

**Feeding the Ewe**  
**A Literature Review**

**Produced for:**  
**AHDB Beef and Lamb**

**Produced by:**  
**LSSC Ltd**

**Gill Povey, Lesley Stubbings and Kate Phillips**

**September 2016**

## Contents Page

|            |  | Page<br>No. |
|------------|--|-------------|
| <b>1.</b>  | <b>Introduction</b>                                  | <b>1</b>    |
| 1.1        | Objectives of Ewe Nutrition                          | 2           |
| 1.2        | Key Performance Indicators and Profitability         | 3           |
| 1.3        | Importance of Body Condition Scoring                 | 4           |
| 1.4        | Maximising Nutrient Contribution from Forage         | 5           |
| <b>2.</b>  | <b>Principles of Ruminant Nutrition</b>              | <b>6</b>    |
| 2.1        | Rumen Function                                       | 6           |
| 2.1.1      | Rumen Microbial Population                           | 6           |
| 2.1.2      | Energy   | 7           |
| 2.1.3      | Protein  | 9           |
| 2.1.4      | Factors Affecting Rumen Function                     | 11          |
| 2.2        | Dry Matter Intake                                    | 12          |
| 2.2.1      | Factors Affecting Dry Matter Intake                  | 12          |
| 2.2.2      | Prediction of Feed Intake                            | 13          |
| 2.2.3      | Maximising Feed Intake                               | 16          |
| 2.3        | Effect of Supplementary Feeding on Forage Intake     | 18          |
| 2.4        | Nutrient Requirements                                | 18          |
| 2.4.1      | Energy Requirements                                  | 19          |
| 2.4.1.1    | Latest Research and Recommendations for Requirements | 20          |
| 2.4.2      | Protein Requirements                                 | 21          |
| 2.4.2.1    | Latest Research on MP Requirements                   | 22          |
| 2.4.2.2    | Effect of MP on Ewe Parasitic Immunity               | 28          |
| 2.4.2.3    | Effect of Rumen Outflow Rate on MP Requirements      | 29          |
| 2.4.2.4    | MP Requirement Recommendations                       | 30          |
| 2.4.3      | Mineral, Trace Element and Vitamin Requirements      | 31          |
| 2.4.3.1    | Mineral and Trace Element Requirements               | 31          |
| 2.4.3.2    | Vitamin Requirements                                 | 37          |
| 2.5        | Forages  | 39          |
| 2.5.1      | Grazed Grass   | 39          |
| 2.5.2      | Grazing Other Crops                                  | 44          |
| 2.5.3      | Conserved Forages                                    | 49          |
| 2.6        | Concentrate Feeding                                  | 53          |
| <b>3.0</b> | <b>Feeding the Ewe During the Production Cycle</b>   | <b>57</b>   |
| 3.1        | Nutritional Management of the Ewe Up to Mating       | 59          |
| 3.1.1      | Energy and Protein Requirements Up to Mating         | 60          |
| 3.1.2      | Effects on the Foetus and Neonate                    | 60          |
| 3.1.3      | Effects Six Months Preceding Mating                  | 60          |
| 3.1.4      | Nutrition Weaning to Mating                          | 61          |
| 3.1.5      | Flushing – Just Prior to Mating                      | 64          |
| 3.1.6      | Prolific and Super Ovulated Ewes                     | 64          |
| 3.1.7      | Effect of Dietary Components on Fertility            | 65          |
| 3.1.8      | Worm Burden on Ewes Pre-Mating                       | 66          |

|            |   |            |
|------------|---|------------|
| 3.2        | Nutritional Management of the Ewe in the First to Third Months of Pregnancy   | 67         |
| 3.2.1      | Embryo Implantation and Survival – First Month of Pregnancy                   | 67         |
| 3.2.2      | Placental Growth – Second and Third Months of Pregnancy                       | 69         |
| 3.2.3      | Energy and Protein Requirements in Early and Mid-Pregnancy                    | 70         |
| 3.3        | Nutritional Management of the Ewe in the Fourth and Fifth Months of Pregnancy | 73         |
| 3.3.1      | Energy and Protein Requirements in Late Pregnancy                             | 74         |
| 3.3.2      | Factors Affecting the Interpretation of the Requirements                      | 76         |
| 3.3.3      | Effects of Under and Over Nutrition in Late Pregnancy                         | 76         |
| 3.3.4      | Lamb Birth Weight and Mortality   | 79         |
| 3.3.5      | Colostrum Production  | 79         |
| 3.3.6      | Pregnancy Toxaemia in Late Pregnant Ewes                                      | 82         |
| 3.3.7      | Use of Metabolic Profiles and Their Interpretation                            | 83         |
| 3.3.8      | Hypocalcaemia in Late Pregnancy   | 84         |
| 3.3.9      | Methods of Feeding Pregnant Ewes  | 85         |
| 3.3.10     | Winter Shearing and Forage Intake   | 88         |
| 3.3.11     | Housing Requirements  | 89         |
| 3.3.12     | Water Requirements  | 90         |
| 3.3.13     | Peri-Parturient Relaxation in Immunity and Faecal Egg Counts                  | 91         |
| 3.3.14     | Alternative Feeds and Their Relative Costs                                    | 92         |
| 3.3.15     | Feed Additives  | 93         |
| 3.4        | Nutritional Management of the Ewe in Lactation                                | 95         |
| 3.4.1      | Energy and Protein Requirements of Lactating Ewes                             | 96         |
| 3.4.2      | Animal Factors Affecting Milk Production                                      | 97         |
| 3.4.3      | Nutritional Factors Affecting Milk Production                                 | 98         |
| 3.4.4      | Ewe Body Condition and Milk Yield   | 101        |
| 3.4.5      | Ewe Feed Intake in Lactation  | 102        |
| 3.4.6      | Forage Intake and Supplementary Feeding                                       | 103        |
| 3.4.7      | Contribution of the Ewe to the Lambs Feed Requirements                        | 104        |
| 3.4.8      | Age of Lambs at Weaning   | 105        |
| 3.4.9      | Mastitis in Lactating Ewes  | 106        |
| 3.4.10     | Hypomagnesaemia in Lactation  | 106        |
| <b>4.0</b> | <b>Nutrition of Replacement Ewes</b>  | <b>108</b> |
| 4.1        | Foetal Growth   | 108        |
| 4.2        | Pre Mating Nutrition  | 109        |
| 4.3        | Nutrition of Pregnant and Lactating Replacements                              | 111        |
|            | References  | 114        |
|            | Appendices  | 133        |
|            | Appendix 1. Feed Database   | 133        |
|            | Appendix 2. Body Condition Scoring  | 134        |
|            | Appendix 3. Guide to Estimated Ewe Mature Live Weights by UK Breed            | 135        |

## 1. Introduction

This literature review is the background and reference document for the new 'Feeding the Ewe' manual for the UK sheep industry, commissioned by AHDB Beef & Lamb. The manual is targeted at consultants, veterinarians and progressive sheep farmers who can influence knowledge uptake in the wider sheep industry through advice, teaching and contact with farmers.

The previous 'Feeding the Ewe' manual was published by the Meat and Livestock Commission (MLC) in 1988. In 1993 the AFRC Technical Committee on Responses to Nutrients (TCORN) published the Energy and Protein Requirements of Ruminants (AFRC, 1993) which was widely adopted by the UK industry. The main focus was on dairy cows but requirements for sheep were also given derived from research reviews, current knowledge and extrapolation of the data. In 2004 the 'Feed into Milk' advisory manual (FIM, 2004) was published for dairy cows and this is now used in the UK dairy industry, but is not applicable to sheep, except for a comprehensive database of feed nutrient analysis as shown Appendix 1. A recently commissioned (DARDNI and AHDB) project, 'Feed into Lamb' has started at the Agri-Food and Biosciences Institute (AFBI) in Northern Ireland and will report in December 2018. The objectives of this project are to review and update the current UK sheep feeding standards for metabolisable energy and to assess any implications of changes to these standards on the environmental footprint of sheep.

Since 1993, there have been two key reviews on nutrient requirements for sheep, these are:

- Robinson (2002) - Review of Nutritional Standards for Sheep.
- Cottrill *et al.*, (2009) - A Review of the Energy, Protein and Phosphorus Requirements of Beef Cattle and Sheep.

As well as an increased understanding of nutrient requirements since the original 'Feeding the Ewe' manual, there has been significant improvement in sheep genetics. Terminal sire reference schemes and genetic selection for maternal traits and higher productivity has resulted in increased lamb birth weights, higher ewe milk production and improved early lamb growth (Marquez *et al.*, 2012).

Stubbings (2014) reviewed the gaps in knowledge in ewe nutrition and their impact on profitability. The issues highlighted were:

- AFRC (1993) protein requirements – are these adequate at key stages of the production cycle?
- sustainable supply of undegradable protein sources,
- the role of and requirements for trace elements,
- supplementing diets with omega 3 oils – is there a role for these?
- the effect of body condition scoring on productivity throughout the production cycle,

- foetal programming in utero as deficiencies in very early pregnancy have been associated with reduced lamb vigour,
- genetic interactions as the industry moves towards more forage based systems and the use of faster growing terminal sire breeds,
- nutrition of the replacement ewe from conception to breeding.

This review will focus on recent research findings and robust industry experience from consultants working with UK sheep farmers.

## 1.1 Objectives of Ewe Nutrition

The profitability of any ewe flock, whether extensive hill or intensive lowland, depends on lamb output from ewes at optimum performance. Good flock nutrition is fundamental to ewe performance through all the stages of the production cycle from weaning to mating, mating to lambing and through lactation. Nutrient requirements vary through the stages of production for maintenance, growth, reproduction, lactation and health. The whole annual production cycle must be considered to get the best results and not only the periods of high nutrient demand in late pregnancy and lactation.

Meeting the ewe's requirements at all stages of the production cycle will lead to:

- Optimum conception rate and embryo survival
- Higher lamb numbers and survival rate
- Stronger, more viable lambs
- Good colostrum supply and higher milk yield
- Fast lamb growth rate and a greater number of lambs weaned
- More lambs finished and potentially higher lamb value
- Good ewe health and fertility
- Lower flock replacement rate
- Higher margins from the enterprise

The cost of under nutrition at each stage of pregnancy was reviewed by Addah *et al.*, (2012). The review concluded that the path of intrauterine growth is influenced more by nutrition than genetics in pregnancy. Poor nutrition has an impact on the productivity of ewes through its negative effects on foetal losses, lamb birth weight, milk yield and ewe mortality. Rooke *et al.*, (2015) reviewed the maternal stressors in gestation. They concluded that maternal under-nutrition in the last third of pregnancy consistently impaired lamb birth weight and subsequent vigour and performance but earlier under-nutrition had a variable effect on performance. Feeding the ewe above her requirements did not have positive effects on lamb performance and ewe welfare.

In a detailed review, Robinson *et al.*, (2005), concluded that nutrition influences fertility directly by the supply of specific nutrients required for the process of oocyte and spermatozoa development, ovulation, fertilization, embryo survival

and establishment of pregnancy. Nutrition of the ewe was directly confirmed as a key factor for improving neonatal survival due to the effect on lamb birth weight, colostrum and milk production and ability to suckle (Dwyer *et al.*, 2016).

## 1.2 Key Performance Indicators and Profitability

Monitoring Key Performance Indicators (KPIs) can help sheep farmers benchmark performance compared with previous years and other flocks. Information needs to be collected at key stages in the production cycle to calculate KPIs. AHDB (2015a) (Sheep BRP Manual 4, Managing ewes for better returns) lists the key data to collect and suggests calculating the following KPIs with targets:

- Ewe to ram ratio – number of ewes each ram serves - target > 60.
- Scanning percentage – depends on flock system.
- Barren rate at pregnancy scanning - target <2%.
- Lambs born alive per 100 ewes – depends on flock system.
- Lambs turned out per 100 ewes – depends on flock system.
- Lambs reared per 100 ewes – depends on flock system.
- Ewe mortality - target <4%.
- Lamb losses from scanning to weaning - target <15%.
- Lamb weaning weight – depends on breed.

