Small Ruminant Research 97 (2011) 41–47

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

Economic values for production and functional traits in Valle del Belice dairy sheep using profit functions

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ARTICLE INFO

Article history:
Received 20 September 2010
Received in revised form 26 January 2011
Accepted 28 January 2011
Available online 2 March 2011

Keywords:
Sheep
Breeding objectives
Economic values
Profit function

ABSTRACT

A deterministic static model was used to estimate the economic values (EV) of production (MY, milk yield; BW, birth weight; and ADG, average daily gain) and functional traits (ASR, adult survival rate; LSR, lamb survival rate; FE, fertility; PR, prolificacy; and LW_{ewe}, mature weight of ewe) in Valle del Belice dairy sheep. In this study, values for the biological parameters and the production traits used in the model were taken from real data, by surveying 15 Valle del Belice farmers and reflected the production circumstances of pasture based dairy production systems. In this system feed cost accounted for 95% of total variable costs, whereas fixed costs were low and reflected traditional and small ruminants' husbandry system. A base situation with a fixed number of animals was considered to estimate the EV for the traits considered in this study. Economic values were positive for production traits: € 0.31 (MY, kg), € 4.40 (BW, kg) and € 0.15 (ADG, g) and for functional traits: € 2.15 (ASR, %), € 0.78 (LSR, %), € 2.64 (FE, %), € 0.39 (PR, %), except for LW_{ewe} that was negative (€ −0.08, kg). Sensitivity analysis of EV to changes in prices indicated that future economic values for traits might change dependent on output and price levels, in particular on milk and meat price level. This study suggests that genetic improvement of milk production, lamb and adult survival rate, fertility and prolificacy will have a positive effect on profitability of pasture based dairy production system.

1. Introduction

Sheep and goat productions are widespread in the Mediterranean regions, in particular in the South of Italy and represent an important resource for the economy of hill and mountain areas, in which other economic activities are difficult to develop (Scintu and Piredda, 2007). Moreover, small ruminants' husbandry has a role in protecting the territory and prevent rural exodus of the population towards the urban and peri-urban areas.

In recent decades, the setup of a breeding program was started for Valle del Belice dairy sheep, which is the most productive autochthonous sheep breed reared in Sicily. In a breeding program, it is often functionally important to improve several traits at the same time. It becomes, therefore, necessary to define the relative economic weight of each trait and their contribution to the overall breeding objective, to ensure that selection emphasis is proportional to the economic importance of each trait (Amer et al., 2001). Firstly, it is important to identify the traits that have to be improved and estimate the relative economic value (EV) of each trait, to define subsequently an aggregate genotype for each animal candidate for selection. In the selection

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0921-4488/$ – see front matter
doi:10.1016/j.smallrumres.2011.01.019

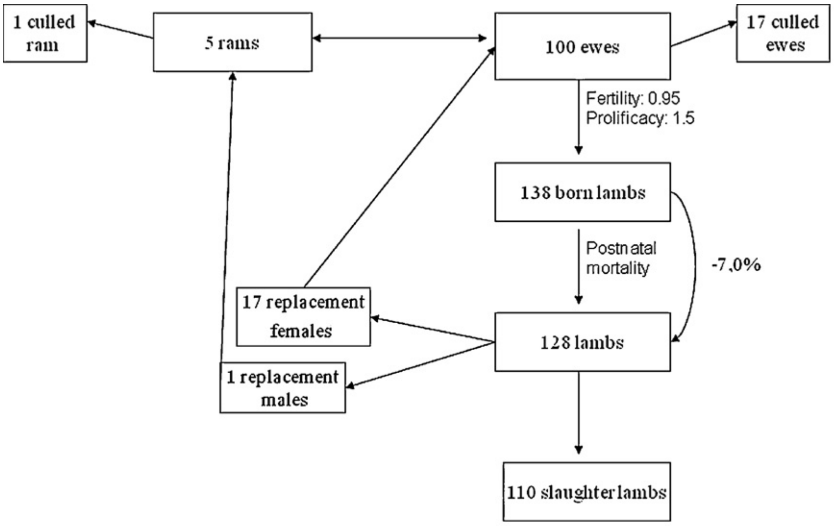

Fig. 1. Flock composition. Composition of a Valle del Belice dairy sheep breed flock based on constant number of ewe.

index theory, the aggregate genotype (i.e., breeding goal) is indeed defined as a linear function of traits to be improved, times the corresponding EV. The EV of a trait is the value of a unit change in the trait, while keeping the other traits in the aggregate genotype at constant level (Hazel, 1943).

