EVALUATION OF THE SMALL RUMINANT NUTRITION SYSTEM MODEL USING GROWTH DATA OF SOUTH AFRICAN MUTTON MERINO AND DORPER LAMBS.

by

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DECLARATION

"I declare that this dissertation submitted for the degree MSc Agric (Animal Nutrition), at the University of Pretoria, has not been submitted by me for a degree at any other University."

Anta Linsky

Pretoria

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SUMMARY

EVALUATION OF THE SMALL RUMINANT NUTRITION SYSTEM MODEL USING GROWTH DATA OF SOUTH AFRICAN MUTTON MERINO AND DORPER LAMBS

by

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The aim of this study was to evaluate the Small Ruminant Nutrition System (SRNS) model's performance predictions for lambs under South African conditions using growth and body composition data of early- (Dorper) and late-maturing (South African Mutton Merino), indigenous sheep breeds. The Cornell Net Carbohydrate and Protein System (CNCPS) biological model has consistently been modified to include recent information. This has led to the development of the SRNS model, but up to now the SRNS model has only been validated with European sheep breeds under European conditions.

Thirty two Dorper, 16 male and 16 female lambs, and 36 South African Mutton Merino, 18 male and 18 female lambs, were fed a grower diet for the experimental period of 60 days. Three groups of lambs of each breed were slaughtered as the lambs reached pre-determined target weights. The first group of 24 animals (slaughter group 1) was slaughtered at the onset of the experiment at a live weight of 20 kg. With the second group (slaughter group 2) the South African Mutton Merinos were slaughtered at an average weight of 35 kg and the Dorpers at an average weight of 30 kg. The last group (slaughter group 3) had an average weight of 50 kg for the South African Mutton Merinos and 40 kg for the Dorpers at slaughter.

Using the data from this trial, predictions of the average daily gain (ADG), feed intake (DMI), empty body gain and the composition of the empty body gain were used to evaluate the model. The animals were divided into three slaughter groups, based on growth stage, for the determination of body composition data. Energy value of gain (EVG), fat and protein content on a shrunk and empty body weight basis were compared with the corresponding values predicted by the SRNS. Growth composition of the lambs was determined by dividing them into two growth periods. Average daily gain and DMI were evaluated in the experiment, and results compared to the mean ADG and DMI predictions obtained from the SNRS model.

Two different equations were compared to estimate EVG and two sets of coefficients were also compared for the EVG. Five different equations were compared to estimate the efficiency of conversion of metabolisable energy (ME) to net energy (NE) for gain, k_g. The correction factor to adjust for the increase in the size of the visceral organs as nutrient intake increases and the coefficient for the effect of gender on maintenance requirements were tested for relevance of use in the SRNS. Overall, based on these evaluations it appears that the original SRNS model gave the best predictions when compared to any of the modifications tested.

With regards to ADG the model over-predicts the requirements of the lambs in the early growth stage and under-predicts the requirements of the lambs in the later growth stage. The DMI predictions that were made using the original SRNS were accurate. The evaluation of the SNRS predictions in relation to the composition of gain indicated that this model over-predicted both the fat and the protein content of gain. The predictions were accurate, however the precision was low. The low precision was probably due to the lack of variation in the measured range of fat and protein content of gain.

Before field application further studies and adjustments to the SRNS model is required, especially with regard to predictions on the fat and protein content of gain and over or under predictions of ADG during different growth stages of Dorper and South African Mutton Merino lambs.

LIST OF ABBREVIATIONS

a_1	Thermal neutral basal maintenance requirements (Mcal/kg of $SBW^{0.75}$)
a_2	Adjustment for previous temperature
ACT	Activity for horizontal and slope walking (Mcal/day of NE_m)
ADF	Acid detergent fibre
ADG	Average daily gain (kg/day)
ADL	Acid detergent lignin
AGE	Adjustment for age effect on maintenance requirements (years)
BCS	Body condition score
BW	Body weight (kg)
Ca	Calcium
CCC	Concordance correlation coefficient
CNCPS	Cornell Net Carbohydrate and Protein System
CP	Crude protein
DM	Dry matter
DMI	Dry matter intake (kg/day)
EBG	Empty body gain = 0.92 ADG (kg/day)
EBW	Empty body weight = 0.851 SBW (kg)
E_{fat}	Fat energy content of the EBG (Mcal/kg)
$E_{protein}$	Protein energy content of the EBG (Mcal/kg)
EVG	Energy content of EBG (Mcal of NE_g/kg)
Fat	Fat in the EBG (g/kg)
FBW	Full body weight (kg)
FCR	Feed conversion ratio (kg feed/kg live weight gain)
FL	Level of feeding in multiples of ME_m (Mcal/Mcal)
GE	Gross energy (MJ/kg DM)
k_m, k_g	Efficiency of conversion of ME to NE_m, NE_g, respectively
L	Level of feeding in multiples of ME_m minus one unit (Mcal/Mcal)
ME	Metabolizable energy (Mcal)
MEC	Feed or diet ME concentration (Mcal/kg of DM)
MEI	Metabolizable energy intake (Mcal/day)

ME_m	ME requirement for maintenance (Mcal/day)
MP	Microbial protein
MSPE	Mean squared prediction error
N	Nitrogen
NDF	Neutral detergent fibre
NE_m	Net energy requirement for maintenance (Mcal/day)
NE_{mcs}	NE_m required for cold stress (Mcal/day)
NPN	Non protein nitrogen
NSC	Non structural carbohydrate
***pe*NDF**	Physically effective fibre
P	Phosphorus
P	Body maturity index (kg/kg)
P – O	Predicted values minus observed values
Protein	Protein in the EBG (g/kg)
q_m	Metabolizablility of the diet (Mcal/Mcal)
RE	NE available for gain (Mcal/day)
Rep	Proportion of protein energy in RE (Mcal/Mcal)
RMSPE	Root of mean squared prediction error
SAMM	South African Mutton Merino
SBW	Shrunk body weight, defined as 96% of full body weight (kg)
SEM	Standard error of the mean
SRNS	Small Ruminant Nutrition System
SRW	Standard reference weight
TE	Total body energy (Mcal of NE)
TF	Total body fat (kg)
TMR	Total mixed ration
TP	Total body protein (kg)
UREA	Cost of excreting excess nitrogen as urea (Mcal of NE_m/day)
Z_1	16.5
Z_2	490
Z_3	0.12

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Chapter 1

Literature Survey

1.1 Introduction

Ruminant meat and milk play an important role in the human food supply chain. Ruminants have the ability to convert forages and feedstuffs unsuitable for human consumption into high quality foods, available for human consumption, under widely varying conditions around the world. There are many reasons for improving efficiency of ruminant nutrition, the most important factors are to reduce the use of scarce resources, improve productivity, and protect the environment. The overall production efficiency of ruminants can be improved by using biological models to predict feed utilization of ruminants in specific production settings and their nutrient requirements (Cannas, 2000).

Biological models such as the CNCPS for cattle and the SRNS for sheep are increasingly being used to fine-tune diet formulation and increase the efficiency of feed utilization. The SRNS has been developed in the USA and Europe, and the growth and carcass composition data used to generate prediction equations, were obtained from research studies using mainly European sheep breeds. The readiness for field application of the SRNS under South African conditions, therefore, have been questioned due to possible differences in growth and carcass composition of South African breeds when compared to European breeds. The aim of this study therefore was to investigate the possibility of improving model predictions using South African sheep breeds and then evaluate the growth predictions and application of the Small Ruminant Nutrition System.

1.1.1 Nutritional models for ruminants

Since World War II, models have been used in the fields of biomedicine, metabolism and nutrition to aid in the research and applications thereof (Baldwin, 1995; NRC, 2001). Models are representations of the reality and may be defined as an ordered way of describing knowledge of some 'real' system. Modeling is a technique to extend and apply a systematic approach to a complex object or problem (Rountree, 1977). In agriculture, models have been useful in ordering our knowledge into practical systems to describe nutrient requirements for feedstock. To a large extent, most research into nutrition of farm animals since the early 1900's has been used to build, evaluate and improve models of nutrient requirements (Lofgreen and Garrett, 1968; NRC, 2001).

In the new millennium, research and development of models of nutrient requirements and metabolism are of no less importance. All around the world it is critical for farmers and producers to use the most efficient way possible to raise food-producing animals. In order to achieve this, it is critical to be able to describe metabolic transactions, and their resultant effect on nutrient requirements. The building of a model involves imagination, intuition, and skill based upon the extension and application of biological principals (Sahin *et al*., 1991). Dynamic computer nutrition models provide input for refining feeding formulations by more precisely defining animal nutrient requirements. They also provide assimilation and quantification of a vast amount of nutrition and feeding information (Roseler, 1991).

There are many different types of models, with the type usually dependent on the objective (McNamara, 2004). Models are also developed for research purposes and so it is often useful to classify them into two broad categories, being either mechanistic models, that attempt to represent the underlying physiological and biochemical mechanisms that determine animal performance, and empirical models, that are predominately based on empirical relationships derived from animal experimentation data, looking at the performance of whole animals (McNamara, 2004). Ultimately, transferring knowledge of animal growth and feeds systemized by the model to the industry is just one of the major objectives for constructing animal models.

Like empirical formulae, empirical models describe the system at the same level at which the user sees or uses it, but by its nature cannot give much insight into the mechanism of action of the system. The NRC models for nutrient requirements are examples of models employing good empirical equations. These equations are very useful and are usually derived from many experiments. However, they cannot describe how the tissues use the net energy for maintenance (McNamara, 2004). They also cannot be continuous over the boundaries within which the data were assembled (NRC, 2001), as efficiencies are not linear for the entire range of milk production and feed intakes for productive functions, digestion, and maintenance. The introduction of more mechanistic elements and non-linear functions has improved the functioning of the models using empirical equations. In contrast, in more mechanistic models, equations describe energy requirements in terms of rates to reaction, for liver, gastrointestinal tissue, muscle and fat and then sum them to give the energy requirement for the whole body. At the level of the animal it is therefore mechanistic, as it helps explain the mechanism by which the body energy requirement was derived. At the organ level, it remains empirical (McNamara, 2004). The Cornell Net Carbohydrate and Protein System for cattle (CNCPS); (Fox *et al*., 1990, 1995, 2004) have successfully sought to improve on the accuracy of empirical models by introducing mechanistic elements.

Models can further be divided into static or dynamic. A model that describes a process at one time, even if the time is a growth or lactation phase over a period of time of several months, through an empirical equation, is static (McNamara, 2004). This is because it only provides a static picture of a certain period of time. A key characteristic of a dynamic model, on the other hand, is that it integrates change over time. The requirements of any animal for any time are always in part a function of what has happened or came before (McNamara, 2004).

1.2 The Cornell Net Carbohydrate and Protein System

The CNCPS for cattle (Fox *et al*., 1990, 1995, 2004) is a deterministic model that integrates empirical and mechanistic methods to predict animal requirements, nutrients that can be derived from feeds, and animal performance on a selected day during a production cycle. This nutrition model compares physiological and metabolic components that describe carbohydrate fermentation and protein degradation, feed intake, intestinal digestion, absorbed nutrients and their partitioning for tissue maintenance and growth, pregnancy, nutrient excretion (milk), and heat production (Fox *et al*., 2004; Reynoso-Campos *et al*., 2004).

In the CNCPS the feed protein and carbohydrates are portioned into fractions. The feed protein has three fractions: true protein, non-protein nitrogen (NPN), and unavailable protein (Van Soest *et al*., 1981). Non-Protein Nitrogen is Fraction A, true protein is fraction B and fraction C is the unavailable protein (Pichard and Van Soest, 1977). Based on rates of degradation in the rumen, fraction B is further divided into three sub-fractions: B1, B2 and B3 (Van Soest *et al*., 1981; Krishnamoorthy *et al*., 1983). Fraction B1 is rapidly degraded in the rumen, B3 is slowly degraded in the rumen because it is associated with the cell wall and B2 is fermented in the rumen and some escapes to the lower gut, depending on the rates of passage and digestion (Pichard, 1977; Van Soest *et al*., 1981; Krishnamoorthy *et al*., 1983).

Carbohydrates are, as is the case with proteins, classified according to their degradation rates. Fraction A (sugars and organic acids) is degraded fast in the rumen, fraction B1 (starch and soluble fibre) has an intermediate degradation rate, fraction B2 (digestible fibre) is degraded slowly and fraction C is unavailable cell wall (Sniffen *et al*., 1992). After the conclusion of this trial, the carbohydrate pools were expanded to four A fractions in the CNCPS v6.1 (Van Amburgh *et al*., 2010). Fraction A1 is for volatile fatty acids, fraction A2 is for lactic acid, fraction A3 is for other organic acids and fraction A4 is for sugars (Van Amburgh *et al*., 2010). The yield of fermentation end-products and microbial protein (MP)

are estimated by comparing the rate of protein hydrolysis with that of carbohydrate hydrolysis (Russel *et al*., 1992; Sniffen *et al*., 1992; Chalupa and Sniffen, 1993). This system is also used to estimate the rates of passage of the various microbial products and undigested feed out of the rumen. The model assumes that feed intake is constant, extent of digestion and rate of passage are functions of intake and all dry matter intake is either passed through the intestinal tract or digested (Fox *et al*., 1990).

1.3 The Small Ruminant Nutrition System

The ability of the structure of the CNCPS for cattle to account for widely varying animal characteristics, differences in feeds of diverse characteristics, fed at different levels of intake, and environmental effects, led it to be considered for modification to provide a sheep model, the CNCPS for Sheep (Cannas *et al*., 2004). Extensive reviews of published equations and report values were used to modify the components of the CNCPS model for cattle, which was considered inadequate for the sheep model. New equations were developed to adapt the CNCPS for sheep where the information available in the literature was inadequate (Cannas *et al*., 2004).

The CNCPS for Sheep lead to the development of the Small Ruminant Nutrition System (SRNS) (Cannas *et al*., 2007a, 2007b, 2008). The SRNS model accounts for energy and protein requirements of sheep and goats under diverse conditions.

Since data was collected and evaluated for this experimental trial there have been new developments to the SRNS model. Changes have been made to the environment, maintenance requirement and body reserve sub models. A sub model for goats for nutrient and energy requirements was also incorporated (As reported on the Mathematical Nutrition Models website http://nutritionmodels.tamu.edu/srns.html).

1.3.1 The SRNS growth model and possible improvements of this model

In this thesis the focus will be on lambs' growth requirements. The requirements of growth in the SRNS are estimated by integrating its supply and the maintenance requirement submodels with the growth model for sheep developed by CSIRO (1990). The resulting model uses the same set of equations for all sheep breeds (Cannas *et al*., 2004; Cannas *et al*., 2006). The main abbreviations used in the SRNS model are reported in Table 1.1.

The SRNS computes average daily gain (**ADG**) with equations based on the CSIRO (1990) (Eq. 1 to 4), with the modifications proposed by Freer *et al*. (1997).

$$ADG = \frac{RE}{EVG \times 0.92} \quad (1)$$

$$EVG = (6.7 + 2 \times (L - 1) + \frac{Z_1 - 2 \times (L - 1)}{1 + e^{-6 \times (P-0.4)}}) \times 0.239 \quad (2)$$

$$L = \frac{MEI}{ME_m} - 1 \quad (3)$$

$$P = \frac{FBW}{SRW} \quad (4)$$

where EVG is the energy content of empty body gain, Mcal/kg of empty body gain; L is the level of feeding relative to maintenance ME minus one unit, Mcal/Mcal; MEI is ME intake, Mcal/d; Z_1 is equal to 16.5; P is a maturity index; FBW is full body weight, kg; SRW is the FBW that would be achieved by a specific animal of a certain breed, age, sex and rate of gain when skeletal development is complete and the empty body contains 250 g of fat/kg (corresponding to BCS 2.8 to 3.0 in ewes using a 0 to 5 scale system); ADG is FBW changes, kg/d; RE is retained energy, i.e. NE available for gain, Mcal/d.

Table 1.1 Definitions for the abbreviations used in the equations (Cannas *et al*., 2004).

a_1	Thermal neutral basal maintenance requirements (Mcal/kg of $SBW^{0.75}$)
a_2	Adjustment for previous temperature
ACT	Activity for horizontal and slope walking (Mcal/day of NE_m)
ADG	Average daily gain (kg/day)
AGE	Adjustment for age effect on maintenance requirements (years)
EBG	Empty body gain = 0.92 ADG (kg/day)
EBW	Empty body weight = 0.851 SBW (kg)
E_{fat}	Fat energy content of the EBG (Mcal/kg)
$E_{protein}$	Protein energy content of the EBG (Mcal/kg)
EVG	Energy content of EBG (Mcal of NE_g/kg)
Fat	Fat in the EBG (g/kg)

FBW	Full body weight (kg)
FL	Level of feeding in multiples of ME_m (Mcal/Mcal)
k_m, k_g	Efficiency of conversion of ME to NE_m, NE_g, respectively
L	Level of feeding in multiples of ME_m minus one unit (Mcal/Mcal)
ME	Metabolizable energy (Mcal)
MEC	Feed or diet ME concentration (Mcal/kg of DM)
MEI	Metabolizable energy intake (Mcal/day)
ME_m	ME requirement for maintenance (Mcal/day)
NE_m	Net energy requirement for maintenance (Mcal/day)
NE_{mcs}	NE_m required for cold stress (Mcal/day)
P	Body maturity index (kg/kg)
Protein	Protein in the EBG (g/kg)
q_m	Metabolizablility of the diet (Mcal/Mcal)
RE	NE available for gain (Mcal/day)
Rep	Proportion of protein energy in RE (Mcal/Mcal)
SBW	Shrunk body weight, defined as 96% of full body weight (kg)
TE	Total body energy (Mcal of NE)
TF	Total body fat (kg)
TP	Total body protein (kg)
UREA	Cost of excreting excess nitrogen as urea (Mcal of NE_m/day)
Z_1	16.5
Z_2	490
Z_3	0.12

Furthermore, ME requirement for maintenance (**ME_m**) are computed by dividing the NE requirement for maintenance (**NE_m**) by the partial efficiency of conversion of ME_m to NE_m (**k_m**), as described by Cannas *et al*. (2004).The standard reference weight (**SRW**) is based on the recommendations of CSIRO (1990).

CSIRO (1990) suggests two values for the parameter Z_1 (Eq 2): 20.3 for the Set A growth parameters for sheep and most cattle breeds or 16.5 for the Set B growth parameters for European cattle breeds. In this model the value of 16.5 (Set B) was preferred to 20.3 (Set A) because most sheep breeds are leaner than the Merino breed from which CSIRO (1990) based the parameters of the growth curves (Cannas and Susmel, 2002). However, the choice between Set A and Set B would require appropriate experimentation.

This approach to predict the energy value of gain (**EVG**) reported in equation 2 was preferred to that of the NRC (1985) model (Eq. 5) and of the ARC (1980) model, specific for non-Merino males, which is also adopted by the AFRC (1995) system (Eq. 6). These growth models have been compared on the basis of literature data only (Cannas *et al*., 2006) and it would be important to do so experimentally within the framework of the SRNS.

$$EVG = (644 - 2.61 \times YBW) \times EBW^{0.75} \quad (5)$$

$$EVG = \frac{2.5 + 0.35 \times SBW}{0.92} \times 0.239 \quad (6)$$

where SBW is shrunk body weight (0.96 FBW), kg; EBW is empty body weight, kg; YBW is yearling BW of rams of the same breed, kg. As the yearling BW of young sheep is largely affected by the level of nutrition of the lambs, and thus a difficult value to estimate or find in the literature, the evaluation of Eq. 5 is problematic and led to abnormal values when previously tested (Cannas *et al*., 2006).

Retained energy (**RE**) is computed by the SRNS using ME available for growth (MEI minus ME_m) times the efficiency of conversion ME to NE_g ($\mathbf{k_g}$), as described in Eq. 7.

$$RE = (MEI - ME_m) \times k_g \quad (7)$$

where MEI is ME intake predicted by the SRNS, Mcal/d; ME_m is ME for maintenance, Mcal/d; and k_g is the partial efficiency of ME to NE_g.

For the prediction of k_g in Eq. 7 the SRNS (Cannas *et al*., 2004) uses the NRC (2000) equation (Eq. 8). However, the validity of this approach should be tested. This can be achieved by comparing the k_g of Equation 8 with other approaches, such as that of the ARC (1980) model (Eq 9), of the CSIRO (1990) model (Eq. 9 and 10 combined) and the theoretical equation developed by Tedeschi *et al*. (2004) (Eq. 11a) or a modification of this equation (Eq. 11b) proposed by Cannas *et al*. (2006). The latter assuming average deposition efficiency of 27% for protein and 68% for fat for growing lambs (Graham, 1980)

$$k_g = \frac{1.42 \times MEC - 0.174 \times MEC^2 + 0.0122 \times MEC^3 - 1.65}{MEC} \quad (8)$$

$$k_g = 0.78 \times q_m + 0.006 \quad (9)$$

$$k_g = 1.16 \times q_m - 0.308 \quad (10)$$

$$k_g = \frac{3}{4 + 11 \times REp} \quad (11a)$$

$$k_g = \frac{18.36}{27 + 41 \times REp} \quad (11b)$$

where MEC is dietary ME concentration, Mcal/kg; q_m (also called metabolizability) is the ratio of ME to gross energy (**GE**) in the diet, where for GE the CSIRO (1990) system assumes a mean value of 4.398 Mcal/kg of DM; and REp is the proportion of protein energy in RE, Mcal/Mcal.

The ARC (1980) model proposed Eq. 9 as valid for "all diets" and was adopted by the AFRC (1995) system. The CSIRO (1990) model uses two different equations, both originally proposed by ARC (1980), depending on the quality of the diet. CSIRO (1990) suggests that Eq. 9 should be used when q_m > 0.52 Mcal ME/Mcal GE, i.e. with diets based on spring growth of grass or legume pastures in a temperate climate or first growth of annual pastures in a Mediterranean climate. Equation 10 should be used when q_m < 0.52 Mcal ME/Mcal GE, i.e. with diets composed of mature temperate and Mediterranean pastures, annual legumes and for all other pastures and forages at all stages of growth, including tropical and subtropical grasses and legumes as well as forage crops such us sorghum. Equation 10 was proposed by ARC (1980) as valid for "aftermaths" of forage based diets.

Equations 8 to 11 have been tested by Cannas *et al*. (2006) by using literature data. The results showed that Eq. 11b gave the best ADG predictions. However, a more extensive evaluation based on experimental data would be necessary.

Equation 9 and 10 require the prediction of the ratio of ME to GE at maintenance feeding level ($\mathbf{q_m}$), with ME being that predicted by the SRNS. However, this system predicts ME at the actual feeding level, not at the maintenance feeding level. Thus, the ratio of ME to GE at actual feeding level ($\mathbf{q_L}$), as predicted by the SRNS, will be adjusted assuming a maintenance feeding level by rearranging an equation (Eq. 3.3 of ARC, 1980) proposed by Blaxter (1969 cited by ARC, 1980):

$$q_m = \frac{q_L + 0.1246 \times L - 0.1246}{0.8 + 0.2 \times FL} \quad (13)$$

where q_m is the ratio between ME and GE in which ME is estimated at maintenance feeding level; FL is the feeding level, i.e. the ratio between total energy intake and maintenance energy requirements, Mcal/Mcal; and q_L is the ratio between ME and GE in which ME estimated at any feeding level.

Equation 11a and 11b require the calculation of the proportion of retained energy as protein (**REp**). The energy content of fat and protein in the gain can be calculated using the equations reported by CSIRO (1990) and modified by Freer *et al*. (1997). First, the fat and protein composition in the empty gain is estimated:

$$EBG_{Fat} = (43 + 56 \times (L - 1) + \frac{Z_2 - 56 \times (L - 1)}{1 + e^{-6 \times (P-0.4)}}) \quad (13)$$

$$EBG_{Protein} = (212 - 8 \times (L - 1) - \frac{Z_3 - 8 \times (L - 1)}{1 + e^{-6 \times (P-0.4)}}) \quad (14)$$

where Z_2 and Z_3 are parameters equal to 490 and to 0.12, respectively (Set B of CSIRO, 1990); and EBG_{fat} and $EBG_{protein}$ are respectively the fat and protein content of the EBG, g/kg EBG.