The AHDB annual Stocktake publication (AHDB, 2015f) gives performance figures for different systems (hill, lowland) to compare performance and a sheep KPI calculator is available in the tools section of the AHDB Beef & Lamb website.

Profitability depends on optimising the flock KPIs to have the best possible output with minimum costs. KPIs are important to guide decisions and maximise the profitability of the flock by showing where improvements can be made.

The AHDB Beef & Lamb is funding a Sheep KPI validation project (AHDB, 2014c), with the aim of identifying, developing and monitoring KPIs, using three commercial flocks. Phase I has been completed, which identified body condition scoring (BCS) as a valuable tool when done at key stages of the production cycle, see Section 1.3. Phase II of the project will assess performance of flocks for two further years and aims to demonstrate the importance of body condition scoring on both ewe and lamb performance and further understand the most important KPIs. This project will conclude in July 2017.

### 1.3 Importance of Body Condition Scoring

Assessing body condition is an essential management tool for all flock managers to check ewe body reserves at each stage of production. It can be used to drive decisions on ewe management. BCS is the manual assessment of the muscle and fat cover over the spine behind the last rib in the loin area of the sheep. A description of how to BCS (AHDB, 2013a) and the traditional five point scoring system is shown in Appendix 2. It is easy to learn and highly repeatable, especially when the same person assesses ewes within a flock on each occasion. It is common place to use half scores, e.g. 2.5 or 3.5, using a ten point scale. Ideally all ewes should be scored so that they can be managed to increase or reduce body condition to meet target for the stage of production. See AHDB (2015a), Sheep BRP Manual 4, Managing ewes for Better Returns for an overview of BCS.

Ensuring ewes have target muscle mass and fat cover for the system and the time of year leads to improved fertility, increased lamb performance and reduced incidence of metabolic disease. Target BCS varies by sheep system (e.g. hill vs. lowland), breed of ewe, time of the year and ewe prolificacy.

The AHDB Sheep KPI Validation Project: Phase I, (AHDB, 2014c) concluded that BCS at key stages of the production cycle appears to be an appropriate KPI to predict weaned lamb weight as follows:

- BCS (with ewe weight) at mating, and weight gain from weaning to mating is independently associated with litter size and lamb weight.
- BCS at scanning is associated with litter weight at lambing and weaning.
- BCS at lambing is associated with lamb eight week and weaning weights.
- Loss of BCS from lambing to 8 weeks and/or weaning is associated with individual and combined weaning weights.

Interim data from lambing 2014 has been analysed (Wright *et al.*, 2016) and it was concluded that BCS improved with successive seasons on all three farms from the start of the project and continues to improve. On two of the farms recorded, ewe BCS and live weight had a significant ( $P<0.05$ ) impact on lamb performance to weaning. Ewe BCS continues to be an important KPI for commercial farms and has an impact on lamb performance through to weaning.

The Lifetime Wool project ([www.lifetimewool.com.au](http://www.lifetimewool.com.au)) involving Merinos in Australia has clearly demonstrated the effect of BCS on conception rates, litter size and lifetime productivity of ewes. Ewes in higher BCS at mating conceive more lambs and have higher twinning rates. In Merinos there is a linear relationship between BCS 1.5 and 4.5. The 'lifetimewool' on-farm demonstration sites in 2005 had an average response of about 24 extra

foetuses scanned for each additional CS at joining. The response is farm specific, which may relate to weaning BCS and the longitudinal effects of BCS.

Research in New Zealand with triplet bearing ewes showed that ewes of BCS 3 compared to those of BCS 2.5 in late pregnancy had lambs with significantly higher ( $P<0.05$ ) survival rates and weaning weights (Kenyon *et al.*, 2013).

Body weight of a ewe is not a good substitute for BCS and it cannot be judged by eye, even in recently shorn ewes. Van Burgel *et al.*, (2011) found that small changes in condition between scores 2 and 3 in Merino ewes had large effects on ewe welfare and flock profit. They concluded that BCS is the most appropriate alternative to live weight measurements for managing the nutritional profile of ewes.

#### **1.4 Maximising Nutrient Contribution from Forage**

The most economical way of meeting nutrient requirements is to maximise forage (grass, brassicas, conserved forage) intake. When nutrient demands are high the best quality forage should be offered as this will maximise intake and reduce the need for concentrate supplementation. The use of high energy dense concentrates helps to maximise forage intake as there is less forage substitution. (See Section 2.3, effect of supplement feeding on intakes).



## **2. Principles of Ruminant Nutrition**

### **2.1 Rumen Function**

Good rumen function is fundamental to the production and health of the ewe at all stages of the production cycle. Rumen function depends on a mutually beneficial relationship between the animal and the microbial population in the rumen. Food, predominantly plant material is consumed by the animal, digested and fermented by the rumen microbes to produce mainly short chain fatty acids, microbial protein, carbon dioxide and methane. The acids are absorbed through the rumen wall and the protein is absorbed in the small intestine. The microbes not only provide the host with a source of energy, but also with proteins, vitamins and other nutrients essential for cell maintenance and production. Favourable rumen fermentation conditions must be provided to the animal to permit the growth of large numbers of diverse microbes for digestion.

McDonald *et al.*, (2011) describes the ruminant's teeth and chewing actions to efficiently grind fibrous materials. Food is diluted with copious quantities of saliva, first during eating and again during rumination, with 10 litres a day typically produced in the adult sheep. Food is broken down by physical and chemical means as the contents of the rumen are continually mixed by rhythmic contractions of the rumen wall, and by rumination. Rumination (or chewing the cud) is when food is drawn back by contraction up the oesophagus to the mouth where the food is chewed again before returning to the rumen. This often occurs when sheep are lying down and the time spent will be proportionate to the fibre content of the diet - the more fibre the longer the ewe will ruminate.

Saliva is important for dilution of food and for ease of swallowing but also for buffering the rumen to maintain the optimum pH level for microbial function. Under normal conditions acids produced by the microbes can reduce rumen pH to 2.5 – 3.0, but pH is maintained near neutral at 5.5 – 6.5 by phosphate and bicarbonate in saliva.

#### **2.1.1 Rumen Microbial Population**

Mackie *et al.*, (2002) review in detail the microbial ecology of the sheep rumen. The microflora comprises of complex communities of bacteria, protozoa, anaerobic fungi and bacteriophages. Rumen microorganisms operate together as a 'soup' to break down food, with the different species selecting different energy substrates to digest and ferment. The products of metabolism (e.g. short chain fatty acids) differ depending on the microbial group (e.g. bacteria, fungi), and the major substrates metabolised (e.g. cellulose, starch).

For optimum rumen function, food must be held long enough in the rumen to allow time for the slow breakdown of plant cell walls, and also the microorganisms must receive a balanced supply of nitrogen and energy from the animal's diet to sustain themselves and reproduce.

Maintaining a stable population of microorganisms is fundamental to efficient digestion of food and passage through the rumen. Food consumed by a ruminant needs to feed the rumen as well as the animal and the balance between the two is important for animal well-being and productivity. Annison *et al.*, (2002) published a detailed review of ruminant digestion and metabolism of energy and protein. The following sections give a summary of the nutrient processes.

### **2.1.2 Energy**

All feedstuffs have a gross energy value and ruminants are typically rationed on the metabolisable energy system (AFRC, 1993). Metabolisable energy (ME) intake of a feed is the portion that can be utilised by the animal and is expressed as:

ME = Gross energy of feed – energy in faeces – energy in urine – energy in gases.

All feedstuffs have a ME value, updated recently in the Feed into Milk Database, partly shown in Appendix 1.

Feed supplies ME in the form of cellulose, fibre, sugars, starch and fats and oils. These energy sources are hydrolysed by various routes in the rumen to pyruvic acid, which is then fermented into acetic, propionic and butyric acids as well as carbon dioxide and methane gases. The volatile fatty acids are absorbed from the rumen and metabolised in the liver to support maintenance and production in the tissues. The extent of energy breakdown and the proportions of acids are determined by the nature of the food. Lignin is particularly indigestible, and is thought to interfere with the digestion of other nutrients.

The key carbohydrate types, fibre, starch and sugar ferment and are digested at different rates. Fibre is the slowest, starch is faster and sugar has the fastest fermentation rate in the rumen. A mixture of all three carbohydrate types is required to meet the energy requirement of the ewe. AFRC (1993) describes these sources of energy as fermentable metabolisable energy (FME), which supply energy to the rumen microbes. Fats and oils cannot supply energy to the rumen microbes.

Different diets promote varying production of volatile fatty acids in the rumen, and this relies on having a good population of various microorganisms. Table 1 shows the changes in volatile fatty acid production in sheep when the concentrate level increases when offered hay. As the level of concentrate increases the production of volatile fatty acids is reduced. Also the proportion of acetic acid falls and the proportion of propionic acid increases as forage level is reduced.

*Table 1. Volatile fatty acid production of sheep fed on a hay and concentrate diet of different proportions (from McDonald et al., 2011)*

| <b>Diet<br/>Hay:<br/>Concentrate</b> | <b>Total VFA<br/>(mmole/litre)</b> | <b>Acetic Acid<br/>(molar<br/>proportion)</b> | <b>Propionic<br/>Acid (molar<br/>proportion)</b> | <b>Butyric Acid<br/>(molar<br/>proportion)</b> |
|--------------------------------------|------------------------------------|---|--|--|
| 1: 0                                 | 97                                 | 0.66  | 0.22   | 0.09   |
| 0.8: 0.2                             | 80                                 | 0.61  | 0.25   | 0.11   |
| 0.6: 0.4                             | 87                                 | 0.61  | 0.23   | 0.13   |
| 0.4: 0.6                             | 76                                 | 0.52  | 0.34   | 0.12   |
| 0.2: 0.8                             | 70                                 | 0.40  | 0.40   | 0.15   |

Mature fibrous forages, such as hay lead to volatile fatty acid mixtures in the rumen containing a high proportion of acetic acid. While less mature forages e.g. grass or silage tend to lead to a higher proportion of propionic and lower proportion of acetic acid. The addition of concentrates to a forage diet will also increase the proportion of propionic at the expense of acetic acid as shown in Table 1. McDonald *et al.*, (2011) found that grinding and pelleting of forage had little effect on the volatile fatty acid proportions when the diet was only forage, but it causes a switch from acetic to propionic if the diet contains concentrates.

Fats and oils (lipids) are hydrolysed in the rumen by bacterial lipases to saturated fatty acids which accounts for the relative hardness of carcass fat.

The rumen microorganisms adapt to digest and ferment different carbohydrate sources offered in forage and concentrate diets. This adaptation does not happen instantly so any changes in diet should be done gradually over a number of days. Energy and protein digestion should not be thought of as separate systems as FME is used by the microorganisms to digest protein. Hence energy and protein digestion work together and this is called the MP system (AFRC, 1993).