The aim of this study was to estimate the EV's for production and functional traits in Valle del Belice dairy sheep, considering a fixed number of animals due to labouring and housing constraints.

2. Materials and methods

2.1. Production system

Data used in this study were obtained by surveying 15 Valle del Belice farmers in two Sicilian provinces, and reflect the husbandry system of this breed on the island. The Valle del Belice sheep breed is mainly reared for milk production, which is used for producing raw-milk traditional cheeses (e.g., Pecorino and Vastedda del Belice cheeses) either by farms, small local dairies, or cheese industries working at the regional level. Only a small part of the income derives from lamb meat. Management of the Valle del Belice breed is characterized by a typical family farming system, and the breed is mainly raised under semi-extensive grazing conditions. Ewes are usually hand-milked twice a day (morning and evening), and are housed in old storehouses or kept in fenced-in enclosures after the evening milking. 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). Replacement ewes are weaned at 60 days of age. The average number of animals per flock usually ranges from 100 to 200, with a 1:20 tertiary sex ratio. In this study, a fixed flock-size scenario of 100 sheep was used, where the dimension of the flock size cannot be increased due to constraints as food resources and labour costs. However, the values calculated can be re-scaled to any desired flock size.

Ewes give birth once per year. Based on both the questionnaires and the data from the Breeders Association (AIA Roma, 2008), 37% of born lambs were assumed to be males and 63% females and a twinning rate of 32% was considered in this study. Moreover, no distinction was made for single or multiple born lambs in terms of birth weight. Based on reproductive traits, voluntary culling, and adults' mortality of Valle del Belice sheep, 17 replacement females and one replacement male per year were selected out of 128 lambs at 35 days of age, whereas the remaining 110 animals were sold (Fig. 1).

Given the farming system adopted for the Valle del Belice breed, in which the use of milking machine and artificial nursing are not diffused and costs for housing are very low, costs considered in this study were only due to the purchase of food and medical cares for the animals. Moreover, the purchase of replacement and fattening animals was not considered.

2.2. Model description and definition

The deterministic static model used in this study estimated inputs and outputs per year of a typical farming system from field data. Based on interpretation limits, a static model assuming no variation in characteristics among animals was used for calculation of EV's.

Food resources are natural pasture and crop residues, whereas hay and concentrates are bought by the farmer. However, the farmers have to buy some food also in June to September, as the availability of pasture is very low in Sicily in this period, due to high temperatures and no rain, and in October to February, to satisfy the energy requirements for production. To estimate the feed costs, total energy requirements, expressed as metabolizable energy in Mcal per day (ME_{tot}), were estimated by summing energy for maintenance (ME_m), energy for lactation (ME_l), and energy for pregnancy (ME_p), using the CNCPS-S model (Cornell Net Carbohydrate and Protein System for Sheep) proposed by Cannas et al. (2004), a factorial approach in which each component was independent from the others.

Performance data and economic parameters used are reported in Table 1 and were assumed to be representative for the Valle del Belice breed. Energy requirements were calculated as shown in Appendix A and summarized in Table 2.

2.3. Biological traits influencing profit

Production (milk and meat) and functional (survival rate, reproduction, and live weight) traits were included in this study (Table 1). Only milk

Table 1
Biological traits influencing profit.

Variable	Mean level	1% increase
Mean of phenotypic performance		
Milk yield (MY) per ewe per lactation (kg)	273	2.73
Birth weight (BW) (kg)	4.00	0.04
Average daily gain (ADG) of lambs (g)	180	1.8
Adults survival rate (ASR)	0.97	0.0097
Lambs survival rate (LSR)	0.93	0.0093
Fertility (FE)	0.95	0.0095
Prolificacy (PR)	1.5	0.015
Ewe live weight (LW_{ewe}) (kg)	55	0.55

Table 2
Values of production and economic variables used in profit function.