Then, the energy accumulated in the gain as fat (E_{fat}) and protein ($E_{protein}$) is calculated and REp is computed as $E_{Protein}/(E_{Fat} + E_{Protein})$:

$$E_{fat} = EBG_{fat} \times 9.4 \times 0.001 \quad (15)$$

$$E_{protein} = EBG_{protein} \times 5.7 \times 0.001 \quad (16)$$

where E_{fat} and $E_{protein}$ are respectively the fat and protein energy content of the EBG, Mcal/kg EBG.

In the SRNS the energy requirements for basal metabolism, expressed as ME_m, are adjusted for age, physiological state, environmental effects, activity, urea excretion, acclimatization and cold stress in order to estimate total NE_m and ME_m as shown in Eq 15.

$$ME_m = ((SBW^{0.75} \times a1 \times a2 \times \exp(-0.03 \times AGE)) + (0.09 \times MEI \times k_m) + ACT + NE_{mcs} + UREA) / k_m \quad (17)$$

where ME_m is in Mcal/d; and $SBW^{0.75}$ is metabolic shrunk body weight, kg. The factor a1 in Eq. 17, the thermal neutral maintenance requirement per kg of metabolic weight for fasting metabolism (CSIRO,

1990), is assumed to be 0.062 Mcal of $NE_m/kg^{0.75}$. This value is corrected for the effect of age on maintenance requirements, using the CSIRO (1990) exponential equation exp(-0.03 × AGE), where AGE is in yr, which decreases the maintenance requirements from 0.062 Mcal to 0.052 Mcal of NE_m per kg of $SBW^{0.75}$ as the animal ages from 0 to 6 yr. The requirements of animals 6 yr of age or older are similar to those of NRC (1985), INRA (1989), and AFRC (1995). The factor a2, an adjustment for the effects of previous temperature, is (1 + 0.0091 × C), where C = (20 - Tp) and Tp is the average daily temperature of the previous month (NRC, 1981). The term (0.09 × MEI × k_m) is based on the CSIRO (1990) adjustment to account for the increase in the size of the visceral organs as nutrient intake increases. The efficiency coefficient k_m is fixed at 0.64. The ACT factor in Eq. 17, in Mcal of NE_m/d, is the effect of activity on maintenance requirements and is fully described in Cannas *et al.* (2004). The factor a1 further includes the minimum activity for eating, rumination and movements of animals kept in stalls, pens, or yards (CSIRO, 1990). NE_{mcs} factor in Eq. 17 is based on the CSIRO (1990) model to estimate the extra maintenance energy required to counterbalance the effect of cold stress (Cannas *et al.*, 2004). The factor UREA, which accounts for the energy cost of excreting excess N as urea, is also fully described in Cannas *et al.* (2004).

Among the factors that modify basal maintenance requirements, and thus energy available for gain, in the SRNS, the MEI adjustment (0.09 × MEI × k_m) has a major impact (Cannas *et al*., 2006). For this reason, its effects on maintenance energy requirements (Eq. 17), and subsequently RE (Eq. 7), should be tested by using the complete original form of Eq. 17 or by excluding this factor.

The CNCPS for sheep also included an adjustment factor (**S**; Eq. 18), a multiplier for the effect of gender on maintenance requirements. It was assumed that S was 1.0 for females and castrates and 1.15 for intact males, based on ARC (1980). This adjustment was also adopted by the CSIRO (1990) system, but it was excluded by an update of it (Freer *et al*., 1997). This gender adjustment was also not supported by experiments carried out on sheep (Bull *et al*., 1976; Ferrell *et al*., 1979). In addition, an evaluation of the CNCPS for sheep showed that the S factor brought an underestimation of lamb growth rate, thus it was excluded by the SRNS, this coefficient requires further testing to evaluate its biological significance and importance.

$$ME_m = ((SBW^{0.75} \times a1 \times a2 \times S \times \exp(-0.03 \times AGE)) + (0.09 \times MEI \times k_m) + ACT + NE_{mcs} + UREA) / k_m \quad (18)$$

where the variable are as for Eq. 17, except for S, which is 1.0 for females and castrates and 1.15 for intact males.

1.3.2 Inputs required by the SRNS

The SRNS equations described above are implemented in specific software, (As reported on the SRNS website http://nutritionmodels.tamu.edu), and requires a series of inputs hereby described. Some of them are specific for adult animals (e.g. milk yield and composition) and are not required for lambs.

1.3.2.1 Animal and environmental factors

Animal type: Category of animals for which the diet is being evaluated. Lambs are growing animals less than 1 year old.

Age: Mean age of the group of animals for which the diet is evaluated. This affects energy maintenance requirements, which are decreased by 16% as age increases from 0 to 6 years.

Body Condition Score (BCS): Current body condition score of adult animals; scale 0 – 5. This affects body fat and protein reserves and the cost of their variation.

Body Weight: Current shrunk body weight (SBW) or full body weight (FBW), where SBW = 0.96 FBW. This affects requirements for maintenance, body reserves and feed passage rate. FBW can be predicted for any Body Condition Score (BCS) as follows:

$$FBW = (0.594 + 0.163 \times FBW @ BCS\ 2.5)$$

where FBW @ BCS 2.5 is the mature weight of ewes of a certain breed, population or flock of ewes at BCS equal to 2.5.

Clean Wool Production: Production of clean wool per year. It affects MP requirements.

Current temperature: Current mean daily (24 h) air temperature (ºC). This affects maintenance requirements for cold stress.

Days pregnant: Number of days since mating. This determines the stage of pregnancy and affects pregnancy requirements, which are particularly important in the last 60 days of pregnancy.

Horizontal distance: Daily distance walked by sheep every day on flat surfaces. The minimum horizontal distance can be estimated on the basis of the distance between the farm and pasture fields. This affects maintenance requirements for movement.

Lamb birth weight: Expected lamb birth weight, (for lambing with twins or triplets, this is the sum of the birth weights of all lambs from the same lambing). This affects pregnancy requirements.

Milk production: Daily milk yield (predicted or measured). This affects energy requirements of lactation.

Milk fat: Measured percentage of fat in the milk for a particular day of lactation. This affects energy requirements for lactation.

Milk true protein: Measured percentage of true milk protein for a particular day of lactation. If only total milk CP (N x 6.38) is known, consider milk true protein = 0.95 total milk CP. This affects protein requirements of lactation.

Previous temperature: Previous month average daily temperature (ºC). This affects maintenance requirements, because animals adapt to either low temperatures, by increasing their metabolic rate and requirements, or to high temperatures, by decreasing their metabolic rate and requirements.

Rainfall: Only for sheep kept outdoors, this influences resistance to cold (rainfall reduces wool thermo insulation).

Standard Reference Weight as BCS 2.5: The FBW that would be achieved by a specific animal of a certain breed, age, sex and rate of gain when skeletal development is complete and BCS is 2.5. FBW @ BCS 2.5 is used to estimate FBW at any other BCS:

$$FBW = (0.594 + 0.163 \times BCS) \times FBW @ BCS\ 2.5.$$

Rearranging this equation, it is possible to estimate FBW @ BCS 2.5 when current BCS and BW are known:

$$FBW @ BCS\ 2.5 = current\ BW / (0.594 + 0.163 \times BCS).$$

In addition, the ratio between current FBW and FBW @ BCS 3.0 determines the composition of gain (% of fat, protein, water, minerals) and thus the growth requirements of lambs.

Wind speed: Measured at ground level, influences resistance to cold (winds reduces wool thermal insulation).

Wool Depth: Depth of the wool measured perpendicular to skin surface. This affects thermo insulation of sheep and therefore cold stress requirements.

Vertical distance: The vertical component of the movement. This affects maintenance requirements for movement.

1.3.2.2 Nutritional inputs required by the SRNS

The SRNS requires the same specific information on feed composition requested by the CNCPS for cattle. In addition, the SNRS utilize the same feed library as appearing in the CNCPS for cattle (Fox *et al.*, 2004).

The SRNS has specific equations to predict DMI of sheep and goats. In the case of lambs, DMI is predicted by using the equations published by Pulina *et al*. (1996):

$$DMI = -0.124 + 0.0711 \times FBW^{0.75} + 0.0015 \times FBW_C \quad (19)$$

where: DMI is DM intake, kg/d; FBW is full-body weight, kg; and FBW_C is FBW changes, g/d.

1.3.3 Output of the SRNS

Based on the inputs used, the SRNS produces an output in which the requirements of the animals and the ration are reported and evaluated.

1.3.3.1 Energy, protein and mineral balances

For all categories of sheep, the first table of the results shows energy, protein, calcium (Ca) and phosphorus (P) balance. Energy balance is estimated as the difference between ME intake and ME requirements. The SRNS calculates specific NE requirements for each function. These requirements are then converted to ME using a specific conversion efficiency of ME to NE for each physiological function. The energy available for growth (young sheep) or for body reserves changes (mature ewes or rams) depending on the energy balance. Regarding MP balance, when it is positive, the MP in excess is converted to urea and contributes to urea cost (see section 1.3.3.4).

1.3.3.2 Lambs' growth rate and composition of the gain

The energy available for growth (lambs and young sheep) depends on the energy balance after maintenance requirements are satisfied, i.e. depends on the retained energy (Eq. 7). Based on this and on the model described in paragraph 1.3.1.1, the SRNS predicts the average daily gain (**ADG**) and the

empty body gain (**EBG**; i.e. gain without the contribution of the content of the gastro-intestinal tract) of the lambs. In addition, the SNRS predicts the composition (on an ADG or EBG basis) of the gain.

1.3.3.3 Rumen conditions

Rumen pH is predicted as a function of the intake of physically effective fibre (peNDF) compared to the required peNDF. The SRNS can not account for the direct effect of NSC on rumen pH and assumes that TMR diets with frequent meals are used. When pH is reduced, there is a reduction in the available NDF degradation rate and also in microbial efficiency (Tedeschi *et al*., 2000).

Rumen N balance predicts whether rumen bacteria N requirements are satisfied. When rumen N balance is positive, excess nitrogen is excreted as urea and contributes to urea cost (see section 1.3.3.4). When rumen N balance is negative, the SRNS reduces feed digestibility and feed energy compared to diets which provide a positive rumen N balance. To maximize intake, feed digestibility and animal performance, rumen N balance should be positive.

1.3.3.4 Protein digestibility and microbial synthesis

Daily MP intake is the sum of MP derived from escape protein (feed MP) and bacteria proteins (bacteria MP) digested in the intestine. Bacteria MP are usually cheaper and of higher biological value than feed MP, for this reason it should be optimised.

Urea cost represents the energetic cost of converting excess N to urea. Excess nitrogen is the sum of rumen N in excess to bacteria needs and MP in excess to animal needs. Urea cost is added to energy maintenance requirements and therefore has a negative impact on animal performance.

1.3.4 Use and applications of the SRNS

The SRNS, as the CNCPS for cattle, can be applied by the commercial feed industry as a valuable educational tool for field staff and nutritionists, to develop tables of requirements and biological values for feeds that cover a wide range of conditions and as a tool for identifying, interpreting, applying and planning critical experiments and input in evaluating research concepts. The model is furthermore a supplement to current formulation schemes by providing precise feed protein degradability and energy values, quantification for adjustment in nutrient requirements for specific groups of animals, a key

diagnostic instrument in diagnosing client-customer problems, optimizing animal productivity and in predicting performance and profits (Fox *et al*., 2004).

When evaluating the suitability of feeds as pasture supplements the SRNS, as the CNCPS for cattle, can prove very useful, due to its ability to predict microbial yield, which allows for a more accurate accounting of protein derived from a feed. The SRNS also allows for economic quantification of the effects of environmental and management factors on animal performance, a feature useful in making management decisions such as how far paddocks can be from the barn without negatively impacting profitability, or at what temperatures provision of shade becomes profitable (Cerosaletti *et al*., 1998).

1.4 A description of the sheep breeds chosen to evaluate the SRNS

Southern Africa, like the majority of the developing world, has a rapidly growing human population. This increase has resulted in a corresponding increase in demand for meat, specifically mutton (Schoeman, 2000). For several decades sheep production was primarily aimed towards wool production, however, over the past three decades, this has changed owing to the high demand for mutton and lamb, the meat versus wool price structure as well as input costs (Schoeman, 2000). The sheep industry, similar to the dairy and beef industry, is a competitive industry and it is of the utmost importance to fine-tune diets for optimal utilization of nutrients and limiting environmental pollution. Validation of the SRNS, under sub-tropical conditions, is therefore of great importance.

The sheep breeds used in this study were the early maturing Dorper and the late maturing South African (**SA**) Mutton Merino.

1.4.1 South African Mutton Merino (Late maturing breed)

1.4.1.1 Origin of the breed

The breed was originally known as the German Mutton Merino. The first ram and ten ewes were imported to South Africa from Germany in 1932 by the department of Agriculture, for a breeding program. In 1971 the uniqueness of the South African breed was recognized when the name changed to the SA Mutton Merino. The SA Mutton Merino is a dual-purpose mutton-wool sheep (80:20 mutton to wool), originally bred for its high adaptability to all farming regions in South Africa. The breed was developed to produce a heavy slaughter lamb at an early age as well as good quality wool (SA Mutton Merino Studbook, 2001).

1.4.1.2 General description

The SA Mutton Merino is the most successful mutton breed in South Africa in terms of growth rate. Average gross feed conversion ratio is 3.91:1 (in finishing lambs), with the optimum rate being achieved between 25 kg and 42 kg live mass. On average mature ewes have a mass of 77 kg and rams 127 kg. SA Mutton Merino ewes typically achieve a lambing percentage of 150% (SA Mutton Merino Studbook, 2001).

The breed excels under all climatic conditions and is known for its strong constitution and its adaptability to a wide variety of environmental conditions. The latter has been a major factor for explaining its popularity. Fat deposition only occurs at a later age and therefore the later-maturing breeds have the advantage of producing carcasses with optimal fat thickness and distribution at a heavier live weight (Schoeman, 2000).

Table 1.2 Breed and performance information of the SA Mutton Merino (SA Mutton Merino Studbook, 2001)

AVERAGES	MALE	FEMALE
Mature weight (kg)	127 kg	77 kg
Birth weight (kg)	4.1 kg	3.8 kg
100 – day weight (kg)	32 kg	29 kg

1.4.2 Dorper (Early maturing breed)

1.4.2.1 Origin of the breed

More than 50 years ago the Department of Agriculture and some farmers decided to develop a sheep breed that can produce a maximum number of lambs, with good mutton qualities and which could be marketed off arid and extensive grazing conditions. The breed was developed through the crossing of the Blackhead Persian ewe with the Dorset Horn and this resulted in the birth of some white Dorper lambs. Dorpers can be completely white or can have black heads. This difference in colour is a matter of preference for each breeder (Dorper Studbook, 2001).

1.4.2.2 General description

Dorper sheep are regarded as early maturing, they tend to fatten at an early age. Dorper lambs put on more localized fat at an early age and as such at lower live weights than later maturing breeds (Schoeman, 2000).

The Dorper is hardy and well adapted to a variety of climatic and grazing conditions and can thrive under poor veld conditions. As a strong and non-selective grazer, the Dorper can be incorporated advantageously into any well-planned veld management system.

Table 1.3 Breed and performance information of the Dorper (Dorper Studbook, 2001)

AVERAGES	MALE	FEMALE
Mature weight (kg)	73.0	61.0
Birth weight* (kg)	4.4	4.06
100-day weight (kg)	31.3	28.6

*Birth weight will be lower if lambs were born as twins.

1.5. Specific objectives of this research project

This project was conducted with the general objective of evaluating the predictions and the applicability of the SRNS under South African conditions. The growth rates and carcass composition of the two sheep breeds used in this study were the early maturing Dorper and the late maturing South African (SA) Mutton Merino.

During the modelling exercise, the specific objectives were to evaluate the prediction of the SRNS on the ADG, EBG and composition of the gain (Eqs. 1, 13, 14) by using:

1. Two different sets of coefficients (Set A versus Set B) for equation 2;
2. Two different equations (Eq. 2 and 6) proposed to estimate the energy value of the gain;
3. Five different equations (Eqs. 8, 9, 10, 11a and 11b) proposed to estimate k_g, the efficiency of conversion of ME to NE for gain;
4. The correction factor $0.09 \times MEI \times k_m$ in equation 17;

5. The coefficient S (1.0 for females and castrates and 1.15 for intact males) of Eq. 18, originally used in the CNCPS for sheep.

In addition, the predictions of the SRNS on lambs' DMI (Eq. 19) were evaluated.

Chapter 2

Materials and Methods

2.1 Introduction

This study was conducted to evaluate the SRNS model for sheep under South African conditions using early- maturing (Dorper) and late-maturing (SA Mutton Merino) indigenous sheep breeds. The growth of the two groups of lambs was monitored and groups of lambs slaughtered at specific growth stages. Carcass composition was subsequently determined and the resulting data utilised for evaluation of the SRNS model. The study was approved by the Animal Use and Care Committee of the University of Pretoria.

2.2 Material and Methods

2.2.1 Experimental animals and location

Thirty two Dorpers, 16 male and 16 female animals and 36 South African Mutton Merinos consisting of 18 male and 18 female animals were used in the experiment. The Dorpers originated from the Kenhardt region in the Northern Cape and the SA Mutton Merinos from the Bloemfontein District, in the Free State Province. The trial was conducted at the Hatfield Experimental Farm of the University of Pretoria, Pretoria, South Africa (28º15'30''E, 25º44'30''S), at an altitude of 1360 m. This is a summer rainfall area, with Table 2.1 illustrating the monthly averages as recorded by the South African Weather Service.

2.2.2 Experimental design

Two breeds were used, a late maturing breed, the SA Mutton Merino, and an early maturing breed, the Dorper. Within each breed there were three slaughter groups. Both male and female animals were used. For each breed the first and third slaughter groups consisted of 12 animals (6 female and 6 male lambs) and the second slaughter group of 8 animals, 4 female and 4 male sheep (per breed), i.e. a group of 64 animals in total. Body weight was used as the selection criterium for the slaughter groups.

The initial slaughter group of 24 animals, 12 per breed, (average live weight of 20 kg) was slaughtered at the onset of the experiment. Within the second slaughter group the SA Mutton Merinos were slaughtered at an average weight of 35 kg and the Dorpers at an average weight of 30 kg. The last slaughter group had an average weight of 50 kg for the SA Mutton Merinos and 40 kg for the Dorpers at slaughtering.

Body weights were recorded once a week and individual feed intake every day. Body condition score was determined once during the trial, the day before the lambs was slaughtered.

Table 2.1 The monthly average temperatures and precipitation for Pretoria (25º 44' S, 28º 11' E) (South African Weather Service)

Month	Temperature(ºC)				Precipitation
	Highest Recorded	Average Daily Maximum	Average Daily Minimum	Lowest Recorded	Average Monthly (mm)
January	36	29	18	8	136
February	36	28	17	11	75
March	35	27	16	6	82
April	33	24	12	3	51
May	29	22	8	-1	13
June	25	19	5	-6	7
July	26	20	5	-4	3
August	31	22	8	-1	6
September	34	26	12	2	22
October	36	27	14	4	71
November	36	27	16	7	98
December	35	28	17	7	110
Year	**36**	**25**	**12**	**-6**	**674**

2.2.3 Diets and feeding

The lambs were initially fed an adaptation diet. At the onset of the experimental period, the lambs were switched to the experimental (grower) diet (Table 2.2). The lambs were individually fed twice daily at approximately 08h00 and 14h00. The amount of feed supplied was adjusted daily, based on previous day's consumption. The intake was measured, 09h00 daily, by weighing the orts left in the feeder. After that, the orts were discarded. Due to the occurrence of problems in the quality of the pellets at the

onset of the experimental period (short roughage particle size), some cases of sub-clinical acidosis occurred. The lambs were subsequently fed with grass hay for a week (from week 3 to week 4); while a new grower diet with longer fibre particles was prepared. Starting from experimental day 29, all the lambs were fed the new grower diet, which was well consumed by the lambs and no further problems occurred. Water was available freely in each pen during the whole trial period.

Table 2.2 Ingredients of adaptation and grower diets

Ingredient	Adaptation Diet (%)	Grower Diet (%)
Lucerne Hay	50.00	27.00
Maize Meal	6.85	10.00
Hominy Chop	28.77	42.00
Cottonseed Oilcake Meal	4.11	6.00
Urea	0.34	0.50
Salt	0.27	0.40
Molasses (Syrup)	4.11	6.00
Wheat straw	4.11	6.00
Sodium bicarbonate	0.34	0.50
Ammonia-chloride	0.34	0.50
Limestone	0.75	1.10
Premix	0.01	0.01
TOTAL	**100**	**100**

2.2.4 Care of the animals

The experimental animals arrived at the experimental farm one week before the onset of the trial and had free access to Lucerne hay and water. Two weeks before placing the lambs in the housing unit, it was cleaned and disinfected. All the lambs were vaccinated with the following inactivated vaccines:

-Tetanus Vaccine, 1 ml subcutaneous, Onderstepoort Biological Products (OBP), Pretoria, South Africa.

- Pasteurella Vaccine for Sheep and Goats, 2 ml subcutaneous, OBP, Pretoria, South Africa.

- Pulpyvax, 1 ml subcutaneous, Intervet ,Isando, South Africa.

All the lambs were treated for internal parasites using Ivomec at 2.5 ml/10 kg body weight (Merial, Midrand, South Africa). The SA Mutton Merinos were docked using a gas burner on the same day that they were placed in the housing unit and a week after they received the tetanus vaccine. The Dorper lambs had already been docked on the farm of origin. Both breeds were placed in the housing unit at the same time. The pen sizes were 8 m^2, but were divided into two 4 m^2 pens for the first period of the trial.

As sheep are herd animals, separating them can potentially cause stress. During the first period of the trial the lambs were therefore paired in the pens in order to prevent them from attempting to jump out of the pens and injuring themselves. After the first group was slaughtered the animals were placed in individual pens since they had adapted to the pens by that time. They were given fresh Lucerne and water twice every day, in the morning and afternoon. After the adaptation period they received feed and fresh water twice a day. The feed was weighed the previous day and kept in sealed plastic bags to prevent variation in moisture content. The diet was given to the sheep in pellet form. Pens were cleaned two to three times a week.

During the beginning of the trial (early March) the sheep became infected with the bluetongue virus. The bluetongue virus shows seasonal variation because of the variation in occurrence of the vector (midges). Midges (*Culicoides* spp.) hatch when the conditions are warm and humid and act as vectors for the virus. Common symptoms of infection with the virus are high fever, loss of appetite and lethargy. The lips of the animals swell and the mucus membranes of the mouth, nose and eyes become red. Ulcers form on the mucus membranes of the mouth that makes it painful for the animal to eat. Inflammation of the nasal mucosa leads to a watery nasal discharge which becomes mucopurulent and eventually forms crusts which interferes with breathing. As a result of the lung oedema associated with bluetongue virus, the animals were handled as little as possible during this period. The housing unit and the lambs were sprayed with Delete X5 twice a week. Delete X5 is a product of Intervet, (Isando, South Africa), and its active ingredient is 5% Deltamethrin. The lights were switched off at night from the time the first lambs were diagnosed up to the end of the trial. The infected lambs were also treated with Norotrim and Phenylbutazone. Norotrim 24 is a trimethoprim-sulpha (containing 200mg Sulphadiazine and 40mg trimethoprim / ml) and is a product of Norbrook (Norbrook Laboratories (Pty) Ltd, PO Box 10698, Centurion). Animals infected with the bluetongue virus are

susceptible to secondary bacterial infections like pneumonia and Norotrim is very effective in the respiratory system. Phenylbutazone is a non-steroidal anti-inflammatory drug (NSAID) and was administered to combat the pain, fever and inflammation generally associated with bluetongue. This, together with the Replenisol, an electrolyte replacement and vitamin supplement that was added to their drinking water, was given to stimulate their appetite and speed up their recovery.