### 2.1.3 Protein

Feed provides two types of crude protein to the ruminant:

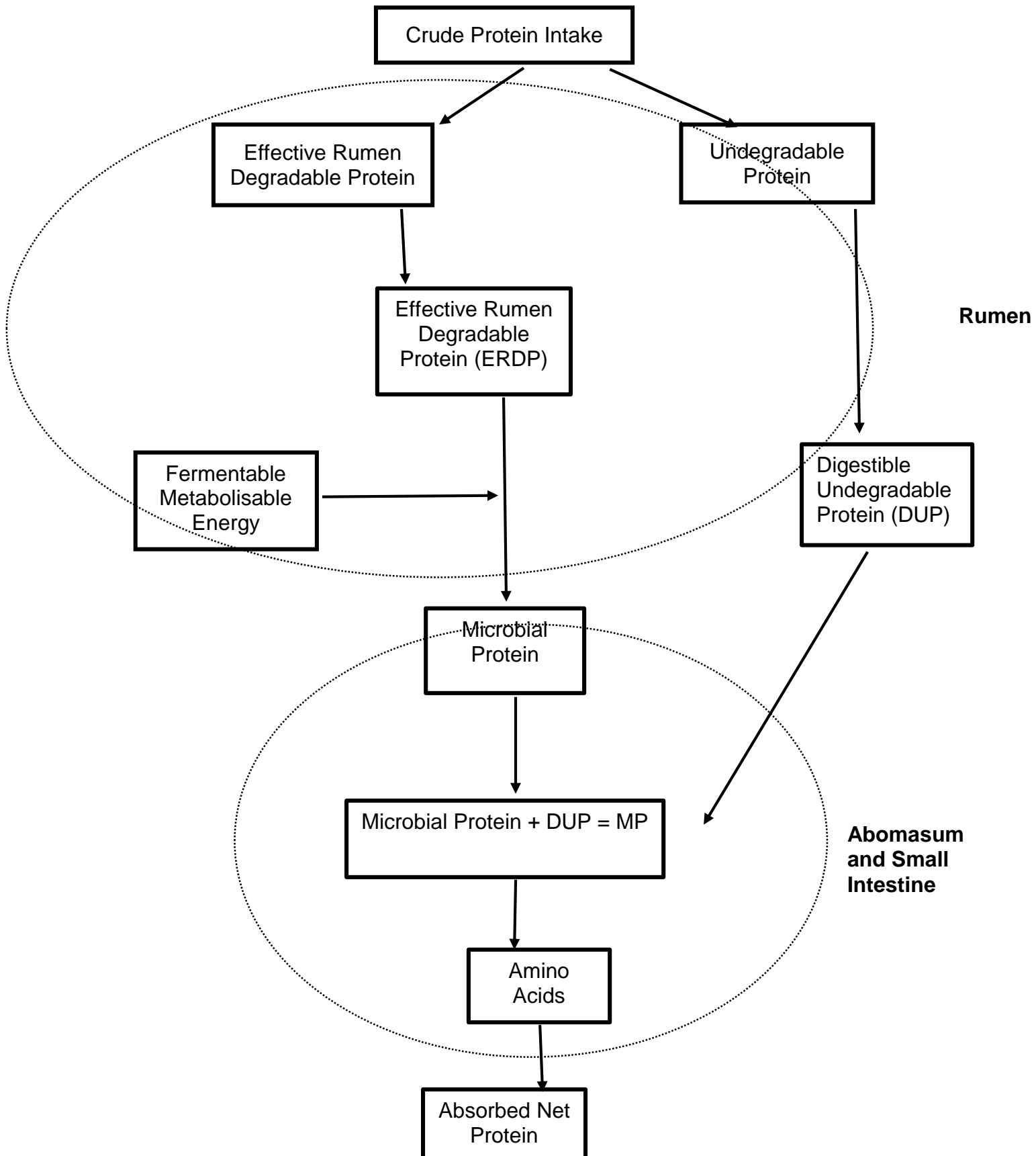
- Rumen degradable protein (RDP), which is broken down in the rumen
- Digestible undegradable protein (DUP) or bypass protein, which passes through the rumen undigested.

Both types of protein are important to the animal, in simple terms RDP feeds the microorganisms in the rumen and DUP is absorbed in the small intestine and feeds the animal along with microbial protein.

McDonald *et al.*, (2011) summarise protein digestion as, RDP proteins are hydrolysed in the rumen to peptides and then to amino acids. The bacteria use amino acids and ammonia from non-protein sources of nitrogen, to produce microbial protein. Microbial proteins pass from the rumen to the abomasum and small intestine where they are digested, along with DUP, by the host animal's digestive enzymes.

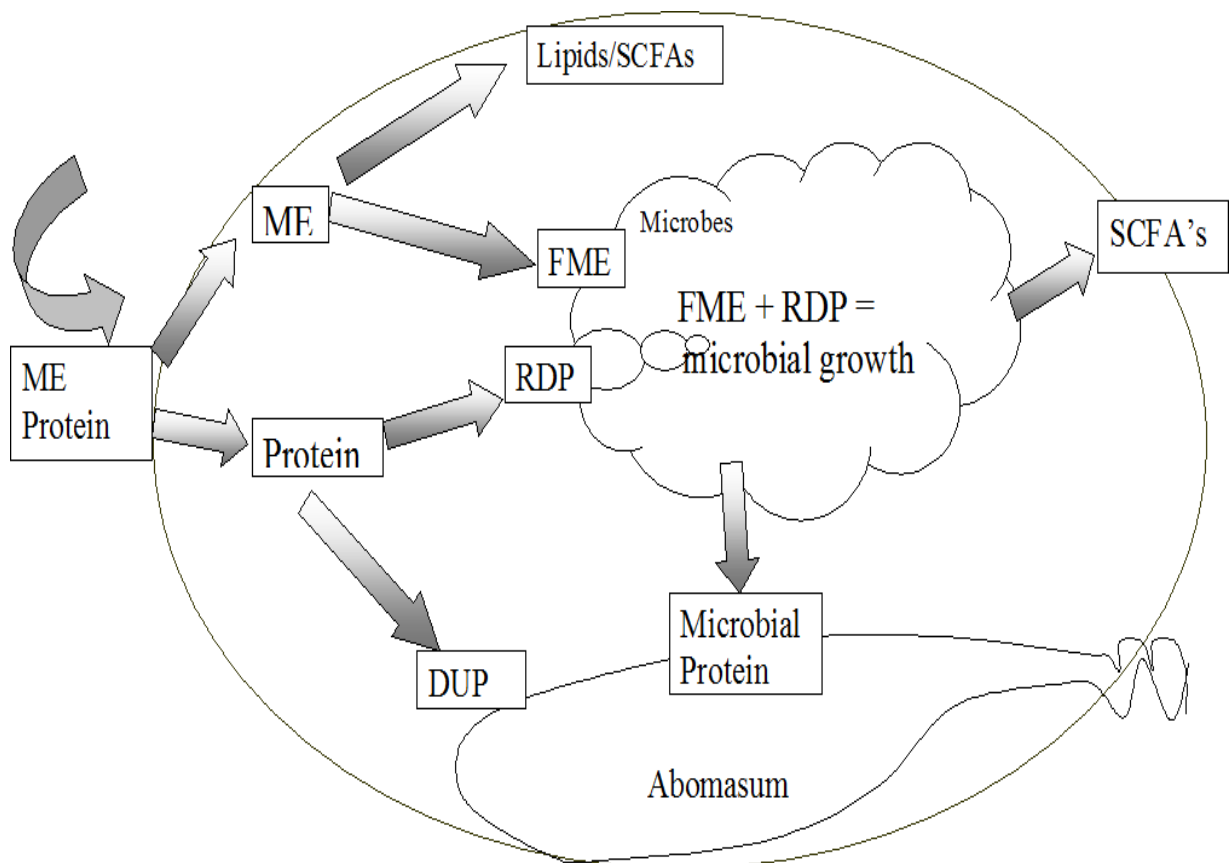
AFRC (1993) describes the metabolisable Protein System. Metabolisable Protein (MP) is defined as the total digestible true protein (amino acids) available to the animal for metabolism after digestion and absorption of the feed. The two components of MP are microbial protein from the rumen and DUP. The energy used by the microorganisms in the rumen, to produce microbial protein is FME. Figure 1 shows a simplified outline of the MP system. At every step of the process there are losses of protein as it is broken down and digested, and this waste is passed out of the animal in the urine, faeces and as gases.

Figure 1. Outline of the MP System



Each component of the diet, whether forage or concentrates, supplies sources of energy and protein required by the ewe. The relationship between energy and protein and metabolism in the rumen is shown in Figure 2.

Figure 2. Diagram of energy and protein metabolism in the rumen (Stubbings, personal communication)



#### 2.1.4 Factors Affecting Rumen Function

The population of microorganisms in the rumen needs to be stable for efficient rumen function. Any sudden change in feed or the animal's situation can affect the microorganisms which can destabilise rumen fermentation and lead to a reduction in feed intake and performance, and potentially cause acidosis.

To maintain stable rumen function, consideration should be given to:

- Minimising any sudden changes in food type (e.g. introduction of concentrates) or food quality (e.g. move to high cereal based diets).
- Frequency and timing of feeding - see Section 2.2.3 (Maximising feed intake).

- Feeding whole grain (rather than crushed or ground), slows fermentation in the rumen and allows the microorganisms more time to digest the starch.
- Reducing stress, by planning stressful events such as handling, transporting and movement (e.g. change of field, moving from housing to grazing) since any period of fasting can affect the rumen population.
- Compromised health (e.g. lameness, worms) leading to periods of low feeding rate or fasting.

-  
See Section 2.2.3 on maximising feed intake for more factors.

## **2.2 Dry Matter Intake**

### **2.2.1 Factors Affecting Dry Matter Intake**

Forbes and Mayes (2002) describes voluntary food intake and diet selection in sheep. McDonald *et al.*, (2011) reviewed the key food characteristics, and animal and environmental factors affecting voluntary food intake in ruminants. The key points are summarised below:

#### Food factors

- Food intake is controlled at the metabolic level and is likely to be a chemostatic mechanism involving volatile fatty acids absorbed from the rumen signalling the need to stop or start feeding and at the level of the digestive system e.g. rumen fill.
- Feeding a high energy diet is controlled by the volatile fatty acids, acetate and propionate, but when the diet consists only of forages, intake is limited by the rate of digestion and rumen fill.
- Forages with a high content of cell walls (high in fibre) are digested slowly, are low in digestibility and have reduced intake. There is a positive relationship between intake and digestibility, the higher the digestibility of the feed the higher the feed intake - as food is broken down more quickly and has a faster rate of passage through the rumen e.g. good grass silage is more digestible and promotes higher intake compared to feeding straw or poor hay.
- The main component that determines digestibility is neutral detergent fibre, a measure of cell wall content. Disruption of the cell walls by mechanical means such as chopping can increase intake.
- Ruminants may eat to maintain a constant amount of dry matter in the rumen.
- Nutrient deficiencies that reduce the activity of the rumen microbes can reduce intake, e.g. nitrogen and some minerals such as phosphorus and cobalt.

### Animal factors

- In pregnant ewes there are two opposing factors which influence intake. There is an increased need for nutrients for foetal development, but in the late stages of pregnancy, the effective volume of the rumen is reduced as the foetuses increase in size. This may lead to a reduction of intake, especially if the diet is predominately poorer quality forage, at this critical feeding time. However it would appear that ewes increase the rate of passage of feed through the rumen so that intake does not fall dramatically.
- Ewes in lactation have a huge demand for energy and without the restriction of foetuses, feed intake increases rapidly after lambing.
- Ill health including endo and ecto-parasite infestations, stimulates the immune system and this is thought to reduce feed intake.

### Environmental factors

- In an intensive system where ewes are offered conserved forage and supplementary feed, there are many factors affecting intake such as ease of access, feeding space, competition, freshness and quality of the feed, timing and frequency of feeding.
- When grazing forage, intake is influenced not only by the chemical composition and digestibility of the herbage but also its physical structure and distribution. Intake of herbage is affected by bite size, bite rate and grazing time.
- A comprehensive review of the constraints on feed intake by grazing sheep was undertaken by Weston (2002).
- In a good grazing environment with short dense swards of high digestibility, sheep will have optimum levels of intake so long as other factors do not affect them e.g. weather conditions, distance to water, herbage contamination.