Variable	Value
Other biological and production parameters	
Lactation length (days)	210
Productivity life time (PLT_{ewe}) of ewes (years)	7
Productivity life time (PLT_{ram}) of rams (years)	5
Ram live weight (LW_{ram}) (kg)	65
ME of maintenance per ewe (Mcal/year)	1100.44
ME of lactation per ewe (Mcal/year)	619.53
ME of pregnancy per ewe (Mcal/year)	45.4
ME of maintenance per ram (Mcal/year)	1249.30
ME of maintenance per replacements (Mcal/year)	1160.24
EC of feed (Mcal/kg of DM)	1.5
Price and cost	
Price of milk (euro/kg)	0.70
Price of lamb meat (euro/kg)	4.00
Price for rams and ewes culled (euro/kg)	1.09
Hay price (euro/kg DM)	0.12
Concentrates (euro/kg DM)	0.18
Medical cost for adults (euro/head)	4.30
Medical cost for lambs (euro/head)	2.00

ME: metabolizable energy; EC: energy content; DM: dry matter.

yield (MY) at 210 days of lactation was considered, by averaging lactation length of both primiparous and multiparous Valle del Belice ewes. Fat, protein, and somatic cell count were not considered, because at present the payment system for sheep milk is only based on milk yield and does not take into account milk composition. Meat traits included in the analysis were birth weight (BW) and average daily gain of lambs (ADG) up to slaughter age. Mean levels of these traits were obtained from the farmers, as the production system is based on milk production and no data were available on lamb weight at different age and incomes and expenses of meat production. However, both traits were important to determine the final revenue from the lambs' sale. Carcass quality traits, such as dressing percentage, were not included because they are not considered in the payment system, i.e., farmers sell alive lambs.

Functional traits included adults (ASR) and lambs (LSR) survival rate that were considered as indicators of the flock health status. An increase in these traits corresponds to a reduction of involuntary culling for adult animals and an increase of lambs to sale, therefore were determinant of the system output. Fertility (FE) and prolificacy (PR) were chosen as reproductive parameters, as they are important to increase lamb meat production and are useful to measure the fitness of a population. Body weight of mature ewes (LW_{ewe}) was assumed constant within lactation and used to determine the maintenance energy requirements.

To estimate the EV's of these traits a genetic change of 1% was assumed.

2.4. Profit equation

The annual profit (P) was calculated as the difference between revenues (R) and costs (C), at both farm and ewe level. However, Ponzoni (1988) showed that the way revenues and costs are expressed (ratio or difference) slightly affects EV's. All costs and prices were expressed in Euro.

Revenues were calculated as follows:

$$R = R_{milk} + R_{lambs} + R_{ewe\_cull} + R_{ram\_cull}$$

where R_{milk} was the revenue from milk sold; R_{lambs} was the revenue from young lambs sold; and R_{ewe_cull} and R_{ram_cull} were revenues from culled ewes and rams, respectively.

Costs were calculated as:

$$C = C_{ewe} + C_{ram} + C_{lamb} + C_{ewe\_cull} + C_{ram\_repl} + C_f,$$

where C_{ewe} and C_{ram} were costs for feeding and treatments of ewes and rams, respectively; C_{lamb} was the cost for suckling lambs and treatments, C_{ewe_repl} and C_{ram_repl} were costs for feeding and treatments of females and males for replacement; and C_f were the fixed costs of the farm, which included a fee for the registration to the breeder association and for the ear tags, whereas it did not include housing and labour costs, as recovery for animals are represented by recycled materials with no costs for the farmer and familiar labour force is prevalent. Government subsidies were not considered in the model. All revenues and costs components were calculated as shown in Appendix B.

2.5. Derivation of economic values

There are mainly two approaches to derive the EV's: the partial budgeting and the partial differentiation method (Brascamp et al., 1985; Smith et al., 1986). In the partial budgeting method, unit change in return (marginal return) and costs (marginal costs) arising from the improvement of a trait are accounted for, whereas in the partial differentiation method, the partial derivative of the profit function with respect to the trait of interest is obtained. However, the partial differentiation method can be only used when it is possible to set up a single equation that describes the change in net economic returns as a function of a series of physical, biological, and economic parameters (Bett et al., 2007).