Overall, four Merino's died and none of the Dorpers. This is not unexpected since it is generally known and accepted that indigenous sheep breeds like the black headed Persian, Dorper and Karakul are less severely affected by the bluetongue virus than European sheep breeds like the Merino.

2.2.5 Slaughtering procedure

Before the lambs were slaughtered they were sheared using a Sunbeam Model EH sheep shearing machine, leaving behind 2 – 5 mm of wool. All the wool was collected and put in sealed plastic bags. The weight of the wool was recorded and reference values used.

As soon as the lambs reached their appropriate slaughter weight (± 1 kg) they were transported to the Irene abattoir, Centurion, after dawn, where they were slaughtered using standard South African techniques and conditions. This entailed the lambs being electrically stunned after which the jugular veins were severed and bled into a container of known mass. Great care was taken to ensure that all the blood was collected. The carcasses were then eviscerated and the rumen pH was determined as soon as possible. The rumen pH was determined by taking three measurements with a digital handheld meat pH meter (Sentron, Model 1001, Integrated Sensor Technologies, The Netherlands) and calculating the average of the three values.

Each lamb carcass was left intact (head, skin, hooves) with the exception of the intestines, and put in a plastic bag (of known mass) with the measurements of 800 by 1050 mm and thickness of 175 microns. The skin was kept attached to ensure that it remained with the carcass for chemical composition analyses and to minimize moisture loss. The sides of the bags were sealed with industrial strength tape to ensure no moisture was gained or lost. The intestines were washed and left to dry before it was placed in plastic bags (of known mass) with the measurements of 400 by 700 mm and thickness of 100 microns. The sides were also sealed in the same way as was done for the carcasses. The warm carcass and intestine masses were recorded separately before it was chilled for 24 hours at a

temperature of 4 ºC. The cold carcass and intestine weights were recorded after the 24 hour period and from there the carcasses and intestines were placed in a freezer room with a constant temperature of -20 ºC on site at the Irene abattoir. Once the slaughtering of all treatment groups were completed, all the carcasses were moved to a freezer room at the University of Pretoria Hatfield Experimental Farm for further processing. The Slagelse Denmark Wolfking Carcass Mill was kept in the experimental farms abattoir, the efficiency and ease of the milling process was increased by storing the carcasses on site.

The carcasses were divided on the median line, along the length of the neck and the spine, into two replicas. The left and the right sides were placed in separate water resistant bags, and placed back in the freezer at -20 ºC. Before milling the carcasses the components were sawed into 50 by 100 mm blocks. This increased the ease with which the components could be minced and ensured a homogeneous end product. The components were minced using the Slagelse Denmark Wolfking Carcass Mill with two sieves of 5 mm and 12 mm (Slagelse, Denmark) respectively. The carcass- and intestine components were minced separately. The components were further milled five times to ensure proper mixing of all the different entities. Freezing the components beforehand ensured that the fat and the meat mixed properly and minimized the wastage of the fat that stuck to the sides of the mill. It also increased the homogenity of the minced product.

2.2.6 Sample collection

A representative sample of between 0.8 – 1.0 kg was collected from carcass and intestine components, by randomly taking a number of grab samples throughout the complete final minced product. The minced product was continuously mixed to ensure that the moisture did not accumulate at the bottom and to ensure a homogeneous end product. The sample was immediately taken to Nutrilab, on the main campus of the University of Pretoria, for dry matter determination.

2.2.7 Preparation of samples for chemical analysis

The samples were freeze-dried to a moisture content of approximately 1 %. After the freeze-drying the samples were further processed in a food processor by chopping it into small pieces to make it more homogenous and ensure that samples collected for analysis are representative of the total sample. These sub-samples were then placed back in the water resistant plastic bag and stored at -20 ºC.

2.2.8 Chemical analysis

2.2.8.1 Carcass analysis

Determination of dry material- (DM), nitrogen- (N), energy-, ether extraction-, and ash determinations were done in triplicate on the freeze dried samples. These determinations were done on the samples that came directly after mincing from the Denmark Wolfking Carcass Mill in the abattoir on the experimental farm.

DM was determined by placing the samples in crucibles in a 100 ºC ventilated oven at a constant mass to dry. The dried samples were placed in a Labcon Muffle Furnace Type RM4 for ash determination at a temperature of 600 ºC. Because of the high fat content of the samples and in order to prevent sample loss, the furnace temperature was initially set at 250 ºC for the first hour and then at 600 ºC for the next 5 hours. Ether extraction after acid hydrolysis was analysed according to the AOAC (2000) procedure. Samples ± 3 g for the Buchi 810 Soxhlet (boiling point 40 ºC - 60 ºC) apparatus (Postfach, Switserland) and ± 2 g for the Soxtec System HT 1043 Extraction Unit (boiling point 60 ºC – 80 ºC) apparatus (Hoganas, Sweden) were weighed. The samples were folded in Whatman Filter papers and placed in Whatman cellulose extraction thimbles and placed into the apparatus. Crude protein analysis was done according to AOAC (2000) procedure 968.06. Energy determination was done by weighing out a sample of approximately 0.3 g weight and burning it in the MC-1000 Modular Bomb-Calorimeter (Moline, Illinois).

2.2.8.2 Feed analysis

Samples of individual feed components were analysed at the University of Sassari, Italy, for a complete CNCPS wet chemistry feed analysis. Feed samples were analyzed for NDF after urea (8 Mol/litre) treatment and without sodium sulfite (Van Soest *et al*., 1991), ADF and acid detergent lignin (Goering and Van Soest, 1970), ash, CP (AOAC, 2000), and CP fractions (Licitra *et al*., 1996).

The NDF particle size was measured by boiling approximately 20 g of each component for 1 hour in a NDF solution with 1 ml of α-amylase. Thereafter, samples were washed with distilled water and dried at room temperature. The feeds rich in starch were pre-treated by immersing them in a solution of 8M urea overnight. The peNDF of the feeds with larger particle size was measured by dry sieving the NDF fraction resulting from the above mentioned treatment with a vertical shaker (Endecotts Octagon 2000).

A series of 6 screens was used (Table 3.2 in the following chapter). The peNDF was calculated by multiplying the proportion of the NDF fraction retained on a 1.18 mm sieve size screen or on the screens with larger sieve size, by the NDF concentration of the feed (Table 3.1 in the following chapter). Despite all treatments applied, the grower diet, which was in a pelleted form, did not filter through the screens.

2.2.9 Statistical analysis

An analysis of variance was performed on the data using the GLM model (Statistical Analysis Systems, 2007) to determine the significance of potential differences between the different breeds, sex, periods for internal offal, external offal and carcass compositions for the balanced data. The response variables were the protein, fat, ash, energy contributions and growth performance. Means and standard error of the means (SEM) were calculated.

Significance of difference (5%) between means was determined by Fisher's test (Samuels, 1989).

2.3 Evaluation of the SRNS predictions on ADG and composition of the gain of the lambs

The information obtained in the experiment was used to evaluate the predictions of the SRNS on the ADG, EBG and composition of the gain (Eqs. 1, 13, 14) (see section1.3.1, page 4 and 8) considering:

1. Two different sets of coefficients (Set A versus Set B) for equation 2;
2. Two different equations (Eqs. 2 and 6) proposed to estimate the energy value of the gain;
3. Five different equations (Eqs. 8, 9, 10, 11a and 11b) proposed to estimate k_g, the efficiency of conversion of ME to NE for gain;
4. The correction factor $0.09 \times MEI \times k_m$ in equation 17;
5. The coefficient S (1.0 for females and castrates and 1.15 for intact males) of Eq. 18, originally used in the CNCPS for sheep.

In addition, the predictions of the SRNS on lambs' DMI (Eq. 19) were evaluated.

2.3.1 Evaluation of the DMI and ADG of the lambs

The evaluation was done by considering the two growing periods for each breed and gender already evaluated. In the evaluation the values of ADG and DMI, measured in the experiment, were compared to the mean ADG and DMI predicted by the SRNS.

Due to the occurrence of problems in the quality of the pellets at the beginning of the experiment and their substitution with hay for a week, the data of both slaughtering groups were considered both starting from the first experimental day (full dataset) and only starting from experimental day 29, when the final grower diet was used (reduced dataset).

For each growing stage, the mean BW, age, feed intake and dietary ingredients were used as inputs in the SRNS. The feeds most similar to those used in the experiment were selected from the feed library of the SRNS. Feed composition was then modified according to the chemical composition and the peNDF measured for each feed. The other values required by the SRNS (mostly degradation rates and mineral values) were obtained from the feed library. The submodel of the SRNS that corrects for ruminal degradation in N deficient diets (Tedeschi *et al*., 2000) was always used. The standard reference weights (SRW) required by the SRNS model (Eq. 4) to estimate the relative size of each animal were estimated by using mature weights reported by the South African Mutton Merino Studbook and Dorper Studbook for each of the breeds used (Tables 1.2 and 1.3). The SRW for Dorper was 61 kg and 73 kg for female and male respectively, while that of SA Merino was 78 kg and 127 kg for females and males, respectively.

The DMI predictions of the SRNS, based on Eq. 19 (Cannas *et al*., 2004), were compared with those actually measured in the experiment. In addition, since the SRNS predicts DMI on the basis of the ADG of the lambs, DMI predictions were also calculated by using the actually measured ADG for ADG in Eq. 19. This was done to separate the intrinsic accuracy of prediction of Eq. 19 from the ability of the model to predict ADG.

2.3.2 Evaluation of the composition of the gain

In this evaluation, EVG, fat and protein content on a shrunk and empty body weight, measured in the experiment, were compared with the corresponding values predicted by the SRNS.

The evaluations for the three slaughter groups (separately for each breed and sex) were conducted by subtracting slaughter groups 2 and 3 from the average composition of group 1 (slaughtered at the beginning of the experiment), from the average body composition of slaughter groups 2 and 3 at slaughter.

Thus, for slaughter group 2 the variations in composition from the beginning to the end of the experiment were calculated as: composition at slaughtering of slaughter group 2 - composition at slaughtering of slaughter group 1. Mean values were calculated separately for Dorper females, Dorper males, Merino females and Merino males.

Similarly, the variations in composition from the beginning to the end of the experiment of the slaughtering groups 3 were calculated as: composition at slaughtering of slaughter group 3 - composition at slaughtering of slaughter group 1.

Since the BW of the three slaughter groups at day 0 (beginning of the experiment and slaughtering date for the group 1) were slightly different, the calculations were carried out adjusting the BW, EBW and the EBW composition of slaughter group 1 proportionally to the difference between its average BW at day 0 and that of the groups 2 and 3 in the same day. All these mean values were calculated separately for Dorper females, Dorper males, Merino females and Merino males for each slaughtering group. Thus 8 treatment means were obtained.

The Dorpers second slaughter group was slaughtered on day 39 and the last slaughter group on day 60. For the SA Mutton Merinos the second slaughter group was slaughtered on day 60 and the third slaughter group was slaughtered on day 80. Evaluations were carried out for individual animals and for the averages of the animals in the two periods.

Note: The fibre content in the diet was not sufficient at the start of the trial and the feed had to be exchanged for new feed. This was also the period in which the lambs were infected with the bluetongue virus. This probably limited the accuracy of experimental measurements and needs to be considered when interpreting and discussing the results.

2.3.3 Assessment of the adequacy of the predictions

The assessment of the adequacy of the models is only possible through the combination of several statistical and empirical analyses and proper investigation regarding the purposes of the model as initially conceptualized (Tedeschi, 2006) and in this study, several techniques were used. The

coefficient of determination (r^2) (Neter *et al*., 1996), confidence intervals for the parameters (Mitchell, 1997), and the simultaneous test for the intercept and slope (Dent and Blackie, 1979; Mayer *et al*., 1994) were compared.

Additional techniques were also used as discussed by Tedeschi (2006), including evaluation for accuracy with concordance correlation coefficient (CCC; Lin, 1989), mean bias (Cochran and Cox, 1957) and mean square error of prediction (MSEP; Bibby and Toutenburg, 1977). The MSEP values were expanded in three fractions to represent errors in central tendency, errors due to regression and errors due to disturbances (or random errors), i.e. unexplained variance that cannot be accounted for by the linear regression (Theil, 1961).

Chapter 3

Results and Discussion

3.1 Feed and diet composition

The chemical analyses of the dietary ingredients which are presented in Table 3.1, were generally well within the expected norms. The NDF concentration of maize, however, was higher when compared to literature values (NRC, 2001) (Table 3.1). The protein fractioning showed that both the A fraction (non-protein nitrogen) and the C (fraction unavailable N) were particularly high (Table 3.1). This pattern reflected the composition of the hominy chop and the Lucerne, the two main ingredients of the diet (Table 2.2). The particle size of the main ingredients of the diet (Table 3.2) were mainly less than 1 mm, therefore the peNDF concentration was low.

For this diet the SRNS predicted (DM basis) a ME concentration of 10.6 $\pm$ 0.035 MJ/kg, and the following digestibility coefficients: 70.5 $\pm$ 0.2 for OM, 75.5 $\pm$ 0.1 for CP and 40.9 $\pm$ 0.5 for NDF. The variability for each coefficient is due to the effect of the variability in dietary intake among the animals. The low NDF digestibility was probably the result of the small particle size and low peNDF that characterized the ingredients of the pelleted feed (Table 3.2).

Table 3.1 Chemical composition of the grower diet and the individual feed ingredients

Feed ingredient	% as fed	% of DM					% of CP				
	DM[2]	Ash	CP[3]	NDF[4]	ADF[5]	ADL[6]	A[7]	B1[7]	B2[7]	B3[7]	C[7]
Hominy	90.05	2.96	10.35	27.09	9.57	1.15	27.38	14.31	43.31	6.43	8.57
Maize	89.49	1.05	7.92	22.45	6.18	0.58	13.98	2.81	59.63	9.08	14.49
COC[1]	93.57	6.86	44.24	29.32	19.95	4.18	12.32	5.66	69.61	1.79	10.62
Lucerne	91.92	13.98	17.22	53.10	46.05	8.20	26.12	4.04	40.84	15.85	13.15
Straw	94.22	8.13	2.88	82.31	55.37	7.30	30.80	8.84	18.63	4.44	37.29
Grower	89.48	8.70	16.97	28.44	18.88	2.68	29.37	2.53	55.29	1.72	11.08

[1] COC = cottonseed oilcake; [2] DM = Dry Matter; [3] CP = Crude Protein; [4] NDF =Neutral Detergent Fibre; [5] ADF = Acid Detergent Fibre; [6] ADL = Acid Detergent Lignin; [7] A, B1, B2, B3 and C = protein fractions graded according to their degradation rates in the rumen.

Table 3.2 Neutral Detergent Fibre particle size and peNDF concentration of some of the ingredients in the grower diet

Feed ingredient	Screen size						NDF	NDF	peNDF
	mm 2.35	mm 1.18	mm 0.6	mm 0.3	mm 0.15	mm <0.15	≥ 1.18 mm	% DM	% DM
COC[1], % retained	29.1	14.45	7.24	10.66	12.65	5.49	43.61	29.3	12.8
HomC[2], % retained	2.40	19.31	24.63	19.85	21.62	12.19	21.71	27.1	5.9
Lucerne, % retained	1.53	17.36	31.52	21.87	16.01	11.72	18.89	53.1	10.0
Straw, % retained	2.42	0.81	0.81	0	0	0	3.23	82.3	2.6

[1] COC = cottonseed oilcake; [2] HomC = hominy chop.

3.2 Results of the growth trial

3.2.1 Growth performance of the lambs

3.2.1.1 Body weight

A summary of the full BW results for the different breeds and growth periods are presented in Table 3.3, and schematically presented in Figure 3.1.

In South Africa, Dorper lambs are slaughtered at a typical live weight of 40.00 kg (Cloete *et al*., 2000), which is in close correlation to body weights for the second period Dorpers in this trial. South African Mutton Merinos lambs are slaughtered at live weights between 45.00 kg and 55.00 kg.

The average starting body weights of the different sheep breeds were 19.36 kg for the Dorper females, 19.83 kg for the Dorper males, 19.53 kg for the SAMM females, and 19.83 kg for the SAMM males.

Male and female Dorper lambs body weights differed ($P < 0.05$) compared between the two periods. There were no differences between the two sexes when Dorpers' body weights were compared within periods. This is contradictory to the findings of Campbell *et al*. (1963); Cloete and De Villiers (1987); Manyuchi *et al*. (1991); and Schoeman and Burger (1992); who reported ram or wether lambs to be heavier and faster growing than female lambs. Matika *et al*. (2003) also reported for indigenous Sabi sheep of Zimbabwe that rams were generally heavier than ewes. The SAMM male and female lambs differed ($P < 0.05$) when comparing body weight between the two periods and the sexes. Male animals performing better than female animals have been attributed to hormonal differences between sexes with the resultant effects on growth (Bell *et al*., 1970).

Between breeds, first and second period body weights for female lambs were similar. For male lambs, the first period body weights between different breeds did not differ. For the second period the SAMM did however outperform ($P < 0.05$) the Dorper. The fact that the SAMM did not also outperform the Doper in the first period may in part be attributed to the side-effects of the outbreak of the bluetongue virus in this experiment.

Table 3.3 Average body weight (BW) (kg) of the lambs during the two growth periods

Breed	Period	Female	Male	SEM
Dorper	1	$31.36^{a}_{x,1}$	$32.91^{a}_{x,1}$	0.48
	2	$38.97^{a}_{y,2}$	$40.16^{a}_{y,2}$	0.64
	SEM	0.60	0.53	
SAMM	1	$31.39^{a}_{x,1}$	$33.16^{b}_{x,1}$	0.44
	2	$39.68^{a}_{y,2}$	$44.93^{b}_{y,3}$	0.55
	SEM	0.50	0.49	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

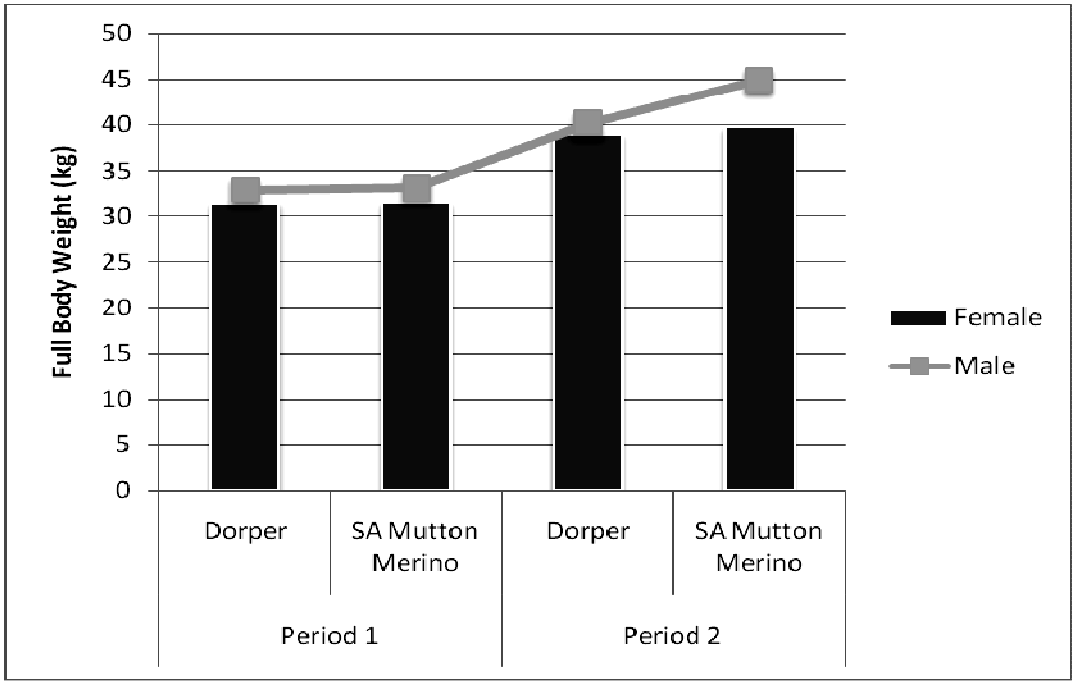

Figure 3.1 A schematic illustration of differences in the full body weight of lambs between breeds, periods and gender

3.2.1.2 Average daily gain

Results for the ADG for the different breeds and growth periods are presented in Table 3.4, and schematically presented in Figure 3.2.

There were differences in ADG ($P < 0.05$) between the two periods for the female and male Dorper lambs, as well as between the female and male Dorper lambs within the first period ($P < 0.05$). Basson *et al*. (1970) reported Dorper lambs weaned at 2 to 3 months grew at a rate of 0.23 kg/day, while Von Seydlitz (1996) reported Dorper lambs to grow 0.18 kg/day from birth to slaughter. As these results are for lambs on pasture and not on a concentrate diet in a feedlot, this would explain the differences in the ADG.

For the SAMM there was a difference in the ADG between the first and second period for both female and male lambs ($P < 0.05$). The SAMM is a late maturing sheep breed and this could contribute to the observed trend that the differences of the ADG between the sexes only appeared at a later stage than in the Dorpers.

Between the breeds for the female lambs, the ADG for both the first and second period was similar. Within all the breeds, the ADG for the first and second periods did however differ ($P < 0.05$). The male lambs between the breeds differed in the second period while significant differences between the first and second period ($P < 0.05$) were also observed within breeds.

Pienaar *et al*. (2012) recorded ADG of 0.33 kg/day for SAMM lambs on a finishing diet. Fourie *et al*. (2009) recorded ADG of 0.22 and 0.23 kg/day for Dorper lambs. These results agree with results found in this study.

Average daily gain of the SAMM male lambs for the second period are considerably higher than that observed by Sheridan *et al*. (2003). A possible explanation could be that lambs were not castrated in this trial. Neser *et al*. (2000) stated that the SAMM is a breed with a high growth rate as seen in the second period.

As is stated in the NRC (1985), male lambs have a greater potential to grow at a faster rate than female lambs. Kashan *et a*l. (2005) reported that for two fat-tail breeds (*Chaal* and *Zandi*), and their crosses with the *Zel* tailed breed, the male lambs had significantly higher live weight gains and average daily gains than the ewe lambs. Christodoulou *et al*. (2007) reported that Florina (Pelagonia) lambs of both sexes consistently gained weight throughout the experiment, with the male lambs gaining weight significantly faster than the female lambs.