### 2.2.2 Prediction of Feed Intake

Ewes are generally fed *ad libitum* which makes an estimate of feed intake difficult. However, an accurate prediction of feed intake, both forage and total intake, is fundamental to any nutritional model providing feeding recommendations. This is to ensure maximum forage intake and efficient, stable rumen function. However, feed intake is difficult to predict as it is thought to depend on many different factors including body weight, stage of production and feed quality and digestibility. In a research environment, feed intake is difficult and expensive to measure with so many factors affecting it and there have been very few studies undertaken. Studies also tend to be undertaken in growing sheep rather than pregnant or lactating ewes. To get accurate information on intake animals need to be individually housed but this then affects the natural intake of a flock animal.



Feed intake is expressed on a dry matter basis (fresh weight of feed x dry matter of feed/100). In the UK, predictions for ewes on conserved forages (hay and silage) were published in AFRC (1993) but information on estimating intakes of grazed grass is difficult to achieve and uncertain.

AFRC (1993) details feed intakes for the final seven weeks of pregnancy for ewes by weight and litter size based on the dry matter intake required to supply the energy and protein requirements specified. Equations to predict intake were considered based on hay or silage quality and the level of concentrate offered, but were found to predict levels of intake which were not high enough to meet the nutrient requirements of the ewe. It was concluded that a level of ewe weight loss in late pregnancy is acceptable.

Estimates of feed intake are also shown in AFRC (1993) for lactating ewes based on ewe weight, milk yield and body weight loss. Again the predicted intakes are those required to supply the amount of energy specified and are not the appetite of the ewe.

A review of nutrient requirements was undertaken by Cottrill *et al.*, (2009). The AFRC equations were reviewed and it was concluded that over the previous 25 years there had been considerable progress in understanding both forage and animal characteristics that influence intake but there were no new robust models of intake available. The review suggested examining Australian models for predicting grazed grass intakes in UK conditions. The use of near infra-red spectroscopy calibrations was also suggested for predicting grass silage intakes. Both suggestions still require more research in the UK to produce robust intake models.

A research team at the SAC carried out a long term study on how body weight, breed, sex and feed composition affected feed intake in sheep (Lewis and Emmans, 2010). Data was collected over a five-year period using both sexes of three breeds (Suffolk, Scottish Blackface and their crosses) from weaning to mature weight. The sheep were fed *ad libitum* on six different diets, varying in protein and energy. The results found that the relationship between intake and body weight on a given feed varied considerably between breeds and sex. At the same weight and sex, males ate more than females and Suffolks ate more than Blackfaces. Much of the variation, but not all, could be removed by genetic scaling, comparing the sheep at the same percent of mature weight. Feed intake was found to be directly proportional to body weight up to about half of mature size.

This research was in non-productive sheep but showed the variation by breed and feed quality. It was concluded that the use of genetic scaling requires further investigation in different breeds of sheep, pregnant and lactating ewes and on commercial feeding systems using fresh and conserved forages.

Pulina *et al.*, (2013) reviewed models for estimating feed intake in small ruminants, covering meat and milk producing sheep and goats. The review assessed the accuracy of prediction models for pregnant and lactating ewes reported by AFRC, NRC and INRA. The conclusions were:

- There has been large variation in experimental approaches and the factors affecting intake considered.
- The accuracy of models for estimating intake of grazing sheep is very low.
- Feeding experiments remain fundamental for better modelling and understanding between feeds and small ruminants.
- There is a need for biological and theoretical frameworks in which experiments should be carried out.

Since the review by Cottrill *et al.*, (2009), neither the research by Lewis and Emmans, (2010) or the review by Pulina *et al.*, (2013) has recommended any changes or updates to the AFRC (1993) prediction models. Consultants have developed their own feed intake estimates when rationing ewes in late pregnancy and lactation based on their experience. SAC has produced a guide of predicted daily forage dry matter intake as a percentage of ewe live weight for rationing ewes, as shown in Table 2 (SAC, 2009a).

*Table 2. Estimated daily forage dry matter intake as percentage of ewe live weight in twin bearing ewes in pregnancy and lactation when fed concentrates (SAC, 2009a).*

| <b>Forage</b> | <b>Forage ME (MJ/kg DM)</b> | <b>Pre-lambing weeks 12 to 3 (% ewe live weight)</b> | <b>Pre-lambing weeks 0 to 3 (% ewe live weight)</b> | <b>Lactation weeks 0 to 3 (% ewe live weight)</b> |
|---------------|-----------------------------|--|---|---|
| Straw         | 6.5                         | 1.0  | 0.8   | n/a   |
| Average Hay   | 8.5                         | 1.5  | 1.1   | 1.2   |
| Good Hay      | 9.5                         | 1.8  | 1.4   | 1.5   |
| Poor Silage   | 9.5                         | 1.4  | 1.2   | 1.3   |
| Good Silage   | 10.5                        | 1.6  | 1.4   | 1.6   |

When rationing it is important to have an accurate assessment of ewe live weight for each flock and to achieve this a range of different sized ewes should be weighed. Mature live weights of different breeds of sheep are shown in Appendix 3. As a guide SAC (2009b) recommends estimating ewe

lambs/hoggets as 60% and shearlings/gimmers as 80% of mature live weight for the breed.

An estimate of potential changes to percentage of ewe live weight as a guide for ewes in late pregnancy carrying single or triplet lambs can be calculated from AFRC (1993). Single bearing ewes can be fed at 15% less and triplet bearing ewes 5% more than twin bearing ewes.

In practice, for sheep fed *ad libitum*, conserved forage should contribute at least 60% of the total intake. If there is no pregnancy scanning information available, then it should be assumed that the ewe is carrying twin lambs for rationing lowland type ewes.

For ewes offered total mixed rations (TMR) total intake predictions need to be increased by 5 to 10% (See Section 3).

### **2.2.3 Maximising Feed Intake**

To achieve the best performance from ewes and their offspring, feed intake needs to be maximised, but especially at critical times, such as in pregnancy and lactation. There are a number of practical considerations which will help optimise feed intake in the ewe:

#### **Frequency and timing of feeding**

Forage needs to be available at all times to maintain stable rumen function. Fresh feed should be added frequently to stimulate intake. Freshening feed by turning over or pushing up forage encourages sheep to come to the feeding point and increases intake. Concentrates should be fed in two feeds per day (or included in a TMR) to help stabilise the rumen by having two peaks of high energy and protein a day. If fed in one large feed per day, this causes a large spike of energy release in the rumen, reducing the rumen pH and potentially reducing forage intake.

Robinson (personal communication, 2016) suggests that the timing of feeding each day is important, as ewes anticipate feeding times and adjust their grazing or forage intake and accompanying saliva flow. Erratic feeding times, particularly with concentrates can upset the rumen microflora by interfering with the ewe's natural rumen buffer, saliva. To keep rumen function stable and maximise intake ewes should be fed consistently at the same times each day.

#### **Presentation of feed**

Feed offered to ewes should be of high quality and digestibility, it should be fresh and free from moulds and contamination to promote intake. As discussed in Section 2.2, the higher the digestibility, the faster the rate of passage through the rumen and the higher the intake. Feed, forage and concentrates, need to

be consistent with as little variation as possible. If change to a new batch of forage or concentrate with different nutritional value is required, this should be done gradually over a few days to allow the rumen microflora to adjust.

Robinson (personal communication, 2016) observed that feed needs to be offered in a controlled situation, especially concentrate feed to ensure all ewes have a good chance of getting their share. Late arriving ewes often do not get sufficient food and early arriving ewes get more than their share in a short space of time, which can lead to acidosis. In this situation both types of ewe are prone to prolapse and pregnancy toxemia.

The use of TMR has been widely observed to increase intakes. Forage and concentrates are mixed together, usually in a feeder wagon. The ewes get a consistently balanced intake of forage and concentrates throughout the day, with none of the large shifts in rumen pH associated with meals of concentrates.

### **Access to feed**

To encourage intake access to feed needs to be good and the set up for feeding needs to minimise wastage and spoilage. Adequate forage feed face must be available to allow ewes to eat whenever they need to and availability should be monitored - this is important with the use of ring feeders where often the sheep cannot reach the middle of the bale.

Providing adequate trough or feed face ensures all ewes get their fair share. As a guide space allowances are:

- Forage ad-libitum 12 – 15cm per ewe
- Rationed concentrates 45cm per ewe.

If feeding outdoors, troughs should be moved regularly to minimise poaching and cleaned regularly to prevent build-up of stale food. Floor feeding, using a dry pellet or cob, is a good option as ewes graze the feed from the bedding or off the grass, allowing intake over a longer period and reducing sudden changes in rumen pH. When using floor feeding, the bedding or grass needs to be clean to prevent spread of disease.

### **Grazing**

Factors affecting, choice of food were reviewed by Forbes and Mayes (2002) and feed intake by grazing sheep was reviewed by Weston (2002). A practical guide detailing the utilisation of grass by management of grass growth and grazing programmes is given in AHDB (2016d) (Beef and Sheep BRP Manual 8, Planning grazing strategies for Better Returns).

### **2.3 Effect of Supplementary Feeding on Forage Intake**

In periods of high nutrient demand or when poor quality forage is offered, supplementary concentrates will be needed to meet the energy and protein requirements of the ewe. Concentrates can be manufactured compound feeds or raw materials e.g. barley or soya bean meal, offered as straight ingredients or in a mix.

Offering a supplement feed has a variable effect on forage intake dependant on the quality and digestibility of both the forage and the supplement. Early trials were completed by Orr and Treacher, (1984 and 1989) who studied the responses of pregnant ewes offered concentrate feed with hay or grass silage, respectively. McDonald *et al.*, (2011) simply explains the relationship between supplementary feeding and responses in forage intake. If the forage digestibility is low (e.g. cereal straw with 0.4 digestibility) total intake will be increased more than if the digestibility is high (e.g. young grassland herbage with 0.8 digestibility). Concentrates offered with low digestibility forage tend to be eaten in addition to the forage, while those offered with high digestibility forage replace the forage. The rate of forage replacement by a concentrate is known as the substitution rate.

Dove (2002) reviews the principles of supplementary feeding focusing on the effect of supplementation on grass intake. Dove explained that the addition of supplements alters rumen fill, dry matter in the rumen, digestion rate of cell wall constituents, pH and ammonia concentration in the rumen, synthesis of microbial protein, outflow rate from the rumen and available energy and protein to the animal. It was concluded that substitution, although simple in concept, is complicated in practice as it is affected by stage of production of the ewe, quality and availability of the forage and quality and quantity of the supplement.

It is widely accepted that to maximise forage intake, supplements need to be of high quality. The nutrients should be supplied in high density form and this reduces the substitution effect especially on highly digestible forages such as young grass, good silage or hay. Feeding less of a high quality concentrate feed not only maximises forage intake but is more cost effective. When larger quantities of low density concentrates are fed it often costs more, reduces forage intake and destabilises rumen function.

### **2.4 Nutrient Requirements**

The energy and protein requirements of sheep, currently used by the industry, are presented in AFRC (1993). The manual concludes that the nutrient requirements of the ewe are defined as a function of body weight, body condition and number of lambs carried and are not influenced by breed.

Although feed type (e.g. forage digestibility), energy density and environment are considered as variables.

### 2.4.1 Energy Requirements

The UK ME system was first proposed for use by the Agricultural Research Council in 1965 and the current ME system is based on this. AFRC (1993) describes the ME requirements for sheep which are based on the relationship between the ME intake from the feed or diet and the net energy utilised or retained in the animal. Net energy is calculated by subtracting the heat increment from the ME. Total requirements are calculated from the efficiency of utilisation of the net energy for the relevant metabolic processes such as, maintenance, live weight gain, milk production, foetal growth and wool growth.

AFRC (1993) presents ME requirements for growing, pregnant and lactating sheep which are currently used in rationing programmes in the UK. A summary of the UK system is presented in McDonald *et al.*, (2011).