The partial budgeting, which involves analysis of field data, was used to obtain EV's for the traits considered. Maximisation of the profit was chosen as breeding objective, because usually the farmer takes breeding decisions, although the national and consumer viewpoints should be considered (Pearson and Miller, 1981). Economic values for the traits considered were evaluated under fixed flock-size system condition. This situation adequately represents most production systems of the Mediterranean regions where feed scarcity is a major limiting factor.

Economic values were derived by comparing farm profit before and after changing the genetic level of each trait from the basic situation, assuming that all the other traits remain constant. Economic values per unit change in the trait of interest were derived from the equation: $EV = (\delta R - \delta C)/\delta t$, where EV is the economic value per unit change in the trait of interest, δR and δC are the marginal changes in revenues and costs after a 1% increase in the trait of interest and δt is the marginal change of the trait after a 1% increase (Table 3).

2.6. Sensitivity of economic values to changes in price

A sensitivity analysis was carried out to analyze the robustness of the profit equation and consequently of the EV's by changing the price of some input and output parameters. Sensitivity of EV's to price levels of input or output gives the likely direction of future genetic improvement and production system, which has important implications for practical breeding programmes (Kosgey et al., 2003). Changes of ±20% with respect to the price of milk, meat, live weight of culled animals, foods and medical care were considered for evaluation system (Table 4). The changes were performed one at time, keeping all other parameters constant.

3. Results and discussion

The profit for the base situation (before changing traits level), marginal changes of revenues and costs, and EV's (€, Euros per ewe per year) for production and functional traits for Valle del Belice dairy sheep, under the fixed flock-size condition, are given in Table 3. Milk and meat production represented 72% and 28% of the total revenues, respectively. In extensive sheep production system, variable costs, i.e., feed and other not fixed costs included 99% of the total costs. Haghdoost et al. (2008) reported that variable costs included 98.5% of the total costs for Arabic sheep production system, whereas Kosgey et al. (2003) estimated a proportion of 5% for fixed costs. The differences may have to be attributed to different assumptions of these models that considered labour and transport costs not included in this study. As expected, feed costs represented the major component of these variable costs, accounting for about 95%. Fixed costs were low and reflected traditional and small ruminants' husbandry system.

Economic values were positive for production traits (MY and ADG) and functional traits (ASR, LSR, FE, PR and BW),

Table 3
Marginal change after 1% increase in genetic merit and economic values based on a hypothetical 100 flock number.

	Initial	MY	BW	ADG	ASR	LSR	FE	PR	LW_{ewe}
Revenues[a]									
Milk	14,520.42	145.20	0	0	149.70	0	185.37	0	0
Lambs sale	4,532.00	0	17.60	27.72	123.60	82.40	82.40	41.20	0
Culled ewes	1,019.15	0	0	0	−59.95	0	0	0	10.19
Culled rams	70.85	0	0	0	0	0	0	0	0
Total	20,142.42	145.20	17.60	27.72	213.35	82.40	267.77	41.20	10.19
Costs[a]									
Feed	12,823.68	61.19	0	0	−6.75	0	0	0	14.65
Medical	736.00	0	0	0	6.00	4.00	4.00	2.00	0
Variable	13,559.68	61.19	0	0	−0.75	4.00	4.00	2.00	14.65
Fixed	66.20	0	0	0	−0.90	0	0	0	0
Total	13,625.88	61.19	0	0	−1.65	4.00	4.00	2.00	14.65
Profit[a] (1–2)	6,516.54	84.01	17.60	27.72	214.99	78.40	263.77	39.20	−4.46
1% increase		2.73	0.04	1.800	0.0097	0.0093	0.0095	0.015	0.55
EV (€/head)		0.31	4.40	0.15	2.15	0.78	2.64	0.39	−0.08
REV		1	14.19	0.48	6.94	2.52	8.52	1.26	−0.26

MY: milk yield; BW: body weight; ADG: average daily gain; ASR: adult survival rate; LSR: lamb survival rate; FE: fertility; PR: prolificacy; LW_{ewe}: ewes live weight.