Table 3.4 Average daily gain (kg/day) of lambs during the two growth periods

Breed	Period	Female	Male	SEM
Dorper	1	$0.213^{a}{}_{x,1}$	$0.316^{b}{}_{x,1}$	0.013
	2	$0.375^{a}{}_{y,2}$	$0.377^{a}{}_{y,2}$	0.017
	SEM	0.017	0.015	
SAMM	1	$0.243^{a}{}_{x,1}$	$0.312^{b}{}_{x,1}$	0.012
	2	$0.400^{a}{}_{y,2}$	$0.535^{b}{}_{y,3}$	0.015
	SEM	0.014	0.014	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

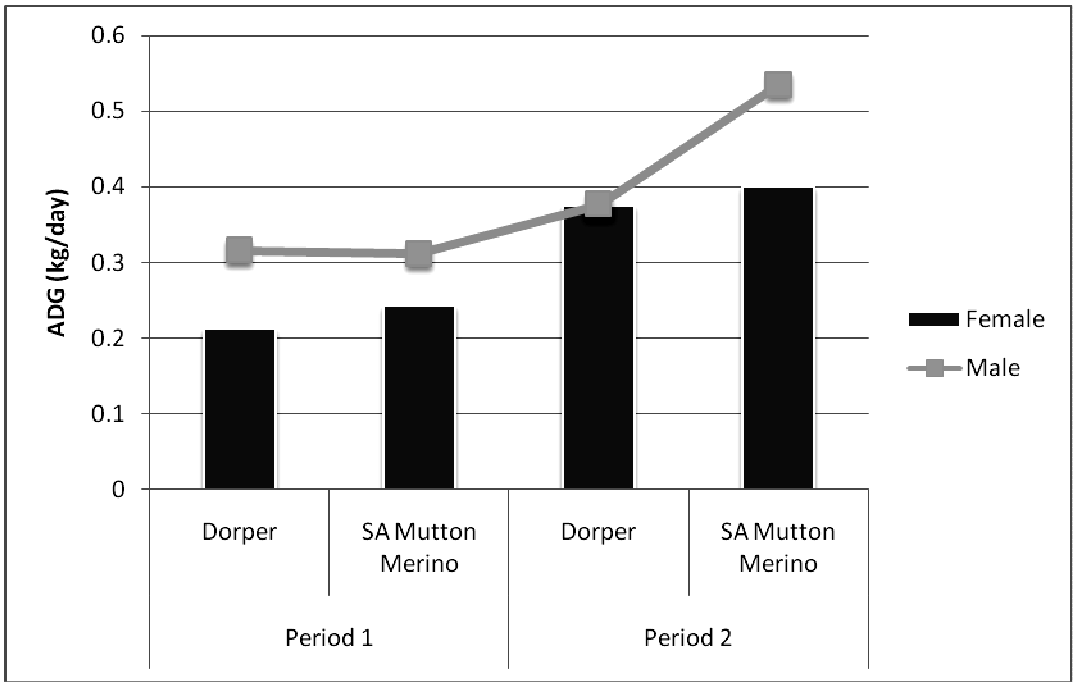

Figure 3.2 A schematic illustration of a comparison of ADG between the different breeds, gender and period

3.2.1.3 Dry matter intake

Results on the DMI for the different breeds and growth periods is presented in Table 3.5, and schematically presented in Figure 3.3.

During the first slaughter period there were differences in DMI ($P < 0.05$) between the sexes when the Dorper lambs are compared. Furthermore, the DMI of the Dorper female lambs differed between the two periods ($P < 0.05$). As expected, the DMI increased as the age and weight of the lambs increased.

Amongst the SAMM the DMI of both the male and the female lambs differed ($P < 0.05$) between the first and the second period. A difference in DMI ($P < 0.05$) between the sexes of the SAMM is only observed during the second period.

Sheridan *et al*. (2003) found the cumulative feed intake of SAMM wethers to be 106.0 kg (day 56), this is a feed intake of 1.89 kg/day when recalculated, which agrees with results obtained in this study for SAMM male lambs in the second period. Pienaar *et al*. (2012) found feed intake for SAMM lambs on a finishing diet to be 1.60 kg/day. Results agree with results found in this study for both periods of SAMM female lambs, and SAMM male lambs in the first period. In a study on SAMM by Price *et al*. (2009), feed intake of 1.38 kg/day was recorded. This is lower than results obtained in this study. An explanation could be that the diet was not in pelleted form. The feeding of pelleted diets increased the ADG when compared to diets fed in non-pelleted form (Casey and Webb, 1995). The lambs cannot select specific feed components from the pelleted diets which are more palatable, therefore higher intakes can be achieved, which in turn also influences the live weight of the lambs (Sheridan *et al*., 2003).

Gatenby (1986) found older sheep to have higher intakes than younger sheep, which was also reported by Mahgoud *et al*. (2000) when monitoring the growth of male Omani lambs. Mahgoud *et al*. (2000) ascribed this to the fact that older sheep had a physically better developed rumen, and better adapted rumen micro organisms, thereby the flow-through of feed would have been increased, resulting in higher feed intakes.

When comparing the first and the second periods, the DMI was similar between breeds for the female lambs. When the growth of male lambs was compared between breed, it was only during the second period that the SAMM outperformed ($P < 0.05$) the Dorper (ADG of 1.90 and 1.57 kg/day respectively). Christodoulou *et al*. (2007) reported on the performance of Florina (Pelagonia) lambs; male lambs consumed significantly more concentrate and total dry matter than the female lambs and the total DMI also increased significantly as the experiment progressed. This is in agreement with results obtained in this trial.

Table 3.5 Average DMI (kg/day) of the lambs during the two growth periods

Breed	Period	Female	Male	SEM
Dorper	1	$1.37^{a}_{x,1}$	$1.53^{b}_{x,1}$	0.03
	2	$1.63^{a}_{y,2}$	$1.57^{a}_{x,1}$	0.05
	SEM	0.04	0.04	
SAMM	1	$1.42^{a}_{x,1}$	$1.52^{a}_{x,1}$	0.03
	2	$1.69^{a}_{y,2}$	$1.90^{b}_{y,2}$	0.04
	SEM	0.04	0.04	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{12}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

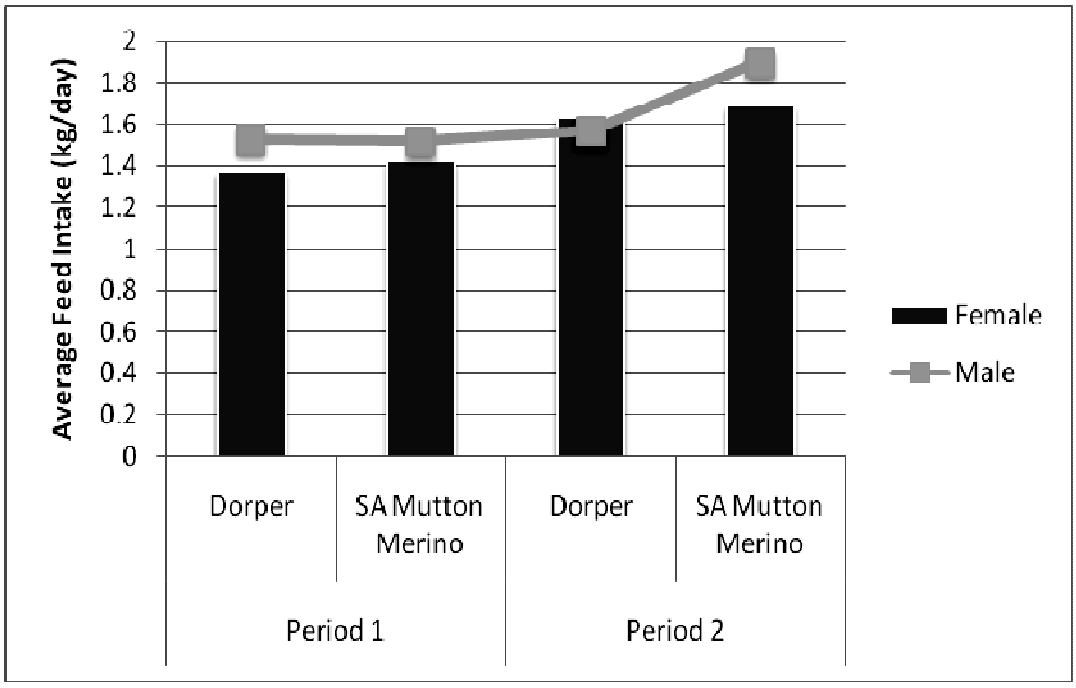

Figure 3.3 A schematic illustration of differences in DMI of lambs between breeds, periods and gender

3.2.1.4 Feed conversion ratio

Results on the FCR for the different breeds and growth periods is presented in Table 3.6, and schematically presented in Figure 3.4.

Differences between the two periods in FCR ($P < 0.05$) were observed for the female Dorper and SAMM male and female lambs. The only difference ($P < 0.05$) between the sexes was observed in the first period, for both breeds. Within the same sex between the breeds, the only difference for the male animals was for the SAMM in the second period ($P < 0.05$). The FCR for female lambs of both breeds between the periods differed ($P < 0.05$).

For the female Dorper lambs in the first period there were three lambs that under-performed, which most probably caused a bias the data for the total group. As a result the latter animals' data was included for the input in the model, but for comparative results the data was also analysed with those data points excluded as is explained later in section 4.1.1.

In a study on Dorper ram lambs, Greyling & Taylor (1999) recorded a FCR of 6.2, which is higher than results found in this trial. The diet had a relatively low energy (10.3 MJ ME/kg) and protein (13%) concentration when compared to this trials energy (10.6 MJ ME/kg) and protein (16.97%) concentration. Fourie *et al*. (2009) found Dorper lambs to have FCR's of between 6.86 and 7.18. These values are also higher than results found in this study. The diet used in this study had a low energy value (9.5 MJ ME/ kg DM). Malik *et al.* (1996) found that lambs fed diets high in energy consumed less than lambs fed diets low in energy. Lambs fed high energy diets were also the most efficient in feed conversion efficiency. This could be an explanation for the considerable improvement in FCR observed here. Price *et al*. (2009) recorded a FCR for SAMM lambs of 4.66. In another study by Pienaar *et al*. (2012), SAMM lambs fed standard feedlot diets achieved a FCR of 4.7. These values agree with results found in this study.

Table 3.6 Average FCR (kg feed/kg live weight gain) of the lambs during the two growth periods

Breed	Period	Female	Male	SEM
Dorper	1	$6.73^{a}{}_{x,1}$	$4.99^{b}{}_{x,1}$	0.23
	2	$4.48^{a}{}_{y,2}$	$4.32^{a}{}_{x,1}$	0.31
	SEM	0.29	0.26	
SAMM	1	$5.91^{a}{}_{x,1}$	$4.89^{b}{}_{x,1}$	0.21
	2	$4.32^{a}{}_{y,2}$	$3.57^{a}{}_{y,2}$	0.27
	SEM	0.24	0.24	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{12}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

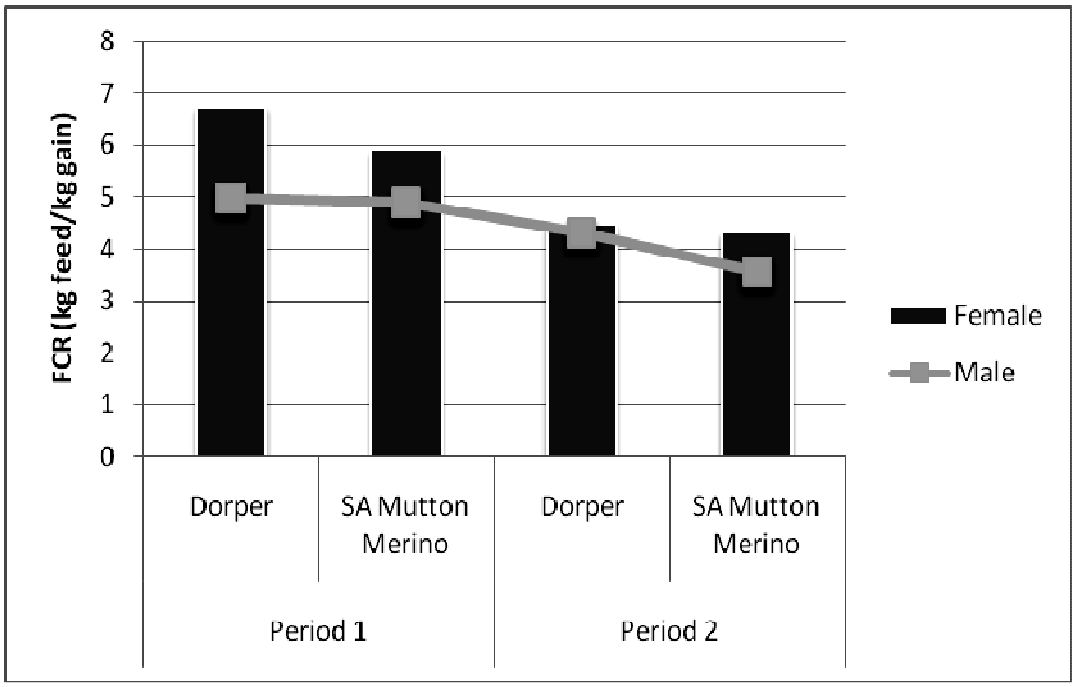

Figure 3.4 A schematic illustration of differences in the FCR of lambs between breeds, periods and gender

3.3 Carcass weight and composition of gain (protein gain, fat gain, water + mineral gain) of the lambs slaughtered at three time intervals

The lambs were not fasted before slaughter and the intestines were washed and cleaned before it was frozen and stored. Keeping the intestines and carcasses separate increased ease of cleaning and shortened the drying period after washing. When dry, the intestines were put in plastic bags before being frozen. Intestines and carcasses were minced separately. This ensured proper mixing and the collection of more homogeneous samples. The initial planning was to calculate total body composition by adding the respective constituents of carcass and offal for each lamb. All the intestine samples were analysed for dry matter, ash, crude protein, fat and gross energy. Intestine weight and total blood mass were also recorded. All the carcass data of the lambs was used in the evaluation of the SRNS and only the data of the fat and protein contents from the intestines was used to evaluate the SRNS. The ADG and whole body composition was determined by using fat and protein data on empty and full body weight. For this reason only the data of fat and protein content in the intestines, and all the data of the carcasses of the lambs, will be discussed. A summary of the results on the intestines chemical composition (GE, DM, Ash) and weight are given in Appendix A, for information purposes.

3.3.1 Chemical composition of the intestines

3.3.1.1 Fat

A summary of the fat percentages (DM basis) for the intestines of different breeds and slaughter stages are presented in Table 3.7, and schematically presented in Figure 3.5.

Between the sexes the fat percentage in the intestines differed in the first stage of the Dorpers ($P < 0.05$), with the rest of the stages all being similar. Between the breeds for the female lambs the first and second stages fat percentages of the intestines of the Dorpers were similar to the first stage of the SAMM female lambs, differed from the third stage of the Dorpers and second and third stages of the SAMM lambs ($P < 0.05$). For the male lambs the first stages were similar but differed from the second and third stages ($P < 0.05$). The second stage of the Dorper male lambs' fat percentage of the intestines differed ($P < 0.05$) from all the stages of the SAMM male lambs.

Table 3.7 A comparison of fat percentages in the intestines of Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$35.50^{a}_{x,1}$	$24.19^{b}_{x,1}$	1.97
	2	$40.82^{a}_{x,1}$	$38.23^{a}_{y,2}$	2.41
	3	$49.61^{a}_{y,2}$	$44.13^{a}_{y,23}$	1.97
	SEM	1.74	1.74	
SAMM	1	$33.10^{a}_{x,1}$	$27.79^{a}_{x,1}$	1.97
	2	$48.43^{a}_{y,2}$	$45.92^{a}_{y,3}$	2.61
	3	$52.70^{a}_{y,2}$	$50.42^{a}_{y,3}$	2.10
	SEM	1.86	1.79	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

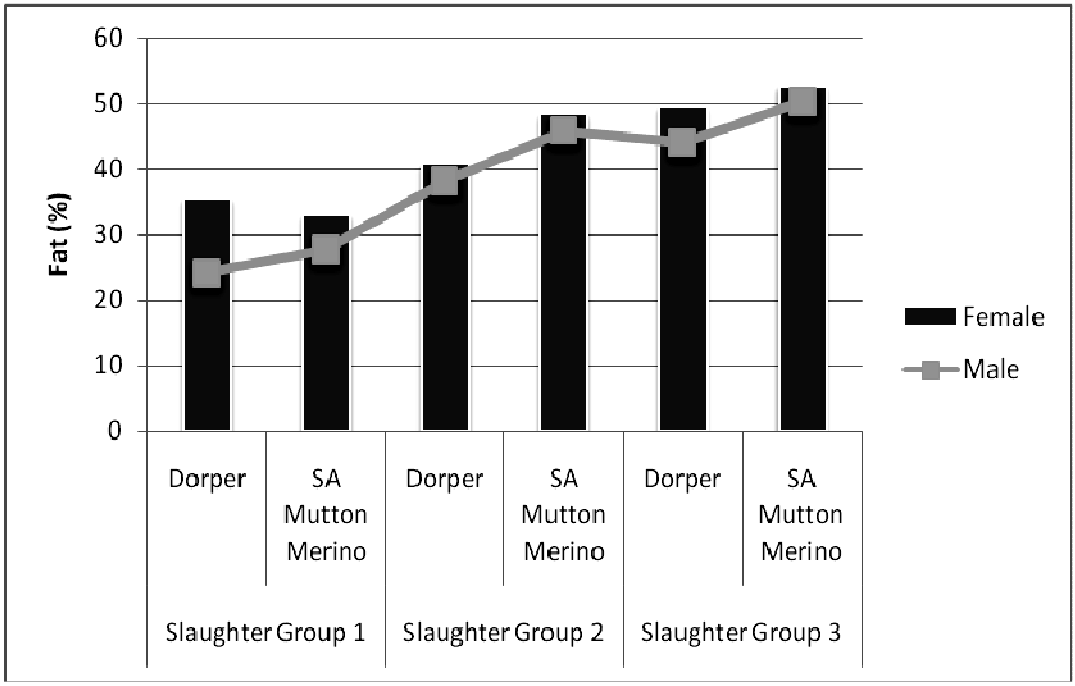

Figure 3.5 A schematic illustration of differences in intestine fat percentages of lambs between breeds, periods and gender

For the duration of the trial the female lambs of both breeds constantly had a numerically higher fat percentage in intestines than the male sheep. Results from a study conducted by Cloete *et al.* (2007) showed a general trend where ewes had a higher fat and dressing percentage than their male counterparts.

According to the NRC (1985) intact ram lambs generally had a higher composition of gain in water and protein and lower in fat than in females, as seen in data represented in this study. The fat percentage in the intestines also increased over the feeding period for both breeds and sexes. There is a definite order of development of different tissues during the growing period of sheep, bone first, then muscle and lastly fat (Tucker, 1976). The young carcass contains a high proportion of bone and a low proportion of fat, by maturity this proportion is reversed (Tucker, 1976).

3.3.1.2 Crude protein

A summary of the CP percentages (DM basis) of the intestines of different breeds and slaughter stages are presented in Table 3.8, and schematically presented in Figure 3.6.

The differences between the sexes for the CP percentage in the intestines were in the first slaughter stage for the Dorpers and in the third stage for the SAMM lambs ($P < 0.05$). Between the breeds the third stage of the Dorper female lambs differed from the first two stages within the breed and also from the first and third stages of the SAMM female lambs ($P < 0.05$). The third stage of the SAMM female lambs was similar to its second stage, but differed ($P < 0.05$) from all the other stages.

The intestinal CP concentration during the second stage of the Dorper male lambs differed from all the other stages ($P < 0.05$), irrespective of breed. All the stages differed in CP concentration within the Dorper breed for the male lambs ($P < 0.05$). Crude protein in the first stage of the SAMM male lambs differed from the second and third stages ($P < 0.05$). More fat and less protein get deposited the older an animal becomes. Ørskov and McDonald (1970), as cited by Rattray *et al*. (1974), reported that the energy cost for protein synthesis was much higher than for fat synthesis. Rattray *et al*. (1974) found in their study, using data from comparative slaughter experiments involving 396 growing and fattening young sheep, that the depositioning of protein was energetically much less efficient than that of fat.

Table 3.8 A comparison of intestinal crude protein percentages of Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$49.34^{a}{}_{x,1}$	$60.24^{b}{}_{x,1}$	1.30
	2	$45.99^{a}{}_{x,1}$	$50.43^{a}{}_{y,2}$	1.59
	3	$39.88^{a}{}_{y,2}$	$44.17^{a}{}_{z,3}$	1.30
	SEM	1.15	1.15	
SAMM	1	$54.95^{a}{}_{x,1}$	$57.75^{a}{}_{x,1}$	1.30
	2	$39.50^{a}{}_{y,23}$	$40.99^{a}{}_{y,3}$	1.72
	3	$33.26^{a}{}_{y,3}$	$39.07^{b}{}_{y,3}$	1.36
	SEM	1.23	1.18	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

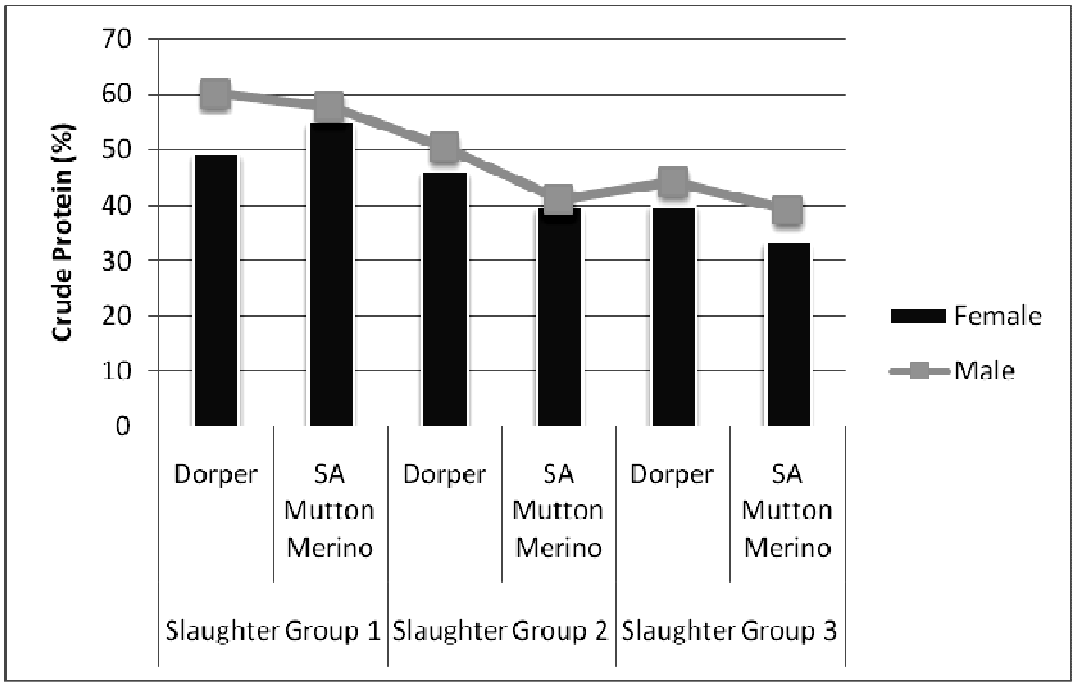

Figure 3.6 A schematic illustration of differences in intestine crude protein percentages of lambs between breeds, periods and gender

In a study using Shropshire male castrated sheep, Burton & Reid (1967) found sheep that increased in weight and contained more than 31% of fat had protein and water weights that increased at a decreasing rate, while fat and energy increased at an increasing rate. Kashan *et a*l. (2005) observed for the two fat-tail breeds (*Chaal* and *Zandi*), and their crosses with the *Zel* tailed breed, that male lambs had significantly higher protein concentrations and lower lipid concentrations, in their carcasses, when compared to the ewe lambs.

3.3.2 Chemical composition of the carcasses

3.3.2.1 Carcass weight

Results on the carcass weights obtained during the different are summarised in Table 3.9 and Figure 3.7.

Between the two breeds, as expected, the carcass weight of male lambs of the second and third stages differed ($P < 0.05$), with the SAMM male lambs consistently outperforming their Dorper counterparts after the first growth stage. For the female lambs carcass weights the corresponding stages were similar, but differed from the other stages ($P < 0.05$). Differences between the sexes within the breeds were only observed in the third stage for the SAMM lambs ($P < 0.05$).

In a study done by Pienaar *et al*. (2012) carcass weight of 22.4 kg were recorded for SAMM lambs. The live weight at slaughter of the SAMM lambs was 43.8 kg, which is similar to the male SAMM live weights recorded in the second growth period in this study (Table 3.3). Fourie *et al*. (2009) recorded carcass weights for Dorper lambs of between 17.6 kg and 17.9 kg. These values are in range of the second stage values recorded in this study.

In general, the animals gained weight as the trial progressed, and thus their carcass size increased. This increase in size and weight of farm animals, as they mature, is one of the simplest manifestations of growth (McDonald *et al*., 2002). Male animals have larger frame sizes at mature weight and will inevitably have larger carcasses than the female animals of the same breed (Kirton *et al*., 1995).