Robinson (2002) reviewed the nutritional standards for sheep and made two recommendations with regard to the AFRC ME requirements:

- There is no allowance for the effects of dietary ME concentration on the efficiency of ME utilisation for foetal growth.
- Higher and more realistic lamb birth weights should be used when calculating ME requirements for pregnant ewes especially those carrying large lambs from lean terminal sire matings, such as the Texel and Suffolk.

Cottrill *et al.*, (2009) undertook a full review of the energy requirements for sheep. Their work examined the energy feeding systems used in the UK, the USA, Australia and France. They concluded that the main difference between the systems was the calculation of maintenance energy requirements. AFRC (1993) calculations potentially underestimate energy maintenance requirements for sheep by up to 28%. This could result in lower performance than expected in growing, pregnant and lactating sheep. The review advised an urgent need to revise the energy requirements in line with increased requirements adopted for dairy cows as part of the 'Feed into Milk' project. The review also suggested that for sheep the Cornell Net Carbohydrate and Protein System (Cannas *et al.*, 2004) should be further examined for its applicability to UK conditions.

Cannas *et al.*, (2004) reviewed the Cornell Net Carbohydrate and Protein System as a mechanistic model for predicting nutrient requirements and feed biological values for sheep. The system can be used to accurately predict nutrient requirements especially when rumen protein balance is positive. They

concluded that further evaluation is needed to improve the system's ability to predict animal performance when rumen protein is deficient.

In autumn 2015, scientists at AFBI were commissioned by DARDNI and AHDB Beef & Lamb to investigate the ME requirements of sheep as part of the 'Feed into Lamb' project. As a preliminary step to calorimetry trials, Aubry and Yan from AFBI produced a literature review on the effects of animal and dietary factors on maintenance energy requirements and energetic efficiencies in growing lambs and breeding sheep as part of the AFBI project.

AFRC (1993) uses maintenance ME requirement of  $0.33 \text{ MJ/kg}^{0.75}$ . The experiments reviewed (Aubry and Yan, 2016) showed requirements of between  $0.32$  and  $0.51 \text{ MJ/kg}^{0.75}$ , with an average of  $0.40 \text{ MJ/kg}^{0.75}$ .

Lou *et al.*, (2015) published research done in China using Dorper x Thin Tail crossbred lactating ewes. The maintenance requirements for non-pregnant and early, mid and late lactation ewes were found to be  $0.37$ ,  $0.33$ ,  $0.32$  and  $0.36 \text{ MJ/kg}^{0.75}$  respectively. The ME maintenance requirements of the early and mid-lactation ewes agreed with the requirements of AFRC (1993), while the non-pregnant and late lactation ewes were higher than AFRC. Nie *et al.*, (2015) also published work undertaken in China using Dorper and Hu crossbred ewes and they concluded that ME requirements for growth and maintenance declined as age increased and the ME requirements were within the USA NRC range. Cottrill *et al.*, (2009) confirmed that the NRC requirement for maintenance ME was the same as AFRC (1993).

The research reviewed by Aubry and Yan (2016) included specific experiments to ascertain the ME requirements and these were done in Brazil, China and Iran, generally using male castrates. There are no specific ME requirement experiments published from the UK using temperate breeds or using breeding, adult female sheep.

#### **2.4.1.1 Latest Research and Recommendations for Requirements**

There are a number of review papers which consider the effect of under and over nutrition in pregnant ewes (Fthenakis *et al.*, 2012, Addah *et al.*, 2012, Kenyon and Blair, 2014, Rooke *et al.*, 2015). These consider general nutrient supply and do not specify the differences in energy or protein from requirements which were offered and also whether they are AFRC requirements or those of another country e.g. Cornell system used in USA. However, the general conclusion is that under nutrition can reduce lamb birthweight and lamb vigour and performance, and feeding over requirements does not have positive effects on lamb performance. This suggests that potentially the AFRC (1993) requirements for ME are satisfactory. The overall effects are discussed in the relevant sections related to stage of production, Sections 3 and 4.

Cottrill *et al.*, (2009) concluded that there is little information on the effect of animal, dietary and management factors on energy requirements for live weight gain of growing sheep, milk production or pregnancy in ewes, or the efficiencies of utilisation of ME for any of the metabolic processes and this position has not changed. McDonald *et al.*, (2011) compared results of ME requirements for dairy cows and concluded that most systems for ruminants produce similar results. They predict that as new information is available the systems will become more complex and that mechanistic models may be required to take in all the variables.

Campion *et al.*, (2016) are publishing trial results to compare the effects of a ME or net energy (French INRA system) for rationing ewes during late gestation. In total, 52 twin bearing ewes were rationed to either 100% of recommended ME requirements or 100, 110 or 120% of net energy requirements. The results show responses in the ewe live weight and BCS at parturition with increasing net energy offered in late pregnancy. There were no significant differences in lamb birthweight or growth rates or colostrum production in ewes fed diets of different energy level. However, when the nutrient intakes are compared for each group of ewes it shows increase protein intake with increased energy. Therefore, it is difficult to conclude a response to energy alone from this experiment. Campion *et al.*, (2016) conclude that both the ME and net energy systems are appropriate for formulating ewe diets in late gestation.

Based on the current information, it is suggested that the ME requirements published in AFRC (1993) continue to be used until the results of the AFBI 'Feed into Lamb' project are published. This view was confirmed by industry consultants at a workshop on 6 April 2016 for this project. The consensus was that the current ME requirements for sheep worked satisfactorily on UK farms so long as realistic weight predictions are used for ewes and for lamb birth weight.

#### **2.4.2 Protein Requirements**

The metabolisable protein (MP) system has been used by the UK industry since publication by AFRC in 1993. McDonald *et al.*, (2011) summarises the MP system and equations used to determine MP requirements. MP requirements have a similar format to the ME system in that the calculations consider net protein, the contents of animal tissues, and the efficiencies of utilisation of the net protein for all metabolic processes, e.g. maintenance, body growth, lactation, growth of the conceptus and wool growth.



Robinson (2002) considered the MP requirements for sheep in a review of nutritional standards. He recommended the following amendments to AFRC (1993) for MP requirements:

- The use of a 20% higher value for requirements for maintenance.
- Where there is a risk of endo parasitic infection in ewes adopt a 10 to 20% increase in late pregnancy/early lactation requirements (see Section 2.4.2.2).
- A separate and higher value for the MP efficiency of utilisation for wool in growing and reproducing animals.
- The adoption of change in body condition rather than change in live weight as a measure of the contribution of body reserves to nutrient supply, particularly during lactation.
- Higher lamb birth weights when estimating MP requirements for pregnancy in ewes carrying lambs sired by terminal sires, notably Suffolk.

Cottrill *et al.*, (2009) reviewed the MP requirements for sheep by comparing AFRC requirements with the standards used in France, USA and Australia. They recommended the following considerations for MP requirements:

- No change to the MP maintenance requirement in sheep.
- There may be scope for reducing the MP requirements for growing lambs by 20% without compromising growth rate, but further research is needed especially in relation to breed differences.
- There is a risk that the estimates for MP requirements in pregnancy are under stated and therefore research is needed to more clearly define the requirements at this critical time.

The review also suggested that for sheep the Cornell Net Carbohydrate and Protein System (Cannas *et al.*, 2004) should be further examined for its applicability to UK conditions. Cannas *et al.*, (2004) suggested that the system can be used to accurately predict nutrient requirements especially when rumen protein balance is positive. They concluded that further evaluation is needed to improve the system's ability to predict animal performance when rumen protein is deficient.

#### **2.4.2.1 Latest Research on MP Requirements**

In the last 20 years there has been ongoing genetic selection in ewes and increased use of fast growing terminal sires for higher productivity, which have increased lamb birth weights and milk production (Marquez *et al.*, 2012). The changes in ewe genetics and potential concern that AFRC (1993) may underestimate MP requirements suggest that ewes may respond to additional MP supply. There have been variable results from a number of studies where ewes have been fed additional MP above the AFRC requirements.

Robinson (1990) reviewed the requirements of the breeding ewe and discussed the need for a source of DUP to meet protein requirements. DUP is required if there is a deficit between the ewe's ME requirements and ME intake or if overall dietary protein supply is low. The review supported the view that in late pregnancy at the same feeding level more amino nitrogen reaches the abomasum than in non-pregnant ewes, shown in Table 3.

*Table 3. The effect of pregnancy in the ewe on the production of microbial protein and the amounts of non-ammonia nitrogen (NAN) reaching the small intestine (Robinson, 1990).*

| <b>Days of Gestation</b>                | <b>0</b> | <b>48</b> | <b>90</b> | <b>117</b> | <b>139</b> |
|---|----------|-----------|-----------|------------|------------|
| Nitrogen intake (g/day)                 | 24.1     | 22.5      | 23.1      | 23.8       | 23.4       |
| Microbial nitrogen (g/day)              | 15.0     | 11.4      | 11.1      | 10.1       | 8.2        |
| NAN at small intestine (g/day)          | 21.6     | 18.8      | 23.3      | 23.6       | 24.9       |
| NAN digested distal to abomasum (g/day) | 16.8     | 13.9      | 18.2      | 19.0       | 20.1       |

McNeill *et al.*, (1997) following experiments at Cornell University, to examine the partitioning of nitrogen between the uterus and maternal tissues highlighted the capacity of maternal carcass tissues to mobilise or deposit amino acids in response to variations in dietary protein supply. Twin bearing ewes in late pregnancy were fed diets of low (8%), medium (12%) or (high 16%) total protein. Whole body nitrogen retention was directly and linearly related to nitrogen intake, but efficiency of deposition of apparently absorbed nitrogen decreased linearly with increasing nitrogen intake. Nitrogen accretion in the uterus, maternal viscera and mammary gland was significantly less in the low protein diet compared to the medium and high protein diets. Nitrogen balance in maternal carcass tissues was linearly related to nitrogen intake.

Variable ewe responses to increased dietary DUP or MP have been found. Some of these are summarised below – but it is apparent that it is not easy to compare trials as some lack adequate detail with regard to MP supply relative to requirements. Dawson *et al.*, (1999) reported on a study to determine the effect of increasing levels of dietary DUP (13 to 65 g/kg DM) on the performance of twin bearing ewes in the last six weeks of pregnancy. The results showed no significant effect of DUP level on ewe blood composition, colostrum production, lamb birth weight or lamb live weight gain. The ewes were in good condition and offered well fermented good quality silage.

The effect of increasing levels of ERDP and DUP in the diets offered to lactating ewes was reported by Wilkinson *et al.*, (2000). The 48 Dorset or Friesland ewes

at pasture were offered concentrates of varying protein levels. The ewes responded to increasing levels of dietary protein with significant improvements in milk yield, milk protein and lactose and a significant decrease in milk fat. There were no significant effects of concentrate DUP supply. They suggested that the concentrate ERDP increased microbial protein synthesis and MP supply, a proportion of which was used to provide precursors for milk synthesis.

Dose response studies (Houdijk *et al.*, 2003 and 2009) found responses in ewe milk production when lactating ewes were offered five levels of MP from 0.65 to 1.25 of calculated requirements. Ocak *et al.*, (2005) found that a high level of crude protein (1.4 times requirement) supplementation to single bearing ewes (Hampshire Down cross Karayaka) in late pregnancy led to a significant increase in lamb birth weight ( $P<0.05$ ), but significant decrease in colostrum yield ( $P<0.01$ ), a significant increase in lambing difficulty ( $P<0.05$ ) and a significant reduction in lamb survival rate to weaning ( $P<0.05$ ) compared to control ewes fed at requirements. The study used only single bearing ewes which have lower requirements and the diets were formulated to supply additional crude protein rather than microbial protein or DUP.