[a] Values are expressed in Euro per year.

except for LW_{ewe} that was negative. Positive EV's were due to an increase in net returns from meat and milk production, despite of possible negative effects on the other sources of revenue, i.e., increasing a 1% of ASR causes a positive effect on milk and meat production, but a reduction of revenues arising from sale of culled animals. The ASR was more important than MY, in fact an increase of 1% of the base value of ASR increased profit per ewe per year by 2.15 € compared to 0.31 € for an increase of 1% of the base value of MY. Milk production was used to estimate the lactation energy requirement for ewes, therefore selection for increasing MY would cause an increase in feeding costs. The EV estimated in this study for MY falls in the range reported in literature per sheep (from 0.32 € to 1.18 €; Kominakis et al., 1997; Legarra et al., 2007; Wolfová et al., 2009). As expected, sensitivity analysis for EV of MY was affected by selling price of milk and purchase price of food; in fact a high percentage of total revenue comes from milk sales. Among the functional traits, BW, FE, ASR, and LSR had the highest impact on increasing profit, as these traits directly affect milk and meat production. In fact, an increase by 1% of the base value of these traits resulted in an increase of 4.40, 2.64, 2.15, and 0.78 € respectively, in profit per ewe per year. Economic values for ADG and PR traits were 0.15 and 0.39 €, respectively. Few results are available for LSR in literature. Amer et al. (1999) studied this trait for several farm types and found EV's ranging from 0.31 to 0.36 $ (about 0.62 to 0.72 €) for an improvement of 1%. Sensitivity analysis for EV of BW and ADG showed that these values increased when the selling price of meat increases. As for MY, EV for LSR trait was affected by the selling price, namely of the meat. Improvement of reproductive traits

Table 4
Sensitivity of economic values (EV) to change in price (±20%) of feed, meat, milk, culled animals and veterinary costs expressed relative to EV for head.

%	MY	BW	ADG	ASR	LSR	FE	PR	LW_{ewe}
	0.31	4.40	0.15	2.15	0.78	2.64	0.39	−0.08
Cost of DM								
+20	0.94	1.00	1.00	1.01	1.00	1.00	1.00	1.63
−20	1.06	1.00	1.00	0.99	1.00	1.00	1.00	0.38
Price meat								
+20	1.00	1.20	1.20	1.12	1.22	1.06	1.21	1.00
−20	1.00	0.80	0.80	0.88	0.79	0.94	0.79	1.00
Price milk								
+20	1.26	1.00	1.00	1.13	1.00	1.14	1.00	1.00
−20	0.74	1.00	1.00	0.87	1.00	0.86	1.00	1.00
Price culled								
+20	1.00	1.00	1.00	0.94	1.00	1.00	1.00	0.50
−20	1.00	1.00	1.00	1.06	1.00	1.00	1.00	1.50
Medical cost mature								
+20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50
−20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Medical cost lambs								
+20	1.00	1.00	1.00	1.00	0.99	1.00	0.97	1.00
−20	1.00	1.00	1.00	1.00	1.01	1.00	1.03	1.00

MY: milk yield; BW: birth weight; ADG: average daily gain; ASR: adult survival rate; LSR: lamb survival rate; FE: fertility; PR: prolificacy; LW_{ewe}: live weight.

(FE and PR) provides a higher profit due to an increase in MY and lamb meat to sale, being the EV's for these traits 2.64 and 0.39 €, respectively. However, Legarra et al. (2007) reported higher values for these traits, 138.6 € and 40 € respectively. The difference was probably due to the different cost for lamb feeding. In fact, in our study lambs were fed only with maternal milk for 35 days, therefore lambs feeding cost was equal to the income lost from the missed sale of milk. Sensitivity analysis showed how EV's for FE depends more on milk than meat price, whereas the EV of PR was more affected by the meat price, being this trait directly related to the number of sold lambs.

The EV for LW_{ewe} was −0.08, similar to the values reported in cows by Visscher et al. (1994) and Koenen et al. (2000), and in ewes by Conington et al. (2004) and Wolfová et al. (2009). However, this result was different from those reported by Kosgey et al. (2003) and Haghdoost et al. (2008). Cost of dry matter was crucial in determining the EV for the LW_{ewe} trait and less important the price of culled animal, as underlined by the sensitivity analysis. This low and negative value was probably due to the fact that bigger animals require more maintenance energy, i.e., higher feeding costs, than smaller ones and to the low price for culled animals. If pasture and forage are adequate, bigger ewes can consume enough to meet nutrient needs, but they may be penalized if food availability is low. For meat trait, EV for BW was higher than ADG trait: 4.4 € and 0.15 € respectively. The higher EV for BW was probably due to the fact that no additional cost was associated to the lambing of heaviest lambs, such as more nutrient requirements or assistance during lambing. Both traits were in fact sensible only to the meat price and no to other costs like feed or veterinary costs.