Table 3.9 A comparison of the weight of the carcasses of the Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$11.67^{a}{}_{x,1}$	$11.31^{a}{}_{x,1}$	0.39
	2	$19.35^{a}{}_{y,2}$	$19.65^{a}{}_{y,2}$	0.47
	3	$25.51^{a}{}_{z,3}$	$26.87^{a}{}_{z,3}$	0.39
	SEM	0.34	0.34	
SAMM	1	$11.33^{a}{}_{x,1}$	$11.55^{a}{}_{x,1}$	0.39
	2	$21.57^{a}{}_{y,2}$	$22.46^{a}{}_{y,4}$	0.51
	3	$26.53^{a}{}_{z,3}$	$30.65^{b}{}_{z,5}$	0.39
	SEM	0.36	0.34	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{12345}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

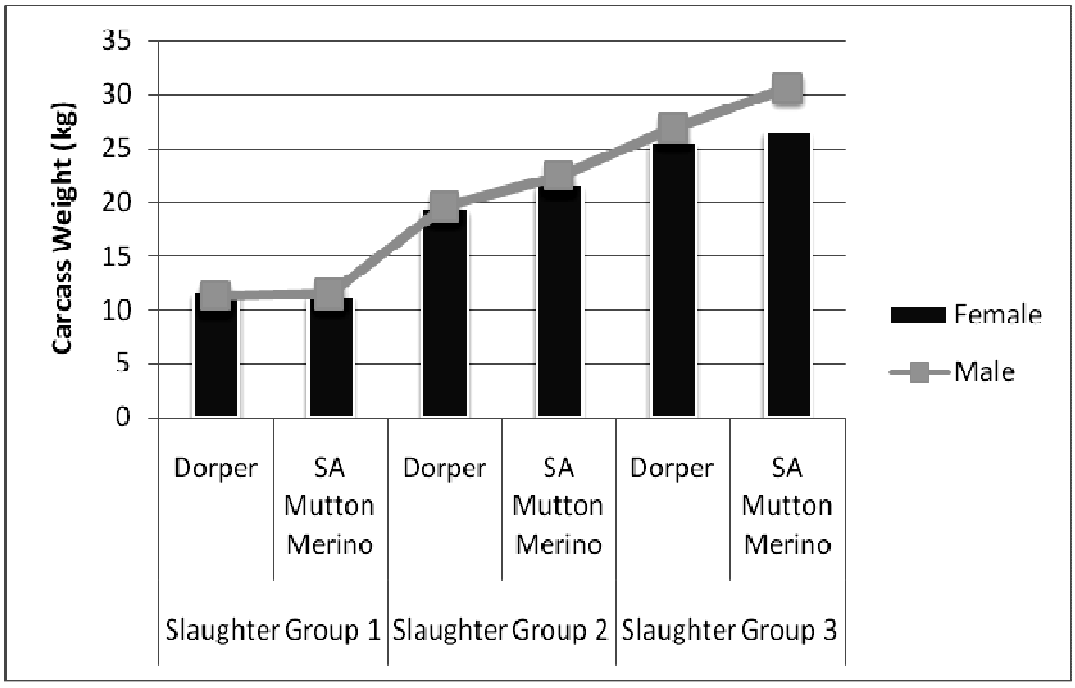

Figure 3.7 A schematic illustration of differences in carcass weights of lambs between breeds, periods and gender

3.3.2.2 Fat

A summary of the fat percentages (DM basis) for the carcasses of different breeds and slaughter stages are presented in Table 3.10, and schematically presented in Figure 3.8.

For the Dorper breed the fat concentration only differed ($P < 0.05$) between the sexes during the third stage. Within the sexes the fat concentration of Dorper breed differed ($P < 0.05$) between all the stages, with an increasing trend being observed with time. For both sexes in the SAMM, there were differences ($P < 0.05$) between the first and the last two groups, but the second and third groups were similar. The stages within the Dorper breed of the female lambs, did not differ from the corresponding stages in the SAMM breed, but the different stages did differ from each other ($P < 0.05$), except for the second and third stages of SAMM breed being similar. There were differences ($P < 0.05$) between all stages in both breeds for the male lambs, except for stage 2 and stage 3 of the SAMM breed being similar. Lawrie (1998) found that with increasing age, the depth of subcutaneous fat also increased. This is in agreement with Webb & Casey (1995) who reported that carcass fat percentage and the thickness of the subcutaneous fat increased with increasing slaughter weight for Dorper and SAMM wethers.

The subcutaneous fat thickness of the early maturing Dorper was found to be significantly higher than the late maturing SAMM. Webb & Casey (1995) also reported that at the same age, SAMM wethers had about half the subcutaneous fat cover compared to that of Dorper wethers.

Goliomytis *et al*. (2006) reported that male Karagouniko sheep were leaner and accumulated less fat than the female sheep. Although it is a different breed than the breed used in this trial, the same tendency was observed. Kirton *et al*. (1995) also reported that rams deposit less total carcass fat than ewes at the same age.

The weight of all the chemical constituents increased as the empty body weight increased, but at different rates. Lean body components are deposited at a decreasing rate whereas fat is deposited at an increasing rate (ARC, 1980). The increasing rate of fat depositioning is clearly seen in Figure 3.7.

According to McDonald *et al*. (2002) the real determinant of the composition of gains is the body weight relative to the mature weight of the animal, and not the absolute bodyweight. This is supported by the effects that sex of the animal have on the composition of gains. Males are larger at maturity than females, therefore at a common weight females achieve gains containing more energy and fat than their male counterparts (McDonald *et al*., 2002).

Table 3.10 A comparison of fat percentages in the carcasses of Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$32.62^{a}_{x,1}$	$28.22^{a}_{x,1}$	1.36
	2	$43.26^{a}_{y,2}$	$36.76^{a}_{y,2}$	1.66
	3	$54.97^{a}_{z,3}$	$46.08^{b}_{z,3}$	1.36
	SEM	1.20	1.20	
SAMM	1	$31.88^{a}_{x,1}$	$27.29^{a}_{x,1}$	1.36
	2	$49.36^{a}_{y,23}$	$46.53^{a}_{y,2}$	1.80
	3	$49.90^{a}_{y,3}$	$50.78^{a}_{y,2}$	1.36
	SEM	1.28	1.20	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

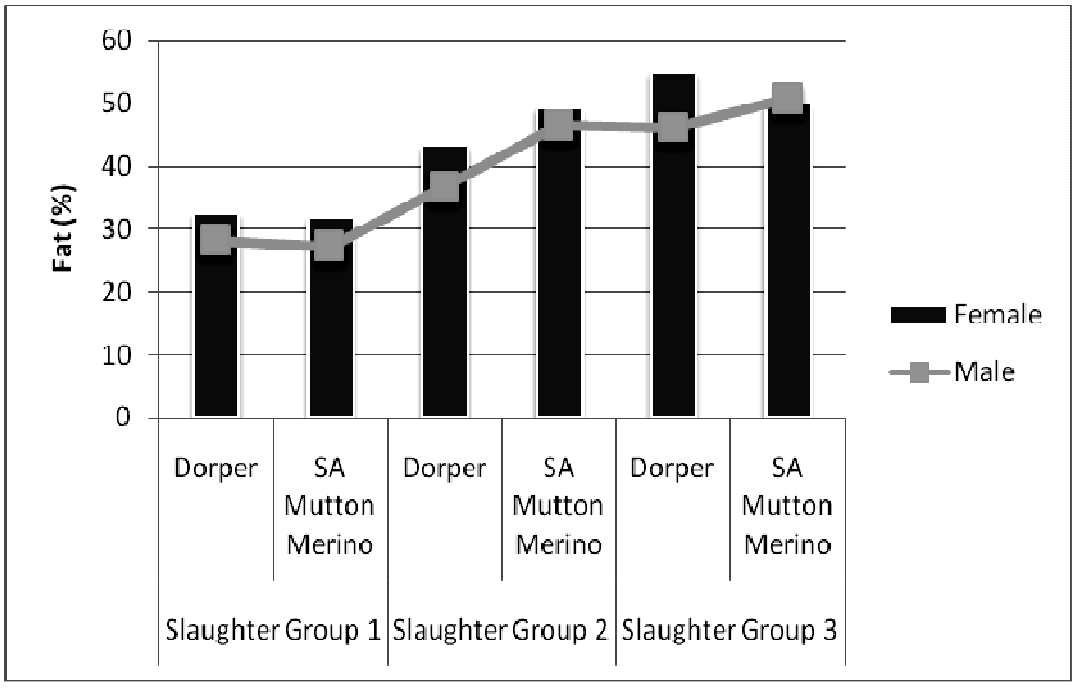

Figure 3.8 A schematic illustration of differences in carcass fat percentages of lambs between breeds, periods and gender

In the pioneer work done by Sir John Hammond, at Cambridge University, the author described the growth of animals to be in a series of 'waves' (McDonald *et al*., 2002). In early life brain (nerve tissue) and bone tissue have priority for development, then muscle tissues and finally adipose (fat) tissues grows most rapid. With fast growing animals these waves can overlap, with fat depositioning starting while muscle growth is still in progress. These growth-waves can clearly be seen in the results obtained from this experiment, where the fat concentration increased as the experiment progressed.

3.3.2.3 Crude protein

Results on CP percentages (DM basis) for the carcasses of different breeds and slaughter stages is presented in Table 3.11, and schematically presented in Figure 3.9.

Results from the first and the third slaughtering stages of the Dorper showed notable differences ($P < 0.05$) in the carcass CP percentages between the sexes, with the male animals having much higher CP percentages than the female lambs. In contrast to this, no differences were observed for CP values between the sexes for all stages of the SAMM. When comparing carcass CP percentages between the two breeds at similar stages, the female lambs only differed ($P < 0.05$) in stage 3, and the male lambs differed in the second stage ($P < 0.05$). Dorper males had, in general, a higher percentage carcass CP than the SAMM males.

For the SAMM carcass CP percentage for female and male lambs differed ($P < 0.05$) in the first stage from the second and third stages. All three the stages of the male Dorper lambs differed ($P < 0.05$), with a decreasing CP value observed. A difference ($P < 0.05$) in CP for female Dorper lambs was however only observed between the second and third stages.

The CP percentage of the carcasses for both the breeds decreased when the full growth period of the trial is considered. For both breeds, within sexes, there were decreases in CP percentages ($P < 0.05$), when stage 1 is compared to stage 3. According to the ARC (1980), weights of all the chemical constituents increase as empty body weights increase. It increases at different rates and lean body components (protein in particular) are deposited at a decreasing rate.

Table 3.11 A comparison of the crude protein percentage of the carcasses of Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$47.56^{a}{}_{x,1}$	$54.87^{b}{}_{x,1}$	1.19
	2	$42.76^{a}{}_{x,12}$	$47.45^{a}{}_{y,2}$	1.46
	3	$35.71^{a}{}_{y,3}$	$40.89^{b}{}_{z,3}$	1.19
	SEM	1.05	1.05	
SAMM	1	$48.30^{a}{}_{x,1}$	$52.28^{a}{}_{x,12}$	1.19
	2	$36.55^{a}{}_{y,23}$	$40.21^{a}{}_{y,3}$	1.58
	3	$36.81^{a}{}_{y,2}$	$39.09^{a}{}_{y,3}$	1.19
	SEM	1.12	1.05	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

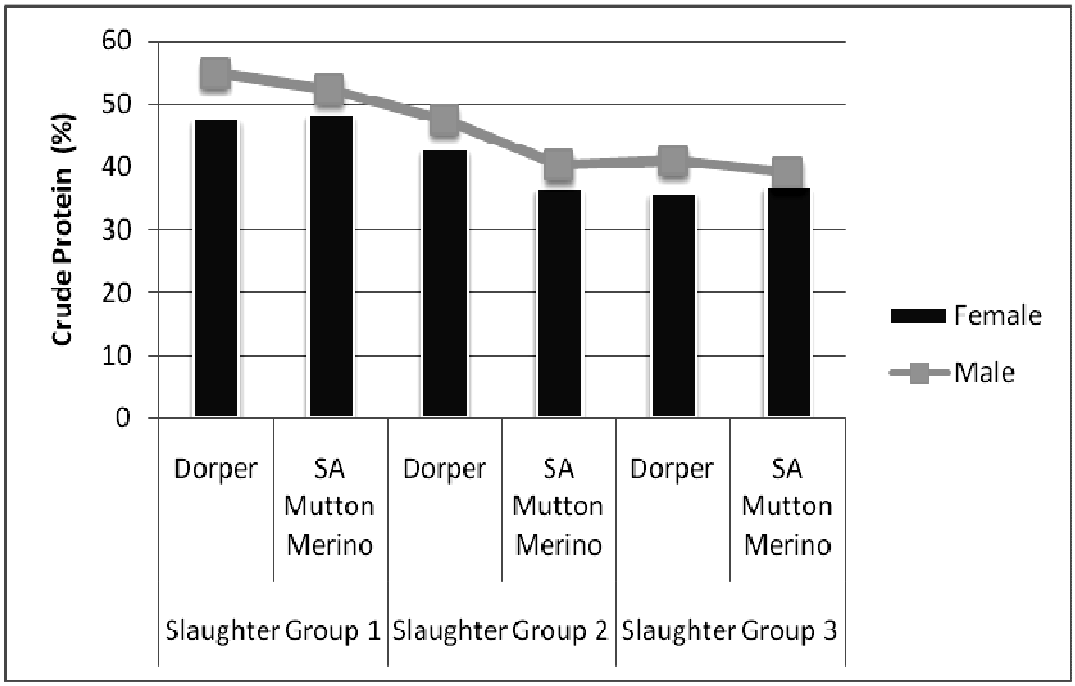

Figure 3.9 A schematic illustration of differences in carcass crude protein percentage of lambs between breeds, periods and gender

Berg & Walters (1983) reported that the higher the proportion of muscle, the lower the proportion of fat, and the higher the proportion of fat, the lower the proportion of muscle. Similarly, carcass muscle percentage decreased with the increase in slaughter weight of SAMM and Dorper wethers (Casey & Webb, 1995); the same was observed in Lori-Bakhtiari sheep in Iran (Shadnoush *et al*., 2003). Similar results were reported by others (Kellaway, 1973; Ely *et al*., 1979, Kemp *et al*., 1979).

3.3.2.4 Gross energy

The results on carcass GE concentration are reported in Table 3.12 and Figure 3.10.

There were no differences in carcass GE concentration between the sexes in corresponding stages for both the breeds. Dorper male and female lambs showed an increase in GE concentration between all three stages ($P < 0.05$), although there was not a significant difference between the initial two stages for the male lambs. For both sexes of the SAMM, the GE concentration also increased over the stages, the only difference ($P < 0.05$) observed was between the first and second stage. After the second stage the GE values remained similar.

McDonald *et al*. (2002) reported that the energy contained in lipids and proteins contribute almost entirely to the energy content of the body. As a carcass gets heavier, the proportions of muscle and bone decrease and the proportion of fat increase (Tucker, 1976). The fat concentration in the carcass of the animals increased over the trial period (see section 3.2.2.1) and fat is higher in energy than protein, it follows that fat was the major contributor to GE content as reflected by the results obtained in this experiment. The ARC (1980) also reported that the energy concentration of the body follows a curve similar to the curve of fat concentration in the body.

Table 3.12 A comparison of gross energy (MJ/kg DM) concentration in the carcass of Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$23.07^{a}_{x,1}$	$22.80^{a}_{x,12}$	0.48
	2	$26.26^{a}_{y,2}$	$24.78^{a}_{x,2}$	0.59
	3	$28.61^{a}_{z,3}$	$28.20^{a}_{y,3}$	0.48
	SEM	0.42	0.42	
SAMM	1	$23.63^{a}_{x,1}$	$22.47^{a}_{x,1}$	0.48
	2	$27.89^{a}_{y,23}$	$27.14^{a}_{y,3}$	0.63
	3	$28.59^{a}_{y,3}$	$28.04^{a}_{y,3}$	0.48
	SEM	0.45	0.42	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

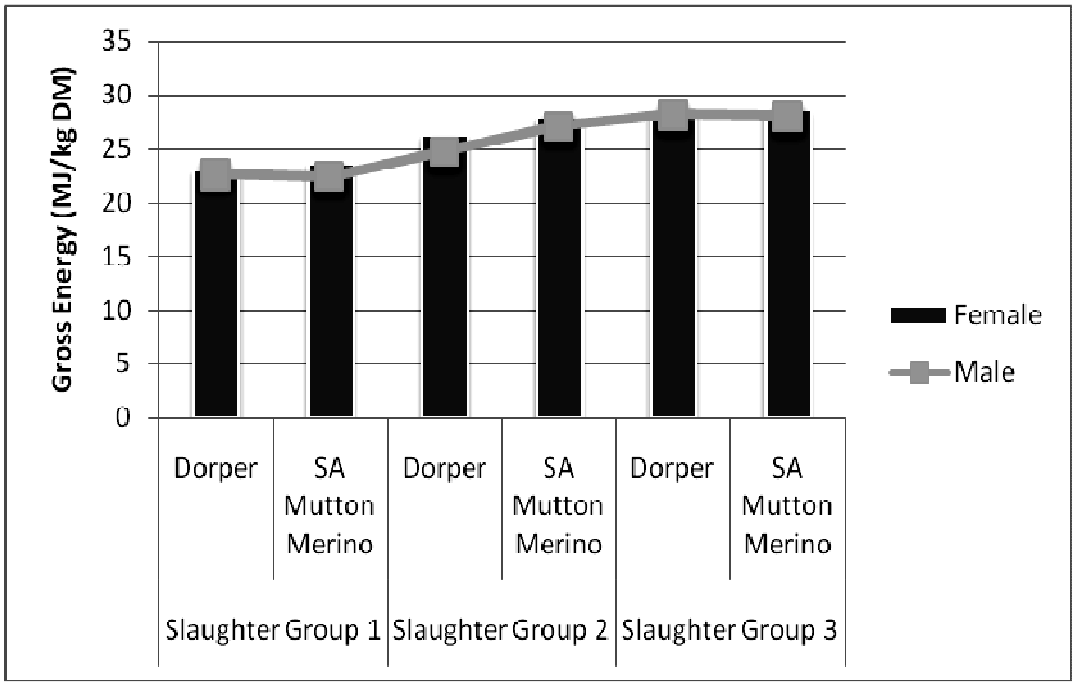

Figure 3.10 A schematic illustration of differences in the gross energy concentration of the carcasses of the lambs between breeds, periods and gender

3.3.2.5 Dry matter

Results on the DM concentration of the carcasses are represented in Table 3.13 and Figure 3.11.

Dorpers had consistent differences in the DM concentration ($P < 0.05$) between the sexes at all the stages, while the SAMM had no differences. The NRC (1985) reported that intact male lambs had higher gains in water than female lambs, thus it is to be expected that male lambs will have lower carcass DM concentrations than the female lambs. There was a general increase in carcass DM concentration between the different growth stages for both sexes within both breeds ($P < 0.05$). The only exception was the first and second stage for male and female Dorper lambs where they were similar. At similar stages of growth, there were no differences between female Dorper and SAMM lambs. The carcass DM concentration for male Dorper and SAMM lambs were only similar at the first stage. Thereafter carcass DM concentration for the second and third stages differed ($P < 0.05$).

Interestingly, carcass DM concentration for male Dorper lambs at the third stage were similar to DM for male SAMM lambs at the second stage, possibly indicating the DM concentration increased at a faster rate in SAMM male lambs than in Dorper male lambs. Shadnoush *et al*. (2004) found that the concentration of DM increased ($P < 0.05$) with an increase in slaughter weight, as reflected in Figure 3.11.

Table 3.13 A comparison of DM in the carcasses of Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$36.98^{a}{}_{x,12}$	$34.15^{b}{}_{x,1}$	0.69
	2	$38.90^{a}{}_{x,2}$	$35.46^{b}{}_{x,1}$	0.84
	3	$44.87^{a}{}_{y,3}$	$40.05^{b}{}_{y,2}$	0.69
	SEM	0.61	0.61	
SAMM	1	$35.58^{a}{}_{x,1}$	$32.92^{a}{}_{x,1}$	0.69
	2	$40.35^{a}{}_{y,2}$	$40.18^{a}{}_{y,2}$	0.91
	3	$46.06^{a}{}_{z,3}$	$43.39^{a}{}_{z,3}$	0.69
	SEM	0.65	0.61	

^{ab} Means in the same row with different superscripts differ ($P < 0.05$)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ ($P < 0.05$)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ ($P < 0.05$)

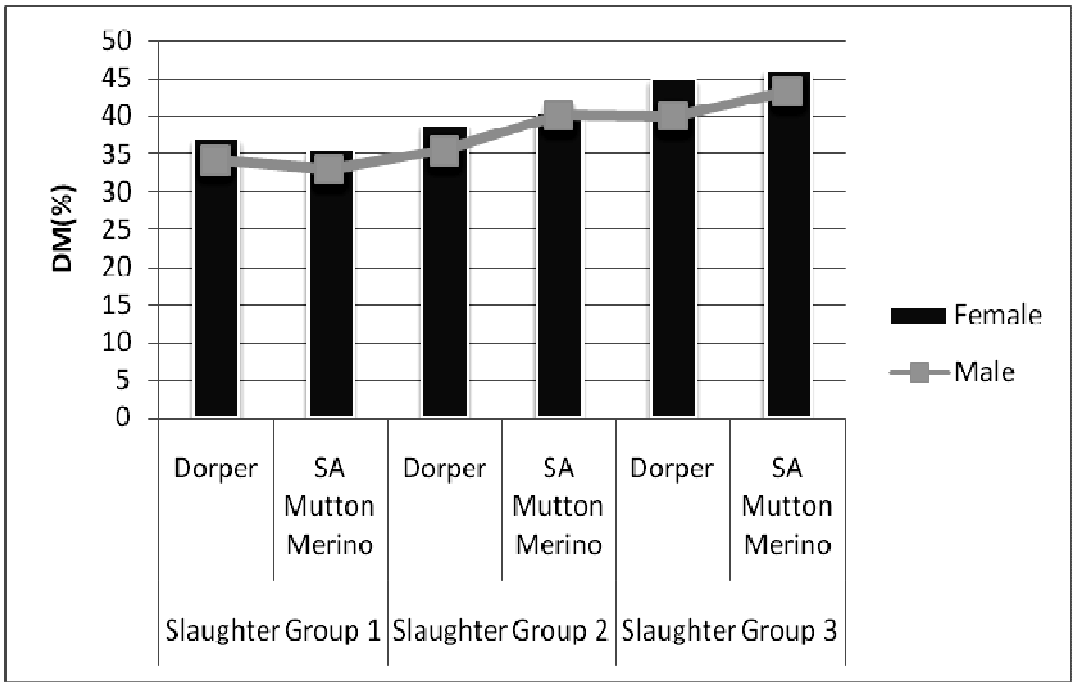

Figure 3.11 A schematic illustration of differences in carcass DM percentage of lambs between breeds, periods and gender

3.3.2.6 Ash

Results on the ash concentration of the carcasses are given in Table 3.14 and Figure 3.12.

For the Dorper breed, there were differences in ash concentration for the female lambs between the second and third stage ($P < 0.05$), with ash concentration showing a decreasing trend over time. For the male Dorper lambs it was only the third stage that differed from the previous two stages ($P < 0.05$). For male and female SAMM lambs all the stages differed ($P < 0.05$).

In studies done by Shadnoush *et al*. (2004) an increase in slaughter weight was also correlated by a decrease in the ash concentration, while Webb & Casey (1995) found that the percentage of bone in the bodies of Dorper and SAMM wethers decreased as the wethers increased in body weight. Bone material is generally one of the main contributors to ash concentration and this is most probably the major reason for the decrease in ash concentration over the trial period.