Positive lamb responses to MP supplementation were also reported by Kidane *et al.*, (2009). Twin bearing Mule ewes were offered diets designed to supply 0.8 and 1.3 times the estimated MP requirements for ewes in late pregnancy and lactation. Lamb birth weight was not significantly different between treatments, but lamb weight at day 24 was significantly ( $P<0.001$ ) higher on the higher MP diet. However, in this study the ewes were infected with *Ostertagia* larvae (see Section 2.4.2.2).

Annett *et al.*, (2008) found no significant response in Greyface cross ewes or their lambs when offered diets with higher levels of DUP or MP compared to a control diet. The results are shown in Table 4.

Table 4. Effect of increased level of DUP on ewe and lamb performance (Annett *et al.*, 2008)

|                                    | DUP Low<br>(25g/kg DM) | DUP High<br>(55g/kg DM) | Significance  |
|------------------------------------|------------------------|-------------------------|---------------|
| <b>Ewe live weight change (kg)</b> |                        |                         |               |
| 6 weeks pre lamb to lambing        | -6.1                   | -6.6                    | NS            |
| Lambing to 6 weeks post            | 0.4                    | 0.7                     | NS            |
| <b>Body condition score change</b> |                        |                         |               |
| 6 weeks pre lamb to lambing        | -0.42                  | -0.33                   | NS            |
|                                    |                        |                         |               |
| Lambing to 6 weeks post            | -0.38                  | -0.31                   | NS            |
| <b>Colostrum Yield (g)</b>         |                        |                         |               |
| 1-hour post lambing                | 467                    | 341                     | NS            |
| 10-hour post lambing               | 576                    | 501                     | NS            |
| Lamb weight (kg)                   |                        |                         |               |
| Lamb birth weight                  | 4.43                   | 4.91                    | <i>P=0.06</i> |
| Lamb 6-week weight                 | 19.7                   | 20.0                    | NS            |
| Lamb weaning weight                | 32.6                   | 32.0                    | NS            |

There were no significant differences in ewe or lamb performance when ewes were offered a high DUP diet compared to those fed a low DUP diet during pregnancy or lactation. There was a trend towards higher lamb birth weight from the ewes offered the high DUP diets but this trend was not seen when lambs were weighed at six weeks of age or at weaning.

Amanlou *et al.*, (2011) (Afshari ewes in Iran) and Van Emon *et al.*, (2014) (Western Whiteface ewes in USA) also found no effects on lamb birth weight and subsequent lamb performance when MP was fed above requirements to pregnant and lactating ewes. Variable ewe performance has been reported, Van Emon *et al.*, (2014) showed additional MP increased ewe live weight gain and reduced BCS loss. Increases in colostrum component yield were reported by Amanlou *et al.*, (2011) when ewes were offered diets with increased MP supply.

With these conflicting responses to an increased supply of MP to ewes in pregnancy and lactation, the AHDB commissioned SRUC and Harper Adams University to investigate the effects of additional MP above accepted requirements (AFRC, 1993) on ewe and lamb performance.

The first experiment at Harper Adams University studied the response of twin bearing ewes (Suffolk cross Mule) to additional MP supply from DUP using soya bean meal or rapeseed meal (Wilkinson *et al.*, 2014). Additional DUP in the diets led to significant ( $P<0.05$ ) improvements in ewe live weight and condition pre lambing and colostrum yield. Ewe live weight and condition score change

post lambing, milk yield and lamb performance showed no significant response to additional dietary DUP. Wilkinson *et al.*, (2014) concluded that when fed diets designed to supply similar levels of ME and optimise microbial protein synthesis, enhancing DUP supply increased pre partum ewe performance and colostrum yield, but had no effect on lamb performance.

Houdijk (2014) reported from the SRUC on the first project experiment which used by-pass protein (SoyPass) to supply additional DUP above standard requirements in Scotch Mules. Similarly changes in ewe body weight and condition score were more pronounced than those of litter weight gain and it was concluded that ewe performance may be more sensitive to DUP nutrition than to crude protein or MP nutrition *per se*.

The second year experiments of the AHDB MP project showed similar results. Wilkinson *et al.*, (2015) found that ewes in good body condition (CS 3.3) showed no response in either ewe or lamb performance, to additional MP supply from DUP. At the SRUC, ewes in good condition (Scotch Mules of CS 3.1) were offered diets of the same ME and calculated to supply 0.85 or 1.20 of the MP requirement by offering increased levels of DUP (Houdijk *et al.*, 2015). In this experiment, DUP supplementation temporarily increased ewe body weight pre lambing but did not affect lamb litter weights. It was concluded from both these experiments that since the ewes were in good condition the lack of response to DUP may be due to the body reserves which are mobilised to maintain performance.

Wilkinson *et al.*, (2016) reported on the final experiment in the project which studied the effect of nutritional restriction in mid pregnancy on the response of ewes to additional MP supply during pregnancy and lactation. Twin bearing Suffolk cross Mule ewes were allocated to one of two treatments on day 70 of gestation and fed to achieve a mean condition score of 2.5 or 3.0. The ewes in each condition score group were then offered a low (28g/kg DM) or high DUP (56g/kg DM) diet. The low DUP diet was calculated to supply 1.0 and 0.85 of MP and the high DUP diet was calculated to supply 1.25 and 1.0 of MP in pregnancy and lactation respectively. The results are shown in Table 5.

Table 5. Effect of nutritional restriction in mid-pregnancy and level of protein supply on ewe and lamb performance (Wilkinson et al., 2016)

| Body Condition          | Low Body Condition |          | High Body Condition |          | Probability    |           |
|-------------------------|--------------------|----------|---------------------|----------|----------------|-----------|
|                         | Low DUP            | High DUP | Low DUP             | High DUP | Body Condition | DUP Level |
| Pre lambing             |                    |          |                     |          |                |           |
| Live weight change (kg) | 10.10              | 13.20    | 9.50                | 11.30    | NS             | 0.008     |
| Body condition change   | -0.60              | -0.54    | -0.40               | -0.21    | 0.020          | NS        |
| Post lambing            |                    |          |                     |          |                |           |
| Live weight change (kg) | -9.02              | -9.55    | -10.06              | -10.18   | NS             | NS        |
| Body condition change   | -0.90              | -0.71    | -0.96               | -0.95    | 0.05           | NS        |
| Colostrum (L/day)       | 2.46               | 3.59     | 2.65                | 3.16     | NS             | 0.009     |
| Milk (L/day)            | 2.89               | 3.26     | 3.05                | 3.19     | NS             | NS        |
| Litter weight (kg)      | 9.26               | 10.44    | 9.26                | 9.74     | NS             | 0.027     |
| Litter gain (g/day)     | 495                | 579      | 545                 | 619      | 0.004          | <0.001    |

Ewes offered the high DUP feed had significantly higher colostrum yield ( $P=0.009$ ), litter weight ( $P=0.027$ ) and litter gain ( $P<0.001$ ). There was no statistically significant interaction between BCS of the ewes and DUP level of the diet. The study concluded that nutritional restriction in mid pregnancy had no effect on litter weight but did reduce lamb growth rate. Additional MP supply increased litter weight and lamb growth rate and the response was greatest in ewes subjected to nutritional restriction.

A review of the MP project was completed by Wilkinson and Houdijk (2016). They concluded that MP requirements may be higher than predicted and that MP is supplied from the diet and potentially also from body reserves. Ewe body condition needs to be considered as observed responses may depend on the ability of the ewe to mobilise nutrients from body tissues. It is thought that during both pregnancy and lactation, ewes in good body condition mobilise nutrients from body tissues so that foetal growth and milk production are not compromised. Energy and protein supply from tissue loss may vary depending on ewe condition and may only be exploited if tissue loss is not physiologically damaging to the animal. Ewes in poor condition do not have the reserves to mobilise and therefore a greater response to MP supply is expected. The review recommended further work to test this hypothesis and to better

understand the relationship between condition loss and nutrient supply from tissues, especially protein.

#### **2.4.2.2 Effect of MP on Ewe Parasitic Immunity**

There have been many studies to understand the interaction between nutrition and infection and it is accepted that well fed animals generally have better health. There is an overall hypothesis that there is a pre-lambing relaxation in immunity to gastrointestinal parasites. Therefore, more recently there has been a focus to determine whether increased MP supply has other effects on the ewe, such as improved immunity to disease and improved health. Early work (Houdijk *et al.*, 2000) found that an increased intake of MP (130% compared to 85% of recommendation) could enhance the expression of immunity to *Teladorsagia circumcincta* of twin bearing and rearing Greyface ewes.

The overall hypothesis (Houdijk *et al.*, 2003) was that the pre lambing breakdown in immunity to parasites was due to the ewes prioritising their scarce nutrient allocation to reproductive function (e.g. foetal growth and milk production) rather than to immune functions. However, in the trial with increasing levels of MP from 0.65 to 1.25 of requirements the ewes did not show better performance or immunity on the MP levels over requirement. In another study (Houdijk *et al.*, 2006) showed that removing a lamb from twin rearing ewes improved immunity by reducing the demand for protein by the ewe, i.e. less milk production when rearing one rather than two lambs.

The response to different intestinal parasite species was considered (Houdijk *et al.*, 2009) in a study to compare small intestinal nematode (*Trichostrongylus colubriformis*) challenged ewes offered diets ranging from 0.6 to 1.2 times MP requirements. The ewes fed the first two increments of MP did show increased milk production and lower worm burden. The work supported the hypothesis that scarce MP allocation is prioritised to milk production over immune functions and concluded that ewes responded differently depending on the species of parasites. Kidane *et al.*, (2009) reported improved lamb performance with MP supplementation of 1.3 times compared to 0.8 times requirement and a reduction in faecal egg counts. The response was independent of infection level. A reduction in faecal egg count was also found when ewes were offered MP supply over requirements compared to half recommended requirement of MP (Zaralis *et al.*, 2009). However, the work concluded that infection with *Teladorsagia circumcincta* results in anorexia in the ewe which is not alleviated by additional MP supply. In further work reported by Kidane *et al.*, (2010a) comparing breeds of sheep, there was found to be a breed and feeding treatment interaction for ewe faecal egg counts with hill type ewes having a higher immunity to nematode infection which could not be explained by differences in their nutritional requirements.

Houdijk *et al.*, (2016) reported on a study to determine if supplementation of pre-lambing ewes with DUP increases ewe body weight and boosts lamb weaning weight in the presence of a parasitic challenge. Twin bearing Dorset cross ewes were used with half the ewes challenged with *Teladorsagia circumcincta* and the other half given a sham treatment. Within each group the ewes were offered either a high or low MP diet. The results showed that the ewes did not respond to the high protein diets as there were no significant differences in ewe faecal egg counts when offered the high MP diets compared to those fed the low MP diets.

The response to MP supply in terms of improved immunity and reduced worm burden is variable. Currently it is not possible to recommend additional MP supply over recommended requirements in parasite control strategies to reduce the reliance on anthelmintics. Robinson (2002) proposed that where there is a risk of gastrointestinal parasite infection in ewes, there should be a 10 to 20% increase in late pregnancy and early lactation MP requirements. However, with inconclusive results, and results that vary with parasite species, breed of sheep and season it is not appropriate to recommend changes to MP requirement for parasitised sheep. This was confirmed by Professor Jos Houdijk at the Feeding the Ewe project workshop in April 2016. He confirmed that results were variable and it was not appropriate to recommend a 'blanket' approach of additional dietary MP to pregnant or lactating ewes.

### **2.4.2.3 Effect of Rumen Outflow Rate on MP Requirement**

The rumen outflow rate, or the residence time of feed in the rumen, has a large impact on the extent of protein degradation in the rumen and hence on the supply of MP to the animal. AFRC (1993) uses single diet values for rumen outflow rates which take no account of diet composition e.g. level of forage and concentrates. The outflow rates for sheep are given as follows:

- Sheep at low level of feeding (1 x maintenance) = 0.02/hour,
- Sheep on higher feeding levels (up to 2 x maintenance) = 0.05/hour,

Current practice suggests that sheep in late pregnancy and early lactation (3 x maintenance) have an outflow rate of 0.08/hour (Stubbings and Phillips, personal communication).