A benefit of the approach presented in this study, in comparison to that used by Kahi and Nitter (2003), was a more explicit accounting for the energy requirements of individual class of animals and the ability to account for some environmental parameters, as proposed by Cannas et al. (2004).

4. Conclusions

The study provides some important information on the traits that should be included as breeding objective in a Mediterranean dairy ewes production system, where annual investments are very low and pasture is the main source of food for the breeding stock. The results show that functional traits, as fertility and prolificacy, are some of the most economically important traits. These traits, even if they are highly management dependent, should be included in a systematic recording to genetic evaluation. However, it could be difficult and economically wasteful in the Valle del Belice sheep breed, which gives birth all throughout the year. In practice increasing milk production still represents the main interest for the producers, which now pay much attention on functional traits.

Due to environmental and management variability, several assumptions were made in this study, such as a constant flock size and an optimized replacements policy. In reality, rams and ewes are not always replaced considering reproductive ability or milk production. Values for the biological parameters and for the production traits used in this model were taken from real data, analyzing three lactations of Valle del Belice dairy ewes (unpublished data), hence the EV's estimated for some production and functional traits can be used to study a selection index to improve the Valle del Belice breed. It is important to highlight that the EV's presented in this study are specific of one breed and production system considered and values can be different for other production systems. A study will be necessary to estimate the EV's for different scenarios to study the robustness of the selection index; and to include other traits as milk composition, somatic cell count, and type traits.

Acknowledgements

The third author had an experienced researcher position within a Marie Curie European Transfer of Knowledge Development project with contract number MTKD/ICT-2004-14412.

Appendix A.

A.1. Calculation of energy requirements

A.1.1. Maintenance energy requirements

Energy requirement for maintenance (ME_m) in Mcal per day was equal to:

$$ME_m = \frac{[LW^{0.75} \times a_1 \times S \times a_2 \times \exp(-0.03 \times MEI \times k_m)] + ACT + NE_{mcs}}{k_m}$$

where $LW^{0.75}$ is the metabolic weight in kilograms; a_1 is a factor that takes into account the neutral temperature and is equal to 0.062 Mcal of $NE_m/LW^{0.75}$, namely net energy per metabolic weight; S is a multiplier for the effect of sex and is equal to 1 for female and 1.5 for male (ARC, 1980); a_2 takes into account the average temperature of the breeding environment and was estimated as: $[1+0.0091 \times (20-T_p)]$, where T_p is the average daily temperature of the previous month (NRC, 1981). This adjustment factor increases the maintenance requirements for low temperature and decreases the value for high temperature; AGE is the age of animals in years and, by using the exponential function proposed by CSIRO (1990), the maintenance requirement decreases from 0.062 to 0.052 Mcal of $NE_m/LW^{0.75}$ as the animal ages from 0 to 6 year old. The adjustment factor $(0.09 \times MEI \times k_m)$ takes into account the increase in the size of visceral organs as nutrient intake increases (CSIRO, 1990), in which MEI is the metabolizable energy intake in Mcal per day and k_m is equal to the efficiency coefficient of conversion for ME in NE for milk production. This value was fixed at 0.644, based on what reported in cows, i.e., lactating cows use energy with a similar degree of efficiency for maintenance and milk production (Moe, 1981; Moe et al., 1972) and no differences in this efficiency between sheep and cows have been ever reported (Van Soest et al., 1994); ACT is the energy requirement for grazing animals to walk on flat and sloped terrains as indicated by ARC (1980); and NE_{mcs} is a factor which allows taking into account energy losses due to cold stresses.