Table 3.14 A comparison of the ash concentration of the carcasses of the Dorper and SAMM lambs at three different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$5.78^{a}{}_{x,12}$	$5.99^{a}{}_{x,1}$	0.15
	2	$4.72^{a}{}_{x,2}$	$4.40^{a}{}_{x,1}$	0.18
	3	$3.95^{a}{}_{y,3}$	$4.39^{a}{}_{y,2}$	0.15
	SEM	0.13	0.13	
SAMM	1	$5.71^{a}{}_{x,1}$	$5.46^{a}{}_{x,1}$	0.15
	2	$5.24^{a}{}_{y,2}$	$4.63^{a}{}_{y,2}$	0.20
	3	$4.55^{a}{}_{z,3}$	$4.29^{a}{}_{z,3}$	0.15
	SEM	0.14	0.13	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

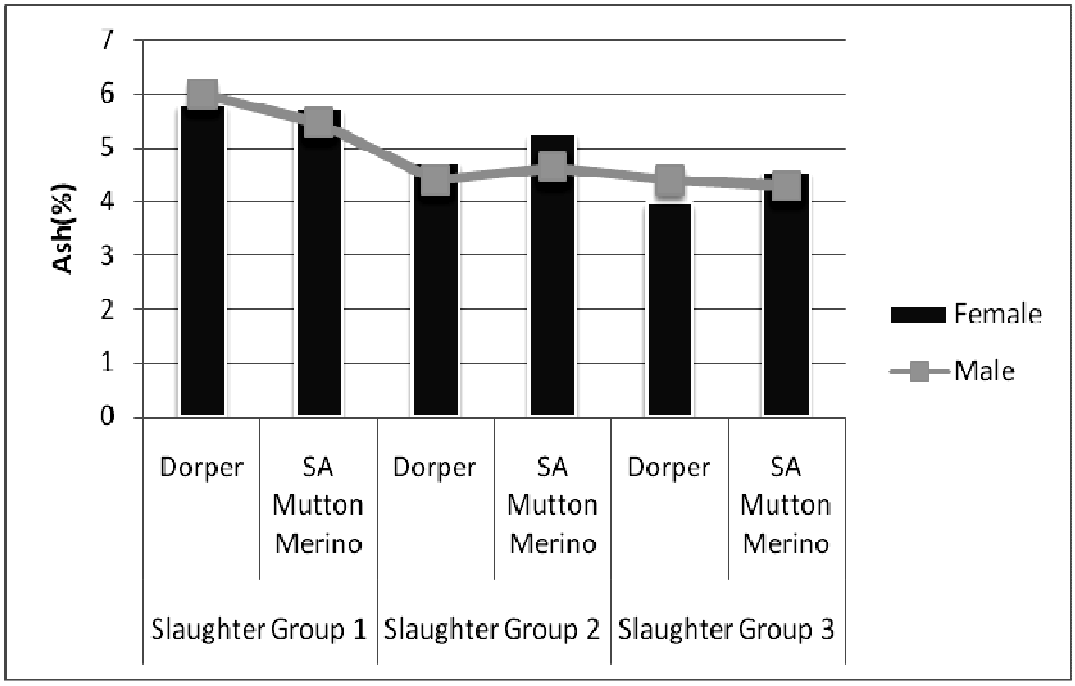

Figure 3.12 A schematic illustration of the differences in the ash percentages of the carcasses of lambs between breeds, periods and gender

Mahoud *et al*. (2000) reported that increased age of Omani sheep was accompanied by decreased carcass protein and water concentrations, but increased concentrations of fat, and had no effect on ash for both non-carcass and carcass components. The observations of Mahoud *et al*. (2000) for protein, fat and water concentrations are in agreement with results obtained in this experiment. Ash concentrations reported, however, are in contrast of what was observed in this experiment.

3.3.2.7 Body condition score

Results on BCS during the different stages are summarised in Table 3.15 and Figure 3.13.

Body condition scoring is a subjective assessment of the subcutaneous fat cover on a live animal (Ermias and Rege, 2003). Body condition scoring for sheep was initially developed as a method to aid in management, by determining the fat status of sheep (Jefferies, 1961). As expected, BCS generally increased with time (i.e. growth stages). For Dorper female and male lambs, significant increases were observed over all three stages ($P < 0.05$), whereas for SAMM male and female lambs the increase BCS was only significant between the first and second stages. The level of improvement in BCS then stabilized in the third stage (no significant differences between the second and third stages).

When comparing performance, in terms of BCS, in corresponding stages for the two breeds, female lambs at the first stage were still similar. At the second stage SAMM lambs started to outperform their Dorper counterparts ($P < 0.05$). At the third stage, the Dorper female lambs caught up with the SAMM female lambs, with BCS being similar again. For the male lambs, differences ($P < 0.05$) were already observed during the first stage, with the SAMM male lambs having higher body condition scores. For the SAMM lambs the change between the second and third stage, for both sexes, was not significant ($P < 0.05$).

Animals of similar mass could have different amounts of body reserves. Gut fill also influences live-mass, therefore BCS is a technique to estimate body reserves of animals quickly (Van der Merwe *et al*., 1995). In order to obtain the desired body condition of animals at the different production stages, the nutritional program needs to be adjusted accordingly. This will enhance the production efficiency of the animals (Hardin, 1990). It was not possible to find any data on the Dorper and SAMM breeds, since it is most probably not a general practice on farms in South Africa.

It was not possible to compare the measured BCS with the predictions of the SRNS because this model uses BCS in mature animals only.

Table 3.15 A comparison of the BCS of Dorper and SAMM lambs at different slaughter stages

Breed	Stage	Female	Male	SEM
Dorper	1	$1.58^{a}_{x,1}$	$1.58^{a}_{x,1}$	0.07
	2	$2.25^{a}_{y,2}$	$2.25^{a}_{y,2}$	0.09
	3	$3.00^{a}_{z,3}$	$2.5^{a}_{z,23}$	0.07
	SEM	0.06	0.06	
SAMM	1	$1.75^{a}_{x,1}$	$1.91^{a}_{x,4}$	0.07
	2	$2.83^{a}_{y,3}$	$2.62^{a}_{y,3}$	0.09
	3	$2.83^{a}_{y,3}$	$2.75^{a}_{y,3}$	0.07
	SEM	0.07	0.06	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{1234}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

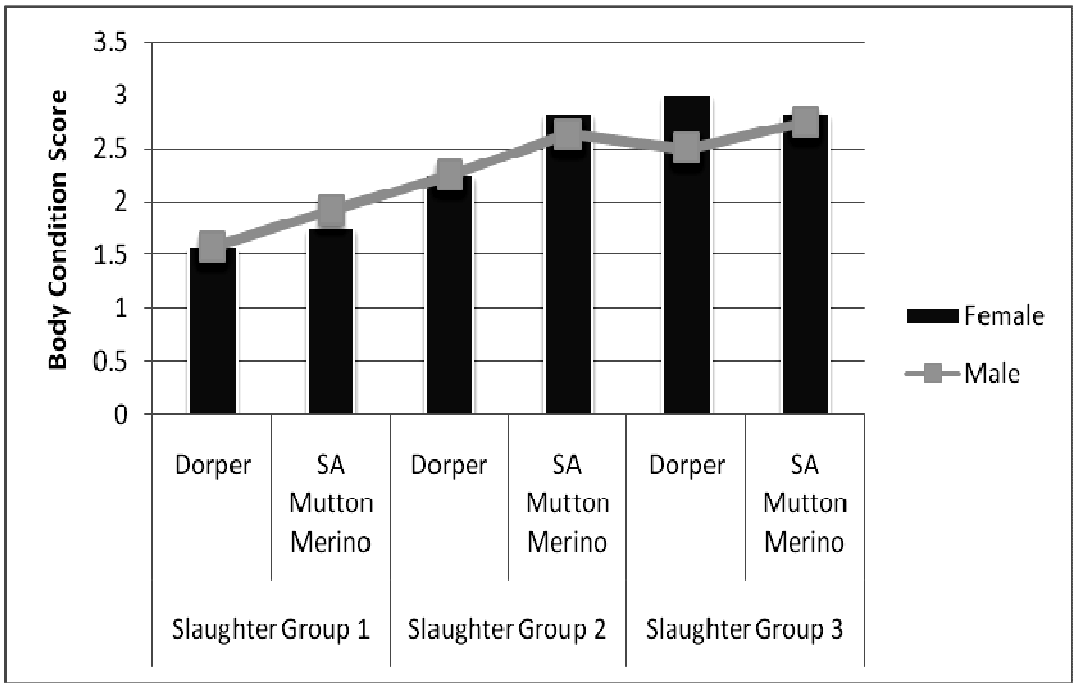

Figure 3.13 A schematic illustration of differences in BCS of lambs between breeds, periods and gender

Chapter 4

Evaluation of the Small Ruminant Nutrition System model using growth data of South African Mutton Merino and Dorper Lambs

4.1 Evaluation of the predictions of the Small Ruminant Nutrition System

As explained in the materials and methods section, due to problems in the quality of the pellets at the beginning of the experiment and their substitution with hay for a week, the data of both the growth groups were considered starting from the first experimental day (**full dataset**), as well as only starting from experimental day 29, when the final grower diet was used (**reduced dataset**), to evaluate the SRNS model. Data was also analysed by using the data of each animal (**individual dataset**) or by using the treatment groups means (**treatment mean dataset**, i.e. Dorper females group 2, Dorper males group 2, Dorper females group 3, Dorper males group 3, Merino females group 2, Merino males group 2, Merino females group 3, Merino males group 3).

In this section the so-called "**original SRNS**" represents the SRNS model in which the EVG is estimated using Eq. 2 employing the B set of coefficients; k_g was based on Eq. 11b and MEm prediction was based on Eq. 17, without the *(0. 09 x MEI x* k_m*)* correction factor and without any sex correction factor.

4.1.1 Predicted versus observed average daily gain of the lambs

The original SRNS model, when applied to the reduced individual dataset, predicted the ADG of the lambs with a very low difference between predicted (P) and observed (O) values, but with a fairly large mean squared prediction error (MSPE) (P-O = 0.5 g/d; root of mean squared prediction error (RMSPE) = 48.5; Table 4.1). The SRNS over-predicted ADG at a low observed ADG and under-predicted at a high observed ADG (Figure 4.1). The regression bias explained 7.3% of the MSPE (Table 4.1).

When Set A was used instead of Set B, all prediction statistics were less accurate (Table 4.1). This confirms the findings of Cannas *et al*. (2006). The evaluation also showed that the utilization of either the *(0.09 x MEI x* k_m*)* or the "*S"* correction factors reduced the accuracy of the predictions (Table 4.1).

Table 4.1 Evaluation of the average daily gain (ADG) predicted with different versions of the Small Ruminant Nutrition System (SRNS). Based on the reduced, individual data set (n=39)

Variable	SRNS predicted (P) (g/day)	SRNS observed (O) (g/day)	P– O (g/day)	Mean bias (% of O)	Components of MSPE[a] (% of MSPE)			RMSPE[b] (g/day)	R^{2c}	P^{d}	C_b[e]	ρ_c[f]
					Mean bias	Regression bias	Unexplained variation					
Original SRNS [g]	289	289	0.5	0.2	0.0	7.3	92.7	48.5	0.66	NS	0.91	0.74
Original SRNS with set A coefficients for EVG	269	289	-19.7	-6.8	13.7	6.0	80.3	53.1	0.64	0.02	0.87	0.70
Original SRNS with the S correction factor [h]	276	289	-13.2	-4.6	5.6	7.0	87.4	55.8	0.57	0.09	0.84	0.64
Original SRNS with correction factor *(0. 09 x MEI x k_m)*	249	289	-40.0	-13.8	39.0	6.8	54.2	64.1	0.65	0.001	0.74	0.60
k_g by NRC (Eq. 8)	233	289	-56.3	-19.5	53.3	0.8	45.9	77.2	0.57	0.001	0.69	0.52
k_g by AFRC/CSIRO (Eq. 9)	265	289	-23.5	-8.1	16.6	0.0	83.1	57.2	0.57	0.04	0.92	0.69
k_g by CSIRO (Eq. 10)	213	289	-76.1	-26.3	67.0	1.5	31.5	92.9	0.57	0.001	0.54	0.41
k_g by Tedeschi (Eq. 11a)	265	289	-24.0	-8.3	18.0	16.0	66.0	56.7	0.66	0.001	0.77	0.63
k_g & EVG by AFRC (Eqs. 5, 9)	273	289	-16.0	-5.5	5.9	10.7	83.4	65.9	0.43	0.04	0.64	0.42
k_g SRNS (Eq. 11b) & EVG by AFRC (Eq. 5)	301	289	11.7	4.1	2.5	0.3	97.2	74.1	0.16	NS	0.73	0.29

[a] MSPE = mean squared prediction error. [b] RMSPE = root of mean squared prediction error. [c] R^2 = coefficient of determination of the best fit regression line not forced through the origin. [d] *P* = probability associated to an F-test to reject the simultaneous hypothesis that the slope = 1 and the intercept = 0; when NS (P > 0.1) in the hypothesis is not rejected (Dent and Blackie, 1979). [e] *C* = Accuracy of the model (Lin, 1989). [f] ρ = Concordance correlation coefficient (CCC) (Lin, 1989). [g] The original model was based on : Eq. 2 for EVG, with set B of coefficients; k_g based on Eq. 11b ; MEm based on Eq. 17 without the correction factor *(0. 09 x MEI x k_m)*. [h] S correction factor (1.0 for females and castrates and 1.15 for intact males) of Eq. 18, without the correction factor *(0. 09 x MEI x k_m)*.

The fact that the utilization of the *(0.09x MEI x k_m)* correction factor induced under-prediction of the ADG has already been reported for lambs (Cannas *et al*., 2006; NRC, 2007) and for kids (Cannas *et al*., 2007).

The S factor in Equation 18 was excluded from the CNCPS-S model (Cannas *et al*., 2006). This exclusion was supported by an updated discussion of the CSIRO (1990) calculations conducted by Freer *et al*. (1997). These authors concluded that experimental data could not support the sex adjustment as reported by Ferrel *et al*. (1979). Despite this update, the CSIRO (2007) model maintained the sex adjustment.

The comparison of different equations to predict the efficiency of conversion of ME to NE for gain demonstrated that the ADG was best predicted by Eq. 11b (modified Tedeschi *et al*. (2004) equation), when compared to predictions employing Eq. 11a (original Tedeschi *et al*. (2004) equation), by Eq. 9 (AFRC and CSIRO), Eq. 8 (NRC) and eventually Eq. 10 (CSIRO) (Table 4.1). These results are in agreement with results reported by Cannas *et al*. (2006).

Regarding the prediction of EVG, the equation used in the original SRNS (Eq. 2) gave the best results when compared with the AFRC equation (Eq. 5) (Table 4.1). This is also in agreement to the findings of Cannas *et al*. (2006).

Overall, based on this evaluation it appears that the original SRNS model gave the best predictions when compared to any of the modifications tested.

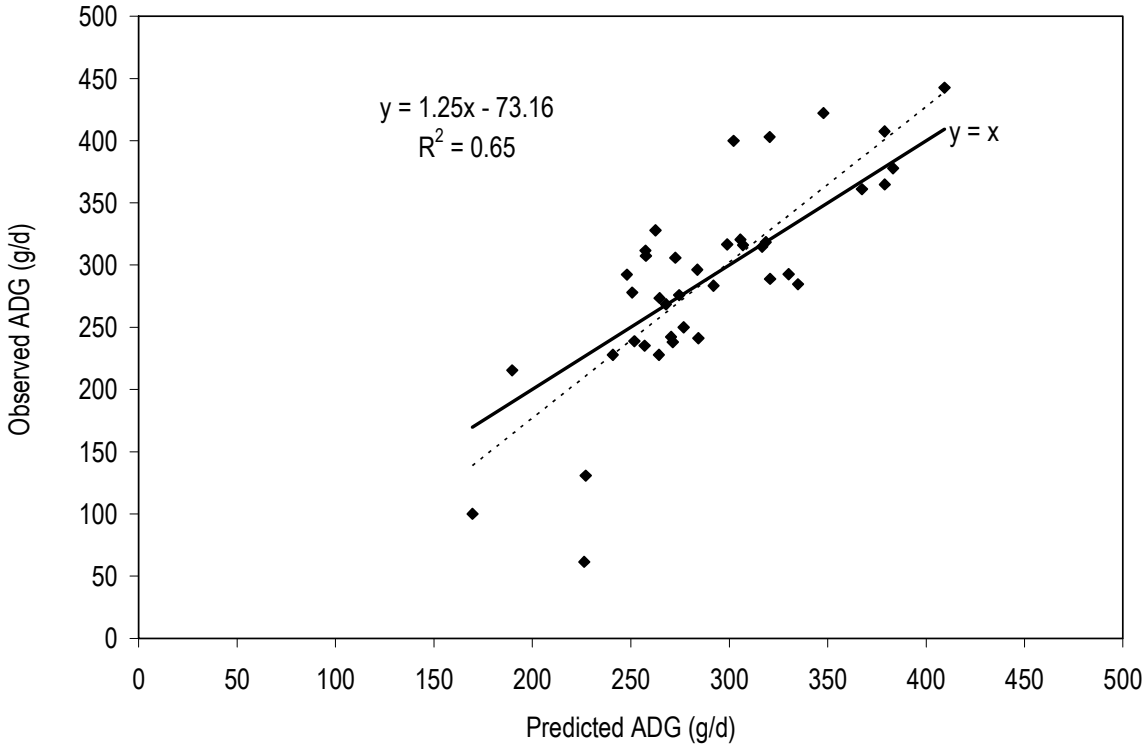

Figure 4.1 Predicted versus observed ADG of the lambs. Reduced dataset including all animals

The data points in Figure 4.1 show that there were three clear outliers that affected the prediction accuracy. These values were from the group 2 Dorper females. Once all the animals (four) of this group were excluded from the evaluation, the RMSPE was reduced to 37.8 g/d, and the regression bias was close to zero (Table 4.2 and Figure 4.2). The accuracy of the prediction was improved (C_b =0.95), while its precision was slightly reduced (R^2 = 0.59; CCC = 0.73) (Table 4.2), probably as an effect of the reduction in the range of variation of the data. There are no clear explanations for the under-prediction of the SRNS for this specific group of animals. It is possible that they were more affected than others by the bluetongue outbreak that occurred in the first weeks of the experiment. In the first period (excluded from the calculations in the reduced dataset) the animals might still have been mobilising body reserves to recover from the bluetongue virus, thus the SRNS over-predicted maintenance requirements and under-predicted lambs' growth rate. This hypothesis does however not support the observation that the SA Mutton Merinos were more severely affected by the bluetongue virus compared to the Dorpers.

Table 4.2 Evaluation of the average daily gain (ADG) predicted by using the Small Ruminant Nutrition System (SRNS) in its original version; Eq. 2 for EVG with Set B of coefficients; k_g based on Eq. 11b ; MEm based on Eq. 17 without the correction factors *(0. 09 x MEI x k_m)* and *S*. Based on the reduced individual dataset

Variable	SRNS predicted (P) (g/day)	SRNS observed (O) (g/day)	P– O (g/day)	Mean bias (% of O)	Components of MSPE[a] (% of MSPE)			RMSPE[b] (g/day)	R^{2c}	P^d	C_b[e]	ρ_c[f]
					Mean bias	Regression bias	Unexplained variation					
ADG original (n=39)	289	289	0.5	0.2	0.0	7.3	92.7	48.5	0.66	NS	0.91	0.74
ADG original minus Dorper females groups 2 (n=35)	299	307	-8.1	-2.6	4.6	0.0	95.4	37.8	0.59	NS	0.95	0.73
Dorper and Merino, Group 2 (n = 15)	266	243	22.9	9.4	13.1	7.2	79.7	63.4	0.56	NS	0.80	0.60
Dorper and Merino, Group 3 (n = 24)	304	317	-13.5	-4.3	14.0	10.2	75.9	36.1	0.69	NS	0.95	0.79
Dorper, all (Groups 2+ 3; n=20)	261	261	0.0	0.1	0.0	13.7	86.3	62.7	0.53	NS	0.76	0.55
Merino, all (Groups 2+ 3; n=19)	319	318	0.7	0.2	0.1	13.4	86.5	26.1	0.84	NS	0.96	0.88

[a] MSPE = mean squared prediction error. [b] RMSPE = root of mean squared prediction error. [c] R^2 = coefficient of determination of the best fit regression line not forced through the origin. [d] *P* = probability associated to an F-test to reject the simultaneous hypothesis that the slope = 1 and the intercept = 0; when NS (P > 0.1) in the hypothesis is not rejected (Dent and Blackie, 1979). [e] *C* = Accuracy of the model (Lin, 1989). [f] ρ = Concordance correlation coefficient (CCC) (Lin,1989)

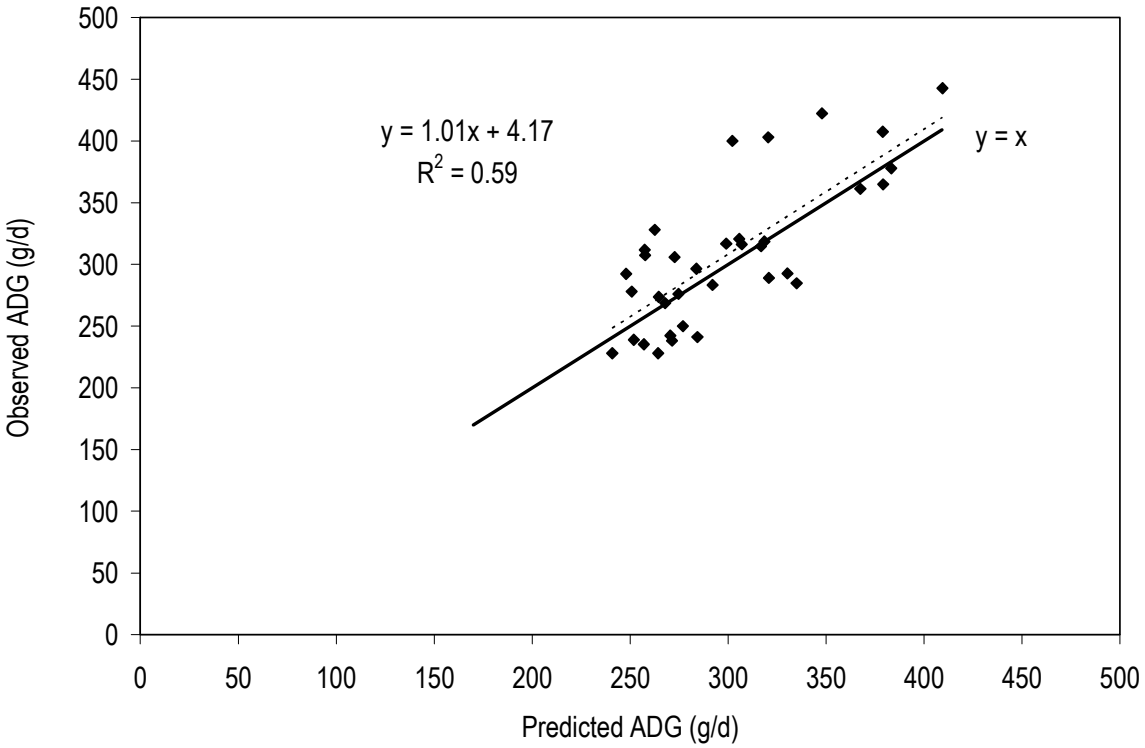

Figure 4.2 Predicted versus observed ADG of the lambs. Reduced individual dataset with the Dorper females of slaughter Group 2 excluded

The evaluations based on the individual reduced dataset showed that the SRNS predicted the ADG of the lambs of slaughter group 3 with higher accuracy than those of slaughter group 2 (Table 4.2 and Figures 4.4 and 4.5). This can probably be attributed to the inclusion of the previously mentioned Dorper female lambs that behaved as outliers compared to the SRNS predictions (as is shown in Figure 4.3).

The effect of the outlying group was also evident when the predictions of the SRNS were carried out separately for the two breeds. While the prediction of the ADG was accurate and precise for the SAMM breed, it was much less reliable for the Dorpers (Table 4.2 and Figures 4.6 and 4.7).

