenced by analysing the pattern of covariances among adjacent Test day measurements within lactation. Measures of milk yield close in time tend to be more correlated far apart in time; this particular pattern is more evident when partial correlations are considered (Table 8) (Macciotta *et al.*, 1999). These figures highlight the short-memory nature of the milk production process: actually an environmental variation, such as feeding availability, minor injuries or climate events could affect milk yield within about 60 days from its occurrence.

Figure 6. Dendrogram of the relationships among some characteristics of the diet and milk production traits.



Relationships between milk production and nutrient content of the diet.

The dendrogram reported in Figure 6 illustrates the result of a multivariate cluster analysis that considered some components of the diet, milk yield and composition, from 120 experimental trials carried out on several sheep breeds (Serra *et al.*, 1998).

The picture highlights the strong relationship among milk production and energy supplied by the diet. In particular, test day yields of milk, fat and protein show the strongest correlation with the energy ingested, then with protein concentration (in % of DM) and finally with fibre content (% DM) of the diet. Therefore, the net energy intake represents the most relevant factor influencing milk yield and composition, followed by protein and fibre content of the diet. Such results can be reasonably explained by the fact that the higher amount of energy available to animals fed diets with a low NDF content, and detectable with an increase of glucose content in the blood, is used to produce, in the following decreasing order of importance, lactose, protein and fat with the following sequence of metabolic events:

1. increase in the blood flux in the mammary gland due to the action of local regulators controlled by main metabolic hormones (insulin, IGF and neuro-hormones);
2. increase in the uptake of milk precursors (glucose, acetate and butyrate, amino acids, NEFA);
3. increase in the amount of glucose available for lactose synthesis (Freetly and Ferrell, 1999);

Table 8. Pearson (above the diagonal) and partial (under the diagonal) correlations among test day yields taken at different time intervals from lambing (Macciotta *et al.*, 1999).

	TDM1	TDM2	TDM3	TDM4	TDM5	TDM6	TDM7
TDM1	*	0.710	0.626	0.499	0.305	0.406	0.301
TDM2	0.458	*	0.792	0.686	0.516	0.481	0.255
TDM3	0.133	0.420	*	0.784	0.592	0.538	0.310
TDM4	0.052	0.096	0.435	*	0.747	0.555	0.233
TDM5	-0.197	0.067	-0.007	0.509	*	0.609	0.310
TDM6	0.044	0.045	0.037	0.104	0.299	*	0.646
TDM7	0.128	-0.083	0.086	-0.176	0.009	0.588	*

TDM1= Test Day milk yield occurring between 20-50 days in milk; TDM2= Test Day milk yield occurring between 51-80 days in milk; TDM3= Test Day milk yield occurring between 81-110 days in milk; TDM4= Test Day milk yield occurring between 111-140 days in milk; TDM5= Test Day milk yield occurring between 141-170 days in milk; TDM6= Test Day milk yield occurring between 171-200 days in milk; TDM7= Test Day milk yield occurring between 201-230 days in milk.

- increase in protein synthesis by the mammary gland due to a greater availability of amino acids that are not used in gluconeogenesis by the liver (mammary gland?);
- increase in the direct (or indirect through the Pentoso-Phosphate pathway) synthesis of triglycerides, especially of those containing fatty acids synthesized by the mammary gland (medium and short chain), from the excess of glucose that is not used for the synthesis of lactose whereas it is processed directly to produce fat (as occurs in monogastric animals).

Data used in the cluster analysis reported above have been subjected to multiple regression analysis in order to estimate the relationship between the outputs represented by milk fat or protein yields, and the protein and fibre daily intake (amount of NDF [NDF-I] and of crude protein [CP-I] ingested, expressed in g/d head⁻¹), body weight (BW, expressed in kilograms) and daily body weight change (dBW expressed in g). Records used for this metanalysis were 39 for fat yield and 32 for protein yields. Estimated equations are the following:

$$\text{Fat (g/d)} = 15.566 (\#) + 0.228 \text{ CP-I} - 0.049 \text{ NDF-I} + 0.497 \text{ BW} (\#) - 0.152 \text{ dBW}$$

(R² = 0.64; RSD = 22.5)

$$\text{Protein (g/d)} = 30.7 (\#) + 0.260 \text{ CP-I} - 0.111 \text{ NDF-I} + 0.887 \text{ BW} - 0.234 \text{ dBW}$$

(R² = 0.77; RSD = 23.12)

All parameters are significantly different from zero (P<0.05), except the scaling factors (*P<0.1).

According to the sign of the coefficients, test day milk yields of fat and protein are positively affected by the CP intake and depressed by the ingested NDF. Negative variations of BW result in an increase in both milk components thus evidencing a phenomenon of transit of nutrients from the animal to the milk.

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