A.1.2. Milk production energy requirements

Energy requirements for lactating ewes (ME_l) were estimated, based on the equation of Pulina et al. (1989), as:

$$ME_1 = \frac{[251 + 89.64 \times PQ + 37.85 \times (PP/0.95)] \times 0.001 \times DMY}{k_1}$$

where PQ and PP are fat and protein concentration of milk; DMY is daily milk yield (kg/d); and k_1 is the efficiency coefficient of utilization of ME to produce milk and is fixed at 0.644.

A.1.3. Pregnancy energy requirements

Pregnancy requirements were estimated with the approach used by CSIRO (1990), which is based on ARC data (1980) that takes into account the energy content of the gravid uterus before lambing using a Gompertz model assuming a lamb weight of 4 kg at birth:

$$\ln(E_t) = 7.649 - 11.465 \times \exp(-0.00643 \times t)$$

where $\ln(E_t)$ is the total energy content in megajoules (MJ) of the gravid uterus. By differentiation, the equation allows for the calculation of the daily net energy requirements for pregnancy (NE_p). Therefore, using the factor 0.239 to convert MJ in Mcal, ME_p are computed as follows:

$$ME_p = \frac{NE_p}{0.13}$$

Appendix B.

B.1. Calculation of revenues

B.1.1. Revenues from the sale of milk

$$R_{milk} = N_{ewe} \times MY \times p_{milk}$$

where revenues depended on the number of ewes (N_{ewe}), their milk production in 210 days of lactation (MY), and price of milk (p_{milk}).

B.1.2. Revenues for meat production

$$R_{lambs} = N_{lambs} \times BW_{35} \times p_{meat}$$

where revenues depended on the number of the lambs (N_{lambs}), their weight at 35 days of age (BW_{35}), and price of lambs meat (p_{meat}). Meat production was represented by the sale of lambs weaned at 35 days of age.

B.1.3. Revenues from ewes and rams culled

$$R_{ewe\_cull} = N_{ewe} \times \frac{1}{PLT_{ewe} + ASR} \times LW_{ewe} \times p_{cull}$$

$$R_{ram\_cull} = N_{ram} \times \frac{1}{PLT_{ram} + ASR} \times LW_{ram} \times p_{cull}$$

where N_{ewe} and N_{ram} were the number of adult ewes and rams; PLT_{ewe} and PLT_{ram} were the productive lifetime for ewes and rams; ASR was the survival rate of adult animals and it was not dependent on gender; LW_{ewe} and LW_{ram} were the mature live weight of ewes and rams; and p_{cull} was the price for culled ewes and rams. Culled animals were sold at fixed age for slaughtering, and no distinction was made between males and females.

B.2. Calculation of costs

B.2.1. Costs for ewes

$$C_{ewe} = N_{ewe} \times \left(\left[\frac{ME_{ewe}}{EC} \times p_f\right] + VC_{ewe}\right)$$

where N_{ewe} was the number of adult ewes, ME_{ewe} was the total metabolizable energy needed for maintenance, pregnancy, and lactation expressed in Mcal, EC the energy content of food expressed in Mcal per kilogram of dry matter, p_f was the price of food, and VC_{ewe} was the veterinary costs that included parasite and mastitis cares.

B.2.2. Costs for rams

$$C_{ram} = N_{ram} \times \left(\left[\frac{ME_{ram}}{EC} \times p_f\right] + VC_{ram}\right)$$

where the same parameters as above were considered, except for ME_{ram} that was the total energy needed only for maintenance.

B.2.3. Costs for suckling lambs

$$C_{lambs} = N_{lambs} \times DMY \times p_m$$

where N_{lambs} was the number of suckling lambs, DMY was the daily milk production of the dams suckled by offspring and p_m was the price of milk.

B.2.4. Costs for replacement ewes

$$C_{er} = (DMY \times 60 \times p_m) + \left(\frac{ME_{er}}{EC} \times 305 \times p_f\right) VC_{er}$$

where ME_{er} was the total energy needed for maintenance and growth of replacement ewes, 60 and 305 were days, VC_{er} were the veterinary costs for vaccinations and parasites control of young animals.

B.2.5. Costs for replacement rams

$$C_{rr} = (DMY \times 60 \times p_m) + \left(\frac{ME_{rr}}{EC} \times 305 \times p_f\right) VC_{rr}$$

where the same parameters as above were considered and the lower case letter rr refers to replacement rams.

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