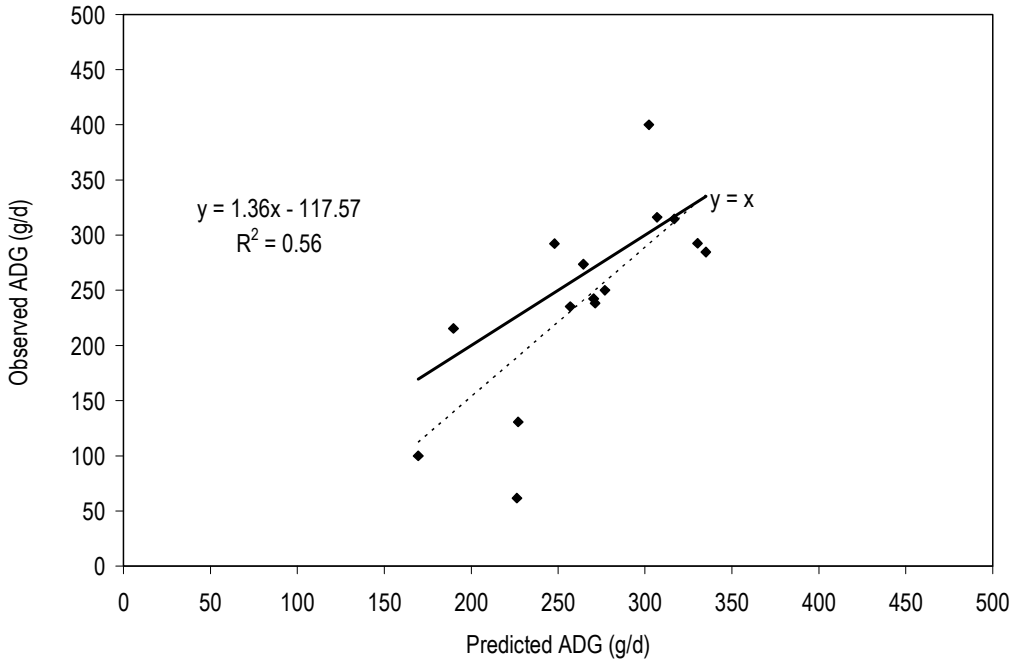

Figure 4.3 Predicted versus observed ADG of the lambs. Individual data for Group 2 (Dorper and SA Mutton Merino) lambs only

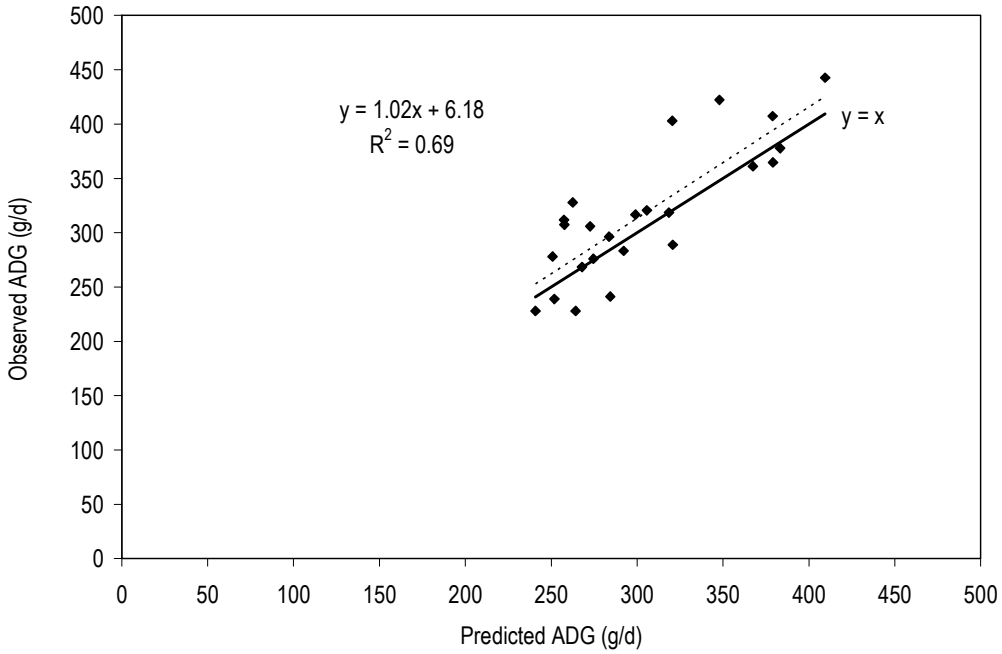

Figure 4.4 Predicted versus observed ADG of the lambs. Individual data for Group 3 lambs (Dorper and SA Mutton Merino) only

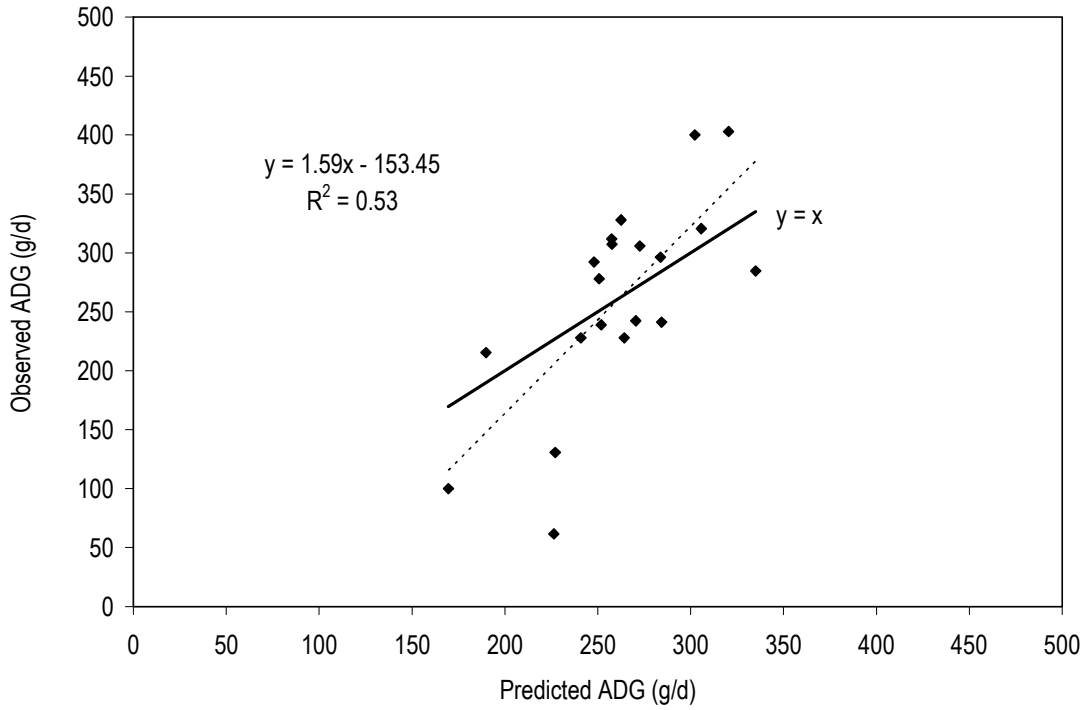

Figure 4.5 Predicted versus observed ADG of the lambs. Individual Dorper data (Groups 2 and 3 pooled)

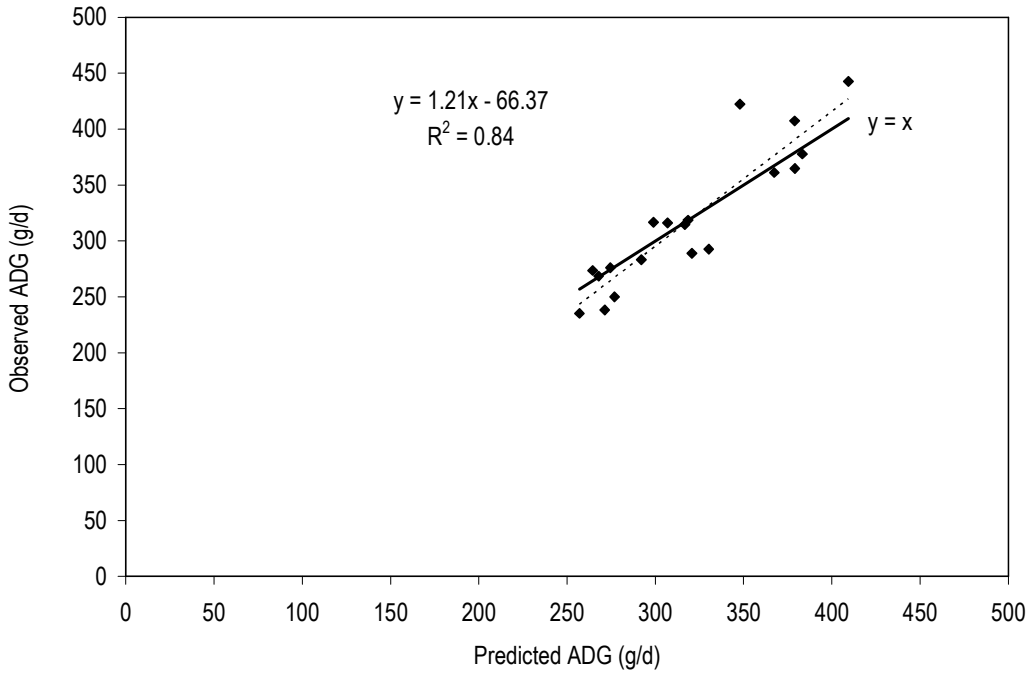

Figure 4.6 Predicted versus observed ADG of the lambs. Individual SA Mutton Merino data (Groups 2 and 3 pooled)

The calculations on the composition of the gain were based on the whole experimental period (full dataset), despite the feeding problems that occurred during the first four weeks of the experiment. This is because the composition of the gain was estimated as the difference between the slaughter body composition of slaughter groups 2 and 3 and the body composition of slaughter group 1.

To test indirectly the quality of the predictions based on the full dataset, the predictions of the SRNS on the ADG measured on the full dataset were compared with those based on the reduced dataset, by using the treatment means for both. The evaluation showed that the SRNS predicted the full dataset with lower RMSPE than when the reduced dataset was used for the prediction (21.4 vs. 32.0 g/d, for full and reduced datasets, respectively; Table 4.3 and Figure 4.7). Specifically, the predictions based on the full dataset were more accurate (C_b 0.98 vs. 0.91) but less precise (R^2 = 0.76 vs. 0.87) than those based on the reduced dataset. The overall concordance correlation coefficient (CCC) for the two datasets was the same (Table 4.3). Overall, the two datasets could therefore be considered equivalent.

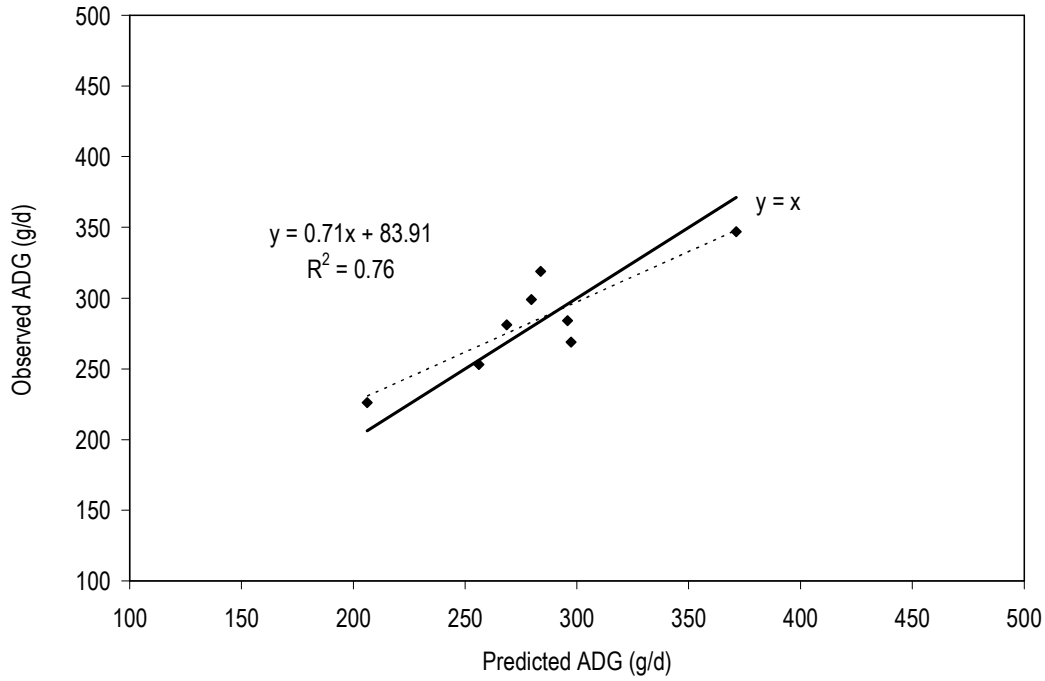

Figure 4.7 Predicted versus observed ADG of the lambs. Mean data of the Dorper and SA Mutton Merino male and female lambs of Groups 2 and 3, based on the treatment means of the full dataset

Table 4.3 Evaluation of the average daily gain (ADG) predicted using different equations to estimate k_g and the energy value of gain (EVG) with the Small Ruminant Nutrition System (SRNS). Based on the treatment means dataset (n = 8)

Variable	SRNS predicted (P)	SRNS observed (O)	P– O	Mean bias (% of O)	Components of MSPE[a] (% of MSPE)			RMSPE[b]	R^{2c}	P^{d}	C_b^{e}	ρ_c^{f}
					Mean bias	Regression bias	Unexplained variation					
DMI based on observed ADG, g/d	1291	1327	-35	-2.7	44.1	30.2	25.7	53.0	0.96	0.03	0.96	0.94
DMI based on predicted ADG, g/d	1291	1327	-35	-2.7	60.0	1.8	38.2	45.5	0.95	0.09	0.96	0.94
ADG based on the full dataset, g/d	282	285	-2.4	0.8	1.2	33.9	64.9	21.4	0.76	NS	0.98	0.85
ADG based on the reduced data set, g/d	281	281	-0.1	-0.04	0.0	39.0	61.0	32.0	0.87	NS	0.91	0.85
EBG based on the full dataset, g/d	260	229	31.0	13.6	66.4	14.2	19.4	38.0	0.69	0.01	0.72	0.60
EVG based on the full data set, MJ/kg EBW	15.20	13.73	1.47	10.7	35.4	6.3	58.3	2.47	0.36	NS	0.83	0.50
Fat based on the full data set, g/kg of EBG	295	275	19.8	7.18	11.1	27.8	61.0	59.2	0.30	NS	0.95	0.51
Protein based on the full data set, g/kg of EBG	152	146	5.8	3.9	8.9	28.6	62.6	19.3	0.10	NS	0.94	0.31

[a] MSPE = mean squared prediction error. [b] RMSPE = root of mean squared prediction error. [c] R^2 = coefficient of determination of the best fit regression line not forced through the origin. [d] *P* = probability associated to an F-test to reject the simultaneous hypothesis that the slope = 1 and the intercept = 0; when NS (P > 0.1) in the hypothesis is not rejected (Dent and Blackie, 1979). [e] *C* = Accuracy of the model (Lin, 1989). [f] ρ = Concordance correlation coefficient (CCC) (Lin, 1989). [g] The values do not sum up to 100 because R^2 is 0.

The statistics obtained for the dataset based on treatment means allow the comparison of this study with those previously published for the SRNS or the CNCPS for sheep, all based on treatment means.

The CNCPS for sheep predictions on the ADG of lambs were evaluated by Cannas *et al*. (2006) using the results of published experiments. Here it was found that by excluding the *S* and the (*0.09 x MEI x* k_m) correction factor from the calculation of maintenance requirements, the model explained 84% of the variation with a mean bias of 1 g/d and RMSPE of 37 g/d. The latter value is slightly higher than the corresponding values obtained here when employing either the reduced or the full treatment means datasets (Table 4.3).

The NRC (2007) also conducted an evaluation of the CNCPS for sheep as published by Cannas *et al*. (2004). For growing and finishing sheep, the NRC (2007) developed a database containing 156 observations (1,876 sheep) from 31 references. When the (0.09x MEI x km) adjustment was included, the CNCPS for sheep accounted for 70% of the variation of the observed ADG, with mean bias of 37 g/d. When this adjustment was excluded, the CNCPS for sheep had a lower mean bias (10 g/d) than the original equation, but similar r^2 (0.70).

4.1.2 Predicted versus observed empty body gains and composition of the gain

In this study the ratio between EBG and ADG was 0.803 ± 0.013 (Table 4.4). This value had very little variability and showed a tendency of being higher for Dorper than for SAMM ewes (0.811 vs. 0.795 for Dorper and Merino, respectively; P< 0.104) and higher for males than for females (0.810 vs. 0.795 for males and females, respectively; P< 0.119). This value was markedly lower than that used by the SRNS, which assumes a ratio of 0.92 (Cannas *et al*., 2006).

By using the slaughtering data it was possible to compare predicted and observed (Table 4.4) empty body gains. The evaluation showed that the mean bias was fairly high and positive (+31.0 g/d) and the RMSPE was almost twice as large as the corresponding values for ADG (Table 4.3). The overall accuracy of the prediction was high (C_b 0.72) and the precision was low (R^2 =0.69 and overall CCC = 0.60) (Table 4.3). Clearly the over-prediction increased as the measured EBG increased (Figure 4.8). It would therefore appear that the overall good accuracy of prediction of the ADG was the result of the errors that cancelled out, namely the over-prediction of EBG and the under-prediction of the ratio between EBG and ADG.

Table 4.4 Average daily gain, EBG and composition of the gain as calculated from the slaughtering data. The values of Group 2 were obtained as the difference in composition between Group 2 and Group 1, those of Group 3 as difference between Group 3 and Group 1

	Dorper				Merino			
Item[1]	Group 2		Group 3		Group 2		Group 3	
	Female	Male	Female	Male	Female	Male	Female	Male
Observed ADG, g/d	226	299	252	319	282	269	284	347
Predicted ADG, g/d	206	280	256	284	269	297	296	371
Observed EBG, g/d	181	246	204	260	222	212	223	282
Predicted EBG, g/d	190	257	236	261	247	274	272	341
Observed EBG/ADG, %	79.7	82.2	80.8	81.5	79.0	79.1	78.6	81.3
Predicted EBG/ADG, %	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0
Observed CP (g/kg of EBG)	141	122	159	134	127	169	153	161
Predicted CP (g/kg of EBG)	142	154	128	138	155	178	147	170
Observed Fat (g/kg of EBG)	257	177	349	335	252	279	324	227
Predicted Fat (g/kg of EBG)	329	287	389	348	279	189	314	223
Observed EVG (KJ/kg of EBG)	13216	9825	17892	16078	11939	13526	14938	12433
Predicted EVG (KJ/kg of EBG)	16336	14935	18352	16992	14674	11662	15862	12795

[1] ADG = Average daily gain; EBG = Empty Body Gain; CP = Crude Protein; EVG = Energy Value of Gain

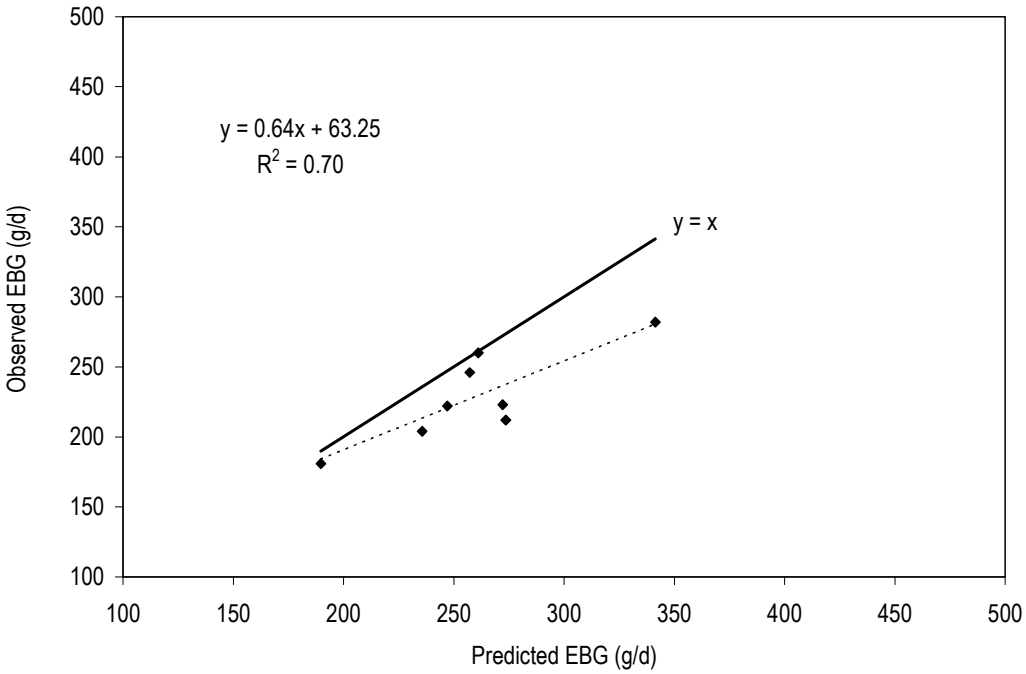

Figure 4.8 Predicted versus observed empty body gain (EBG). Mean data of the Dorper and SA Mutton Merino male and female lambs of Groups 2 and 3, based on the full dataset

The evaluation of the SNRS predictions on the composition of the gain further suggested that this model over-predicted both the fat and the protein concentration of gain (by 7.2% and 3.9%, respectively; Table 4.3 and Figure 4.9). The predictions were accurate but the precision was low (Table 4.3). The low precision was probably due to the fact that the measured range of variation of fat and for the protein content of gain was narrow (Table 4.3 and Figure 4.9). There were a couple of outliers for fat and protein. Genetic and environmental factors play a role on growth rates. Some sheep will have the inherent ability to grow faster than others (Tucker, 1976). This could explain what was observed in this trial.