The figures imply that 0.02 to 0.08 of the total rumen contents leave the rumen each hour. The faster the outflow rate the less degraded the feed is due to the reduced retention time of the food in the rumen. Cottrill *et al.*, (2009) suggest that for grass the effective degradability of the protein declines from 83 % to 65% as the rumen outflow rate increase from 0.02/hour to 0.08/hour (for dairy cows). Outflow rate is determined by quantity of feed consumed, type of feed, the degradability of the feed and the stage of production of the sheep. For pregnant and lactating ewes on feeding levels higher than maintenance the



outflow rate of 0.05/hour is recommended in AFRC (1993). Robinson (2002) recommends specific outflow rates for a variety of diets and at different stages of production. This view was confirmed in the review of requirements by Cottrill *et al.*, (2009).

The Feed into Milk (2004) outflow rates for dairy cows are split down and given for small particles, concentrates and forage, but this sort of information is not currently available for sheep. This could be considered for sheep nutrition in the future.

#### **2.4.2.4 MP Requirement Recommendations**

Based on current information, it is suggested that the MP requirements published in AFRC (1993) continue to be used, as a minimum requirement. This view was confirmed by industry consultants at a workshop on 6 April 2016 for this project. However, when rationing ewes it is essential to consider their live weight and body condition, the predicted lamb birth weight and number of lambs and also the potential level of parasitic infection the ewe is exposed to. The consensus was that the current ME requirements for sheep worked satisfactorily on UK farms with 'practical adjustment'. There is not sufficient evidence, currently, to adjust MP requirements and the potential cost could be greater without a guaranteed benefit.

There are clearly some questions to be answered. Significant omissions include:

- Increased amount of amino nitrogen (15%) reaching the duodenum and therefore available for absorption in the small intestine. It is thought that ewes in pregnancy have a modified maternal digestive system and the source of the extra protein reaching the small intestine is increased undegraded protein. Cottrill *et al.*, (2009) confirmed this concept was still an omission in all current feeding systems.
- Amino acid supply:

Liamadis and Milis, (2007) offered ewes in late pregnancy and early lactation diets which were calculated to provide equal amounts of ME and MP. In one diet the main protein source was corn gluten meal and the other diet the protein was supplied by soya bean meal. Ewes offered the diet with soya bean meal had higher body weights, litter birth weights and milk production compared to ewes fed the diet containing corn gluten meal. They concluded that the responses seen were due to the higher lysine (thought to be the first limiting amino acid) content in the diet containing the soya bean meal. In a more recent study (Wilkinson *et al.*, 2015) found no significant differences in ewe weight and condition pre lambing or in milk yield and lamb performance when the diet MP was supplied from soya bean meal, rapeseed meal or field beans. However,

during lactation ewes fed soya bean meal tended to maintain body condition better than those ewes offered rapeseed or field beans. The Suffolk cross Mule ewes in this trial were in good body condition at the start of the trial.

The amino acid requirements in late pregnancy were considered by Robinson (1990) who discussed the amounts of truly digestible amino acids that are likely to be supplied from microbial protein. The level of amino acids depends on ME supply and the amount of microbial protein produced in the rumen. Cystine, histidine and proline were identified as potentially limiting amino acids when rates of accretion in foetal tissue were compared.

A different immune response to protein source was demonstrated by Sakkas *et al.*, (2012). Mule ewes were trickle infected with *Teladorsagia circumcincta* and offered diets of the same ME and MP, but with protein supplied by soya bean meal or faba beans. The MP supplied by the soya bean meal was more effective in reducing parasitism than MP from the bean based ration. They concluded that protein source and quality are important factors to consider for the nutritional control of parasitism.

The effects of dietary fishmeal and soya bean meal on the immune response during pregnancy and lactation was reported by Stryker *et al.*, (2013). Fishmeal is superior in its supply of omega 3 fatty acids and amino acids compared to soya bean meal and was found to affect the innate and acquired immune response compared to soya bean meal. Fishmeal cannot be offered in ruminant diets under EU law, but the experiment raises the issue of limiting fatty acids and amino acids in sheep diets at key stages of the production cycle.

## **2.4.3 Mineral, Trace Element and Vitamin Requirements**

### **2.4.3.1 Mineral and Trace Element Requirements**

Ewes require at least 12 different minerals and trace elements for good health and productivity. These fulfil vital physiological, structural and regulatory functions. McDonald *et al.*, (2011) describes the functions and the effects of deficiency. A summary is shown in Table 6.

Sheep normally require minerals and trace elements on a daily basis with their requirements varying according to the element and the stage of production. The body copes well with short term fluctuations but longer term deficiencies or excesses may have long term negative effects. Forages represent the main component of the diet and as such provide minerals and trace elements to the animal. However, the mineral and trace element status of the forage can vary widely, depending on the type of crop (e.g. grass, roots), the stage of maturity of the crop, the mineral status of the soil and the climate.

Table 6. The role of individual mineral elements and the effect of deficiency (McDonald et al., 2011 and (AHDB, 2016g)

| <b>Mineral Element</b> | <b>Role</b>  | <b>Effect of Deficiency</b>                             |
|------------------------|--|---|
| Calcium                | Bone and teeth; nerve pulse transmission                       | Hypocalcaemia; rickets, osteomalacia.                   |
| Phosphorus             | Bone and teeth; energy metabolism                              | Loss of appetite; poor fertility; rickets; osteomalacia |
| Magnesium              | Bone; activates enzymes for carbohydrate and lipid metabolism  | Hypomagnesaemia; nervous irritability and convulsions   |
| Potassium              | Osmoregulation; acid base balance; nerve and muscle excitation | Retarded growth; muscle weakness                        |
| Sodium                 | Acid-base balance; osmoregulation                              | Dehydration; poor growth                                |
| Chlorine               | Acid-base balance; osmoregulation; gastric secretion           | Alkalosis   |
| Sulphur                | Structure of amino acids, vitamins and hormones                | Equivalent to protein deficiency                        |
| Iron                   | Haemoglobin; enzymes of electron transport chain               | Anaemia   |
| Copper                 | Haemoglobin synthesis; enzyme systems; pigmentation            | Anaemia; poor growth; loss of hair pigment; swayback    |
| Cobalt                 | Component of vitamin B <sub>12</sub>                           | Pine (emaciation; anaemia; listlessness)                |
| Iodine                 | Thyroid hormones   | Goitre; hair loss; weak or dead lambs                   |
| Manganese              | Enzyme activation  | Retarded growth; skeletal abnormality; ataxia           |
| Zinc                   | Enzyme component and activator                                 | Parakeratosis; poor growth; depressed appetite          |
| Selenium               | Vitamin E and iodine metabolism; immune function               | White muscle disease; ill thrift; infertility           |

The efficiency of absorption is affected by availability to the animal and also level of feeding and chemical form of the mineral. The availability of the mineral and/or trace element to the animal (i.e. not excreted), is variable between elements and difficult to predict. The balance of mineral and trace element

supply is important and the presence or absence of other minerals may be influential in suppressing or enhancing normal uptake. Suttle (2010) gives the requirements, sources, deficiency and toxicity details for all minerals and trace elements.

The major minerals, calcium and phosphorus are essential elements with over 80% of the body content found in bones and teeth. In plants, generally the leafy parts are relatively high in calcium and low in phosphorus, whereas the reverse is true for seeds and cereals. Traditionally dietary amounts for maintenance are based on estimates of endogenous faecal and urinary losses and for production, on net accretion rates combined with absorption and utilisation efficiencies. AFRC (1991) expresses requirements for calcium and phosphorus in relation to the ME concentration of the diet and dry matter intake. The two major minerals that affect ewe production are calcium and magnesium, deficiencies of these minerals at key stages of production can cause clinical diseases, hypocalcaemia and hypomagnesaemia respectively.

Calcium recommendations for sheep at all stages of production at a given dry matter intake are presented in Suttle (2010) who advises maintaining those suggested in AFRC (1991). Hypocalcaemia, a deficiency in calcium can occur in late pregnancy, especially in ewes carrying multiple lambs. It is caused by the sudden increase in demand for calcium to make colostrum and milk and is discussed in Section 3.3.8. Suttle (2010) describes hypocalcaemia as the inability to release calcium from the bones, possibly due to excess dietary calcium but also due to antagonistic effects of phosphorus or magnesium. Robinson (1990) discusses the mobilisation of calcium from bone due to a fall in circulating blood calcium, which goes against feeding more calcium in the diet. Also illustrated, older ewes are more susceptible to calcium deficiency due to the loss of receptors for calcium in both the intestines and bones.

About 70% of magnesium is found in the skeleton but unlike calcium it is not readily released from bone to the animal. Magnesium is the commonest enzyme activator and therefore sufficient supply of dietary magnesium is important (McDonald *et al.*, 2011). Suttle (2010) presents requirements for magnesium in pregnancy and lactation, based on number of lambs and whether the diet is high or low in potassium, its major antagonist to absorption. Hypomagnesaemia (also known as grass staggers or grass tetany) is caused by a magnesium deficiency during early lactation when demand for the mineral is high. Most cases occur when ewes are turned out onto lush spring grass especially if nitrogen or potash fertilisers have been applied to the pasture. Hypomagnesaemia is generally caused by a rise in potassium in the diet from a sudden change to grass or warm weather which reduces the availability of magnesium to the animal (Suttle, 2010) (see Section 3.4.10).

Phosphorus is not only required by the ewe but also by rumen microorganisms, and failure to meet these needs can lead to a reduction in cellulose digestion,

microbial protein synthesis and feed intake. The animal's needs for phosphorus are met from that absorbed in the small intestine, while the main source of phosphorus for the rumen microbes is that recycled in saliva. The requirement for phosphorus is dictated by both the animal and the needs of the microbial population.

Cottrill *et al.*, (2009) reviewed phosphorus requirements for sheep. Lactating ewes have the highest requirement for phosphorus which is used for milk secretion. They concluded that there are large differences in the estimates of phosphorus requirements given in the different published systems from UK (AFRC), Australia, USA and France, especially in older animals. The differences are in the estimates of requirement for maintenance and the lack of data on availability of phosphorus from different feeds. They recommended that on the basis of recent research there may be scope to reduce the requirements but that reliable methods of estimating availability in feeds are required.

The most recent phosphorus requirements are shown in Suttle (2010), which are modified AFRC (1991) recommendations. There are two phosphorus requirement levels based on two rates of saliva flow, low when offered dry diets such as hay based diets and high saliva flow when grazing fresh grass.

The most important trace elements for sheep in the UK are copper, selenium, cobalt and iodine, followed by zinc and manganese. Suttle (2010) gives a comprehensive review of each trace element and AHDB (2016g) Trace Element Supplementation of Beef Cattle and Sheep provides a good overview and details of on farm supplementation. The key messages from AHDB (2016g) are:

- Requirements vary with the production level e.g. pregnant, lactating.
- Deficiency should be confirmed by independent testing and advice before supplementing.
- Grass and forage varies widely in content due to soil type, pH, drainage, plant species and fertiliser use.
- Clay soils generally have higher trace element levels than sandy soils.
- Soil testing can reveal gross deficiencies but should only be used as a guide.
- Herbage analysis can also be misleading and needs careful interpretation.
- Diagnosis of a deficiency should be confirmed by monitoring the response to supplementation.
- Over supplementation can cause toxicity or other undesirable consequences in the animal, as well as wasting money.
- Methods of on farm supplementation are free access minerals, in feed minerals, drenches, slow release boluses, injections or top dressing of pasture.