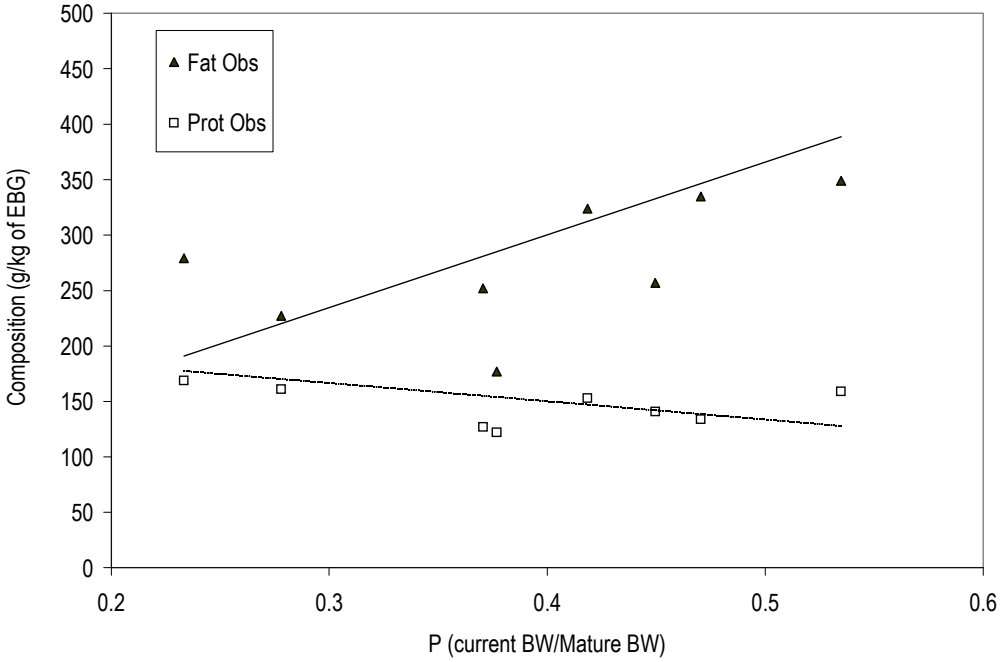

Figure 4.9 Predicted (fat = continuous line; protein= dotted line) versus observed fat (triangles) and protein (squares) composition of the gain in relation to the relative size P (current weight/mature weight). Mean data of the Dorper and SA Mutton Merino male and female lambs of slaughter Groups 2 and 3, based on the full dataset

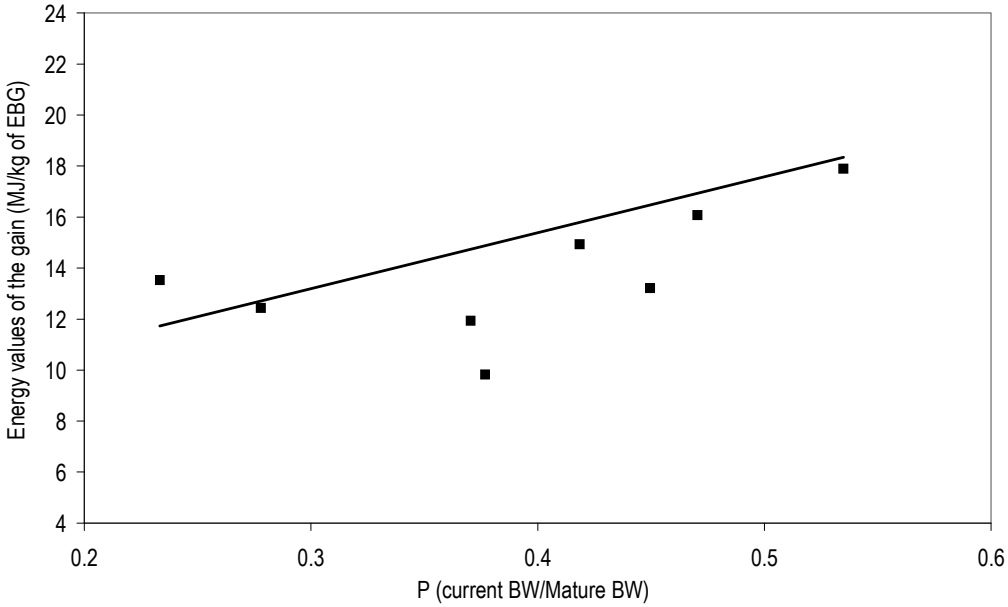

Figure 4.10 Predicted (continuous line) versus observed (squares) energy content of the gain in relation to the relative size P (current weight/mature weight). Mean data of the Dorper and SA Mutton Merino male and female lambs of the Groups 2 and 3, based on the full dataset

The EVG was also over-predicted (by 10.7%; Table 4.3 and Figure 4.10), as a result of the over-prediction of EBG fat concentration. Indeed, most of the energy in the EVG originates from fat. This result is particularly interesting because the SNRS, as the CNCPS for sheep (Cannas *et al*., 2004), uses for equation 2 the Set B of coefficients, which gave a lower EVG than those actually proposed by CSIRO (1990) and Freer *et al*. (1997) for sheep (Set A). It is not possible to compare the results of this experiment with others because it is the first time the application of the CSIRO (1990) and Freer *et al*. (1997) growth model, as adopted by the SRNS, is evaluated with slaughtering data.

4.1.3 Predicted versus observed dietary feed intake

The SRNS predictions of DMI were accurate and precise both when the predicted and the observed ADG were used in Eq. 19 (Table 4.3 and Figures 4.11 and 4.12). In particular, the predictions were more accurate and resulted in lower systematic bias when the predicted instead of the observed ADG was used. The fairly large difference between predicted and observed values for one data point (Figure 4.12), probably contributed to this observation.

It is not possible to compare the results of this evaluation with others because it is the first time Eq. 19 is evaluated. Despite this, considering the difficulties usually observed in the literature for DMI prediction, the results found in this evaluation should be considered particularly positive.

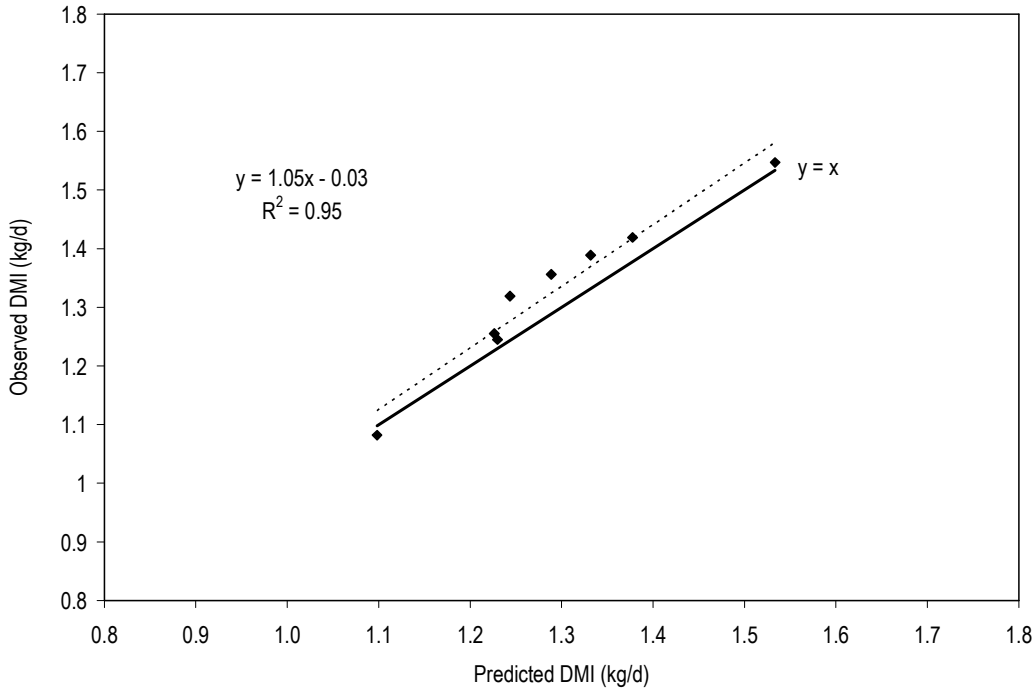

Figure 4.11 Predicted versus observed dry matter intake (DMI). Predictions based on Eq. 19 in which the predicted ADG of Dorper and SA Mutton Merino males and females of Groups 2 and 3 were used

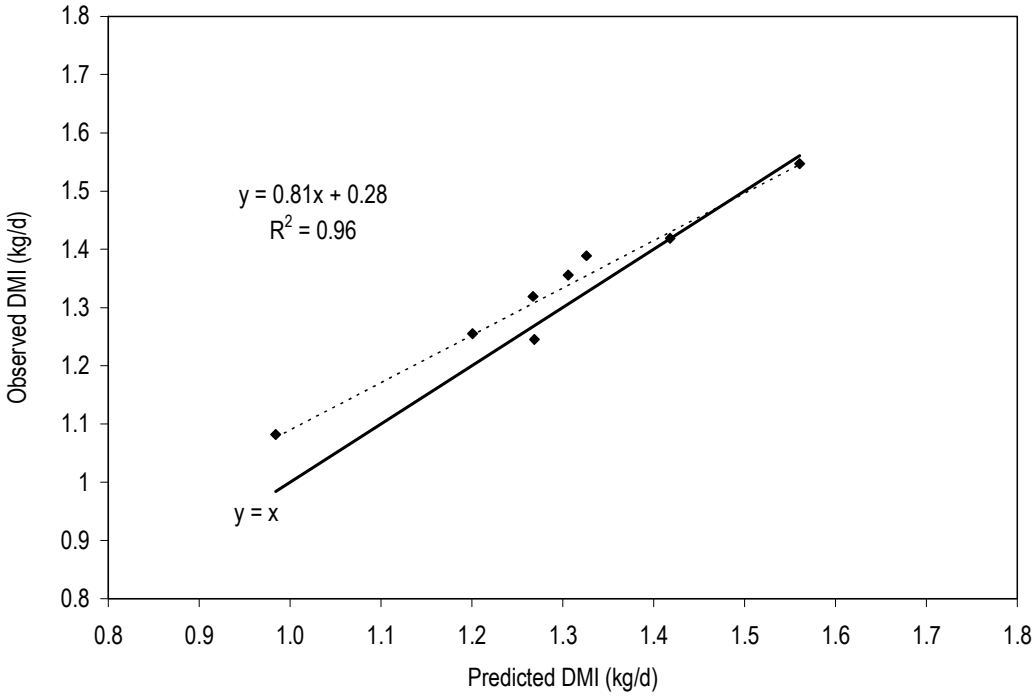

Figure 4.12 Predicted versus observed dry matter intake (DMI). Predictions based on Eq. 19 in which the observed ADG of Dorper and SA Mutton Merino males and females of Groups 2 and 3 were used

4.1.4 Predicted versus observed rumen pH

Rumen pH prediction is important because when pH is low, there is an inhibition of cellulolytic micro-organisms causing fibre digestibility to be suppressed, with a reduction of available NDF degradation rate and microbial efficiency (Tedeschi *et al*., 2000).

The average rumen pH was 6.05 and 6.46 for Dorper and SAMM lambs respectively ($P < 0.05$). There were no differences of rumen pH, when comparing between groups, breeds or sexes (Table 4.5).

In the SRNS model, as in the CNCPS, rumen pH is predicted as a function of the concentration of physically effective fibre (peNDF) in the diet (reported in Table 3.2) compared to the required peNDF. Indeed, the SRNS predicted a fixed value of pH of 5.9 for all animals because all the animals consumed the same diet. The predicted value was lower than those measured in the experiments (Tables 3.41 and 3.42) This probably happened because the SRNS cannot account for the effects of total daily intake of peNDF, for the direct effect of NSC on rumen pH and also assumes that total mixed ration (TMR) diets with frequent meals are fed. Refinement of the SRNS rumen pH prediction submodel is clearly needed.

Growth of fibre digesting bacteria is favoured with a pH 6.0 – 6.8, while growth of starch digesting bacteria is favoured by a pH 5.5 – 6.0. The rumen must thus maintain a pH near 6.0 for optimal growth of both bacterial populations (Hutjens, 2003). This is in line with the pH values observed in this study. Differences in pH therefore should not be over interpreted due to low numbers of animals used in this experiment and the fact that average pH values were close to optimum. Furthermore, models are characterized by more accurate (stronger) and less accurate (weaker) prediction equations. The rumen pH and peNDF prediction can be considered weaker points in the SRNS model, similar to the dairy and beef CNCPS and CPM Dairy models. More research is needed in refining these aspects of the model.

Table 4.5 Observed rumen pH of the different slaughter groups, breeds and genders

Breed	Stage	Female	Male	SEM
Dorper	1	$6.19^{a}{}_{x,1}$	$6.05^{a}{}_{x,1}$	0.08
	2	$6.39^{a}{}_{x,1}$	$6.53^{a}{}_{x,1}$	0.10
	3	$6.18^{a}{}_{x,1}$	$5.99^{a}{}_{x,1}$	0.08
	SEM	0.07	0.07	
SA MM	1	$6.30^{a}{}_{x,1}$	$6.46^{a}{}_{x,1}$	0.08
	2	$6.10^{a}{}_{x,1}$	$6.19^{a}{}_{x,1}$	0.11
	3	$6.28^{a}{}_{x,1}$	$6.18^{a}{}_{x,1}$	0.08
	SEM	0.08	0.07	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{12}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

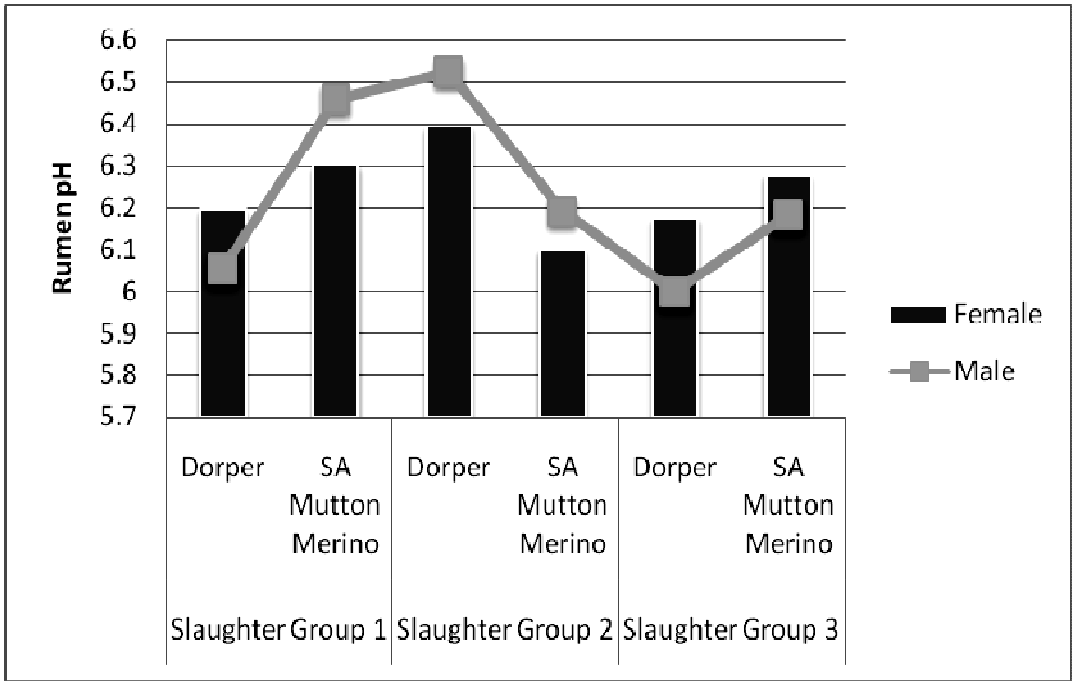

Figure 4.13 A schematic representation of the observed rumen pH

Chapter 5

Conclusion

The purpose of this study was to evaluate the Small Ruminant Nutrition System (SRNS) model's performance predictions for lambs under South African conditions using growth and body composition data of early- (Dorper) and late-maturing (South African Mutton Merino) indigenous sheep breeds. The Cornell Net Carbohydrate and Protein System biological model is continually being updated with new data. This has led to the development of the SRNS model, but up to now the SRNS model has only been validated using European sheep breeds under European conditions.

The results from the experimental trial using data on average daily gain (ADG), feed intake (DMI), empty body gain and the composition of the empty body gain were used to evaluate the model. The Dorper and SAMM lambs were divided into three slaughter groups for the determination of body composition data. Energy Value of Gain (EVG), fat and protein content on shrunk and empty body weight basis were compared with the corresponding values predicted by the SRNS. For determination of growth composition the lambs were divided into two growth periods, with ADG values and DMI's being measured during the experiment compared to the mean ADG and DMI predictions using the SRNS.

When comparing ADG's between the breeds, there were differences ($P < 0.05$), for the male lambs in the second period. Differences were also observed ($P < 0.05$) between the first and second period within the breeds of the male lambs. The SAMM is a late maturing breed and it was expected that they would have a higher ADG at the end of the experiment than the Dorper that is an early maturing sheep breed. This was not relevant for the female lambs, where the corresponding stages were similar. The predictions and conclusions of almost all studies were invariably calculated for healthy animals, however, it is normal in the production systems on farms for the animals to have encountered one, or usually more, some sort of parasite infection or viral disease.

Within the breeds between the stages, there were differences ($P < 0.05$) in feed intake for both sexes of the SAMM, and only the female Dorper lambs. Between the breeds the corresponding stages were similar, with the only exception of the second stage for the male lambs, with the SAMM having a higher

feed intake than the Dorper male lambs ($P < 0.05$). As expected, the CP concentration of the carcasses decreased and the fat concentration increased over time.

The effect of the low effective fibre content and the possible occurrence of rumen acidosis in the beginning of the experiment together with the incidence of the bluetongue virus have definitely influenced the accuracy of prediction. If further studies are to be conducted care should be taken to ensure that the animals are properly vaccinated. The experiment can also be conducted in a season that is not favourable for the spread of the virus. The over- and under-prediction of the ADG in the early and late stages of the growth of the lambs must still be investigated to determine if it was due to the bluetongue virus, which may have had an influence on some animals during the experiment, or an effect of the inability of the SRNS to compensate accurately for the influence of the indigenous sheep breeds under Southern African conditions. The DMI predictions made by the SRNS showed excellent agreement with experimental data, and thus can be applied with confidence. It was not possible to compare the measured BCS with the predictions of the SRNS because this model uses BCS in mature animals only.

Two different equations (Eqs. 2 and 6) were compared to estimate EVG as well as two sets of coefficients (Set A and Set B) for Eq. 2. Five different equations were compared to estimate the efficiency of conversion of Metabolisable Energy (ME) to Net Energy (NE) for gain, k_g (Eqs. 8, 9, 10, 11a and 11b). The correction factor to adjust for the increase in the size of the visceral organs as nutrient intake increases *(0.09x MEI x k_m),* and the S coefficient for the effect of gender on maintenance requirements were tested for relevance of use in the SRNS.

The model over-predicted the ADG at low ADG values, and under-predicted at high ADG values. For Eq. 2 Set B resulted in the best predictions when compared to Set A. Equation 2 also predicted the EVG the best when compared to Eq. 6. When the *(0.09x MEI x k_m)* correction factor was used it resulted in the under-prediction of ADG. The use of the gender correction factor, S, was also excluded. Body weight relative to mature weight of the animal is a more reliable determinant of the composition of gain than the absolute body weight. The ADG was best predicted by Eq. 11b (modified Tedeschi *et al*. (2004) equation), when compared to the different equations for the prediction of the efficiency of conversion of ME to NE for gain. The DMI predictions made by the original SRNS were also accurate. The evaluation of the SNRS predictions on the composition of the gain showed that this model over-predicted both the fat and the protein content of gain. The predictions were of acceptable accuracy but the precision was low. The low precision was probably due to the fact that the measured range of variation of fat and protein content of gain was fairly narrow

Models are representations of reality, and we are still learning about the reality of nutrition in the animal husbandry field, work will never be completed on the development of models. Further experimentation and adaptations to the SRNS model can only improve the predictions made and increase the fields of application. As for the applicability of the SRNS under South African conditions with indigenous sheep breeds, some further adaptations and fine-tuning should still be made to the predictions of the protein and fat content of the composition of gain, and these over-predictions should be kept in mind when using the SRNS.

Chapter 6

Critical Review

Worldwide, consumers have a strong tendency to buy high quality meat. The preference is for leaner, healthier cuts of meat and excessive fat impacts negatively on the price of meat. It is therefore a possibility that Dorper breeders could have selected against carcass fat and for larger carcasses over the years. This would have influenced the maturity type of the breed and made it more of a medium maturing breed than an early maturing breed. For future research Dorper lambs can be sourced from different farms with long term breeding goals and records.

In South Africa, the Dorper and South African Mutton Merino sheep breeds are two of the most popular breeds used by farmers in extensive and intensive farming systems. Results obtained from this experiment could therefore be applied over a broad spectrum. It is because of these reasons that they were selected as early and late maturing breeds for this experiment. If an earlier maturing breed, like the Pedi, was used, more marked differences could have been observed. The Pedi, however, is not a popular breed in South Africa, and of a much smaller population size than the before mentioned two breeds, for this reason it was excluded from this experiment. Should this trial be repeated, the Pedi can be included, and more animals per breed used.

Feed prices have increased dramatically the last couple of years. It has been a very difficult time for farmers to keep making a livelihood from farming. Future nutritional models should insure that the production systems the farmers employ stay economically sustainable. Most of South African and African farmers make use of extensive production systems. For a broader reach and applicability of the nutrition model, extensive systems should also be evaluated in future studies.

The long term objective of models such as the CNCPS and SRNS has been to provide a field usable model that accounts for a large proportion of the variation in diet formulation and animal performance and is based on a functional mathematical description of the biology of both growing and lactating cattle and/or sheep and their diet and management. Models such as the SRNS are evolutionary and many small contributions such as from this study will enhance and improve accuracy of prediction. Young researcher are encouraged to continue to improve the modelling accuracy of the SRNS but also to take note of lessons learned and cautions expressed in published research.

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APPENDIX A

Table A1 Dry Matter concentration of the intestines

Breed	Stage	Female	Male	SEM
Dorper	1	$23.54^{a}_{x,1}$	$19.96^{a}_{x,1}$	1.05
	2	$26.13^{a}_{xy,12}$	$24.19^{a}_{xy,12}$	1.29
	3	$28.33^{a}_{y,23}$	$25.68^{a}_{y,2}$	1.05
	SEM	0.93	0.93	
SA MM	1	$21.50^{a}_{x,12}$	$20.55^{a}_{x,1}$	1.05
	2	$20.25^{a}_{x,1}$	$26.84^{b}_{y,2}$	1.39
	3	$31.70^{a}_{y,3}$	$28.77^{a}_{y,2}$	1.10
	SEM	0.99	0.95	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

Table A2 Ash concentration of the intestines

Breed	Stage	Female	Male	SEM
Dorper	1	$1.11^{a}_{xy,12}$	$0.95^{a}_{x,1}$	0.13
	2	$1.44^{a}_{y,12}$	$0.93^{a}_{x,1}$	1.29
	3	$0.80^{a}_{x,2}$	$1.17^{a}_{x,1}$	0.13
	SEM	0.11	0.11	
SA MM	1	$1.44^{a}_{x,1}$	$1.20^{a}_{x,1}$	0.13
	2	$0.85^{a}_{xy,12}$	$0.84^{a}_{x,1}$	1.39
	3	$0.77^{a}_{x,2}$	$0.86^{a}_{x,1}$	0.13
	SEM	0.12	0.11	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

Table A3 Gross Energy concentration of the intestines (MJ/kg DM)

Breed	Stage	Female	Male	SEM
Dorper	1	$25.59^{a}_{x,1}$	$24.15^{a}_{x,1}$	0.55
	2	$27.31^{a}_{xy,12}$	$25.60^{a}_{xy,12}$	0.67
	3	$29.21^{a}_{y,23}$	$27.59^{a}_{y,23}$	0.55
	SEM	0.49	0.49	
SA MM	1	$26.30^{a}_{x,1}$	$23.67^{b}_{x,1}$	0.55
	2	$28.29^{a}_{x,12}$	$28.20^{a}_{y,23}$	0.73
	3	$31.19^{a}_{y,3}$	$29.63^{a}_{y,3}$	0.58
	SEM	0.52	0.5	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

Table A4 Intestine weights (kg)

Breed	Stage	Female	Male	SEM
Dorper	1	$2.71^{a}_{x,1}$	$2.86^{a}_{x,1}$	0.11
	2	$4.16^{a}_{y,2}$	$4.85^{b}_{y,2}$	0.14
	3	$5.45^{a}_{z,23}$	$5.55^{a}_{z,3}$	0.11
	SEM	0.10	0.10	
SA MM	1	$3.13^{a}_{x,1}$	$3.20^{a}_{x,1}$	0.11
	2	$5.00^{a}_{y,3}$	$5.04^{a}_{y,2}$	0.15
	3	$5.72^{a}_{z,4}$	$6.62^{b}_{z,4}$	0.12
	SEM	0.11	0.10	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xyz}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{1234}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)

Table A5 Total blood mass (kg)

Breed	Stage	Female	Male	SEM
Dorper	1	$25.59^{a}_{x,1}$	$24.15^{a}_{x,1}$	0.04
	2	$27.31^{a}_{xy,12}$	$25.60^{a}_{xy,12}$	0.05
	3	$29.21^{a}_{y,23}$	$27.59^{a}_{y,23}$	0.04
	SEM	0.03	0.03	
SA MM	1	$26.30^{a}_{x,1}$	$23.67^{b}_{x,1}$	0.04
	2	$28.29^{a}_{x,12}$	$28.20^{a}_{y,23}$	0.05
	3	$31.19^{a}_{y,3}$	$29.63^{a}_{y,3}$	0.04
	SEM	0.04	0.04	

^{ab} Means in the same row with different superscripts differ (P <0.05)

$_{xy}$ Means in the same column, within the same breed, with different subscripts differ (P < 0.05)

$_{123}$ Means in the same column, between the breeds, with different subscripts differ (P < 0.05)