Deficiencies in trace elements can impair animal productivity, fertility and health, which cause loss of lamb output to the industry. Suttle (2010) predicted variability between animals in their susceptibility to deficiencies e.g. Texel sheep absorb copper efficiently compared to Scottish Blackface sheep. To investigate this AHDB Beef & Lamb are funding a project (AHDB, 2013d) on the 'Genetics of Trace Element Deficiencies in Sheep' using Texel sheep, and this is due to report in August 2016.

**Copper** is an essential part of a number of enzymes which allow the body to function. The amount of copper that sheep absorb from the diet is variable with excess copper being stored in the liver. Sheep can suffer from both copper deficiency and toxicity and these are described by Suttle (2010). Other minerals, which are antagonists, are iron, molybdenum, zinc, manganese, sulphur and calcium which interact with copper reducing its availability. Over exposure to these elements can cause copper deficiency which causes swayback in lambs. Copper should not be added to sheep diets so that the risk of copper toxicity, caused by accumulation in the liver, is reduced. Generally, only housed sheep on very high levels of concentrates are at risk. Traditionally iron, sulphur and molybdenum are added to the diet to 'lock up' copper and reduce risk of toxicity (Suttle, 2010).

A recent trial studied the response of lambs offered diets with low and high ratios of iron and sulphur (Sefdeen *et al.*, 2016). The results showed that high dietary iron reduced liver copper concentration but that increased sulphur levels had no effect on liver copper content. It was concluded that liver copper levels are mainly influenced by high dietary iron rather than addition of sulphur to the diet. Hussein *et al.*, (2016) reported on a trial designed to investigate the effect of forage type on the copper status of lambs. The trial compared feeding grass haylage to maize silage on rumen pH and copper status of lambs. It was concluded that lambs offered maize silage had higher liver copper concentrations and this was associated with lower rumen pH caused by higher levels of starch in the diet.

**Cobalt** is an essential component of vitamin B<sub>12</sub> which is associated with energy metabolism. In ruminants, vitamin B<sub>12</sub> is produced by rumen microorganisms which need a regular supply of cobalt from the diet. Cobalt deficiency results in ill thrift and poor appetite in lambs and is also associated with reduced immunity and lamb viability at birth (Suttle, 2010).

MacPherson *et al.*, (1988) showed that cobalt deficiency lead to impaired immune function in ewes causing increased susceptibility to infection and reduced viability in new born lambs. Cobalt deficiency is also associated with poorer reproductive performance and lamb viability. Fisher (1991) found that cobalt deficient ewes produced fewer lambs, had more still births and more neonatal mortalities than ewes supplied with sufficient cobalt in the diet. Lambs from deficient ewes were slower to start to suckle and had reduced

concentrations of serum immunoglobulin and vitamin B<sub>12</sub>. Lower levels of blood vitamin B<sub>12</sub> were also found in cobalt deficient ewes and their lambs compared to ewes with adequate cobalt supply (Mitchell *et al.*, 2007). This showed in the number of ovum produced and the quality of the ovum which was significantly higher in cobalt adequate compared to deficient ewes. However, there was no effect of ewe cobalt status on lamb birth weight or neonatal vigour, but lambs were significantly more active when born to ewes with adequate cobalt supply.

**Selenium** acts with vitamin E to protect tissues against oxidation and breakdown of cell membranes, it is also important for immune function. Suttle (2010) describes the link between selenium and vitamin E. When there is a deficiency of either selenium or vitamin E the deficiency symptoms (e.g. white muscle disease) can be alleviated by the supply of the other but the efficiency is poor. Therefore, it is important to determine the deficient element when deficiency symptoms are seen. Oxidative stress, such as exposure to cold, muscular exercise and dietary polyunsaturated fatty acids found in spring grass are found to affect vitamin E and selenium availability (Suttle, 2010).

For information on vitamin E, see Section 2.4.3.2.

AHDB funded a project to refine and confirm the level of selenium and iodine supplementation for breeding ewes (AHDB, 2014d). The study selected four farms with historic trace element deficiencies. Groups of ewes were given intraruminal boluses containing either selenium or iodine at levels increasing above requirements. The results showed that the recommended level of selenium (ARC, 1980) provided adequate levels of selenium on a farm with a known deficiency with no observed benefits of supplementing with higher levels of selenium. The results for iodine supplementation were inconclusive with higher levels of iodine not being found in the ewe's blood when treated with boluses containing higher levels of iodine and there were no animal responses. The project team suggested that current guidelines for the interpretation of iodine blood levels need reassessing.

Rooke *et al.*, (2015) reviewed the requirements for trace elements in the gestation period of the ewe and the effects on lamb vigour and well-being. It was concluded that an inadequate supply of iodine, cobalt and selenium during pregnancy can have adverse consequences for lamb vigour and mortality. The potential for response depends on several factors, but maternal status for the elements is likely to be important. However, evidence for responses to supplementation above requirement are either non-existent (for cobalt), possibly adverse effects (iodine) or, no or positive effects (selenium, see vitamin E in Section 2.4.3.2).

Over supply of minerals and trace elements in late pregnancy can detrimentally affect the immunity of the lambs. Boland *et al.*, (2005) found that when ewes were over fed a mineral and trace element supplement in the last seven weeks

of pregnancy, their lambs had compromised digestion. This resulted in reduced serum immunoglobulin at birth and reduced absorption of immunoglobulin from colostrum by the lamb. A similar response was found in ewes offered diets with excess selenium in late pregnancy (Hammer *et al.*, 2011). Ewes with high levels of supplementary selenium had higher mortality in their lambs and were treated more frequently for respiratory and gastrointestinal diseases.

The review (Rooke *et al.*, 2015) confirmed the importance of adequate mineral supplementation of the maternal diet especially in the last trimester of pregnancy. Based on current knowledge the recommended levels of all minerals and trace elements for sheep shown in Suttle (2010), based on AFRC (1991) should be used in practice.

### 2.4.3.2 Vitamin Requirements

Natural forage based sheep diets usually contain a good supply of vitamins A, D and E. The B vitamins and vitamin K are synthesised by the rumen microorganisms. Vitamin C is synthesised in the tissues of the sheep and vitamin A can be stored in the liver for many months. Conversely vitamin E is poorly stored in the body and a daily intake is required. Generally, diets are only supplemented with vitamins at times of high demand (e.g. late pregnancy and lactation) and when conserved forages and concentrates are offered. Compound diets and mineral/vitamin supplements generally just contain vitamins A, D and E and on occasion B vitamins. Table 7. shows the role of key vitamins and the effects of deficiency.

Table 7. The role of key vitamins and the effect of deficiency (Lee *et al.*, 2002)

| Vitamin                 | Role  | Effect of Deficiency   |
|-------------------------|---|--|
| Vitamin A               | Maintenance of epithelial cells; vision; immune –cell function.         | Night blindness; ill thrift; infertility; disease susceptibility |
| Vitamin B <sub>1</sub>  | Carbohydrate metabolism   | Poor growth rate; ill thrift; cerebral cortical necrosis         |
| Vitamin B <sub>12</sub> | Propionate metabolism and methionine synthesis                          | Poor growth; reduced wool growth; staggers, anaemia              |
| Vitamin D               | Maintenance of calcium and phosphorus concentrations                    | Poor bone mineralisation; ill thrift; rickets                    |
| Vitamin E               | Protects the polyunsaturated fatty acids in membranes and plasma lipids | Poor cell function; white muscle disease                         |



Robinson (2002) concluded that the long established standards, (ARC (1980) The nutrient requirements of ruminant livestock) give adequate requirements for vitamins. This is except for vitamin E, where more recent research has shown an increased requirement in late pregnancy improving lamb vigour and viability.

Merrell (1998) reported on three MAFF funded research projects studying supplementation of hill and upland ewes with vitamin E from 0 to 300mg/kg in compound feeds. Ewe ( $P<0.001$ ) and lamb ( $P<0.01$ ) blood plasma vitamin E levels increased significantly with increased vitamin E level up to 300mg/kg. There was no effect on lamb birth weight but supplementation significantly ( $P<0.05$ ) improved lamb growth rate with additional vitamin E in late pregnancy diets up to 100mg/day dose rate. The effect on ewe performance and lamb mortality was inconclusive in this work. Following an industry review, an additional 100mg/day (111 IU) of vitamin E in concentrate feed was recommended and this level is widely used today.

A review was completed on research into vitamin E and selenium requirements for ewes and lambs (Rooke *et al.*, 2004). Vitamin E functions in the animal mainly as a biological antioxidant, in association with the selenium containing enzyme glutathione peroxidase. The review concluded that published responses in production and health of ewes and lambs to supplementary vitamin E and selenium are variable and not always positive. This was due to the variability of supply of the elements from fresh and conserved forages and concentrate supplements.

The underlying vitamin E status of the ewe may be a cause for discrepancy in the responses to vitamin E (Rooke *et al.*, 2009). An experiment was conducted on young (21 months of age) previously unmated lowland crossbred ewes offered diets containing 50 to 250 IU supplementary vitamin E per day pre lambing. There were positive linear ( $P<0.001$ ) effects of dietary vitamin E on ewe plasma levels and colostrum vitamin E concentrations. Lamb birth weights and weaning weights were unaffected by vitamin E supplementation of the ewe.

Donnem *et al.*, (2015) conducted an experiment to evaluate the effect of offering 0 or 360 IU of vitamin E pre-lambing to ewes carrying multiple lambs in 19 flocks. Significant increases in ewe plasma vitamin E levels were found in the ewes fed the high dose of vitamin E pre lambing. They concluded that, when carrying three or more lambs, ewes offered 360 IU of vitamin E per day had decreased levels of stillbirths ( $P<0.001$ ). However, there was no difference in the rate of stillbirths in ewes carrying two lambs or less. The suggestion from this work was that ewes carrying three lambs or more benefit from very high levels of vitamin E (360 IU per day).

It is thought that improved vigour in lambs may be due to oxidative stress. In a trial reviewed by Rooke *et al.*, (2015) lamb vigour was improved with supplemental vitamin E when ewes were in nutritional oxidative stress (offered saturated fatty acids). The lambs from supplemented ewes were better able to maintain their body temperature. Suttle (2010) describes the effect of oxidative stresses e.g. cold exposure, muscular exercise and dietary polyunsaturated fatty acids, on availability of vitamin E. Lambs born outdoors, on green swards in cold weather may be low in selenium, but as polyunsaturated fatty acid levels in lush spring grass increase, vitamin E may be low as well. Housed livestock are most at risk from low vitamin E levels as this vitamin is most readily found in green fresh forage.

Based on the current information it is suggested that the vitamin requirement recommendations for ewes remain as per ARC (1980) except for vitamin E. Vitamin E is widely added to late pregnancy compound feeds at 100mg/kg by compounders and mineral/vitamin suppliers and it is suggested that this remains unchanged.

## **2.5 Forages**

Feed is a major cost (50-55% of variable costs, AHDB Stocktake, 2015f) to sheep producers and its quality has a direct effect on enterprise productivity and ewe and lamb performance. Good quality forage should be offered at all times, whether grazed grass, brassicas or conserved forage e.g. silage or hay. It is false economy and potentially has a detrimental effect on ewe and lamb productivity to offer poor quality forage. It is more efficient to use home grown forages to reduce reliance on bought in feeds. Crops such as grass, clover, brassicas, roots and chicory can be used for ewes depending on system of production, and land and soil type. The AHDB (2014a) BRP Home Grown Forage Directory, gives a summary of all forage crops and McDonald *et al.*, (2011) discusses the nutritive value of grass and forage crops. The Kingshay Forage Costings Report is also a good source of information on growing and harvesting a variety of crops and also gives costs of production (Forage Costings Report 2015 available through Kingshay).

The full nutrient analysis for a range of grass and forage crops is shown in Appendix 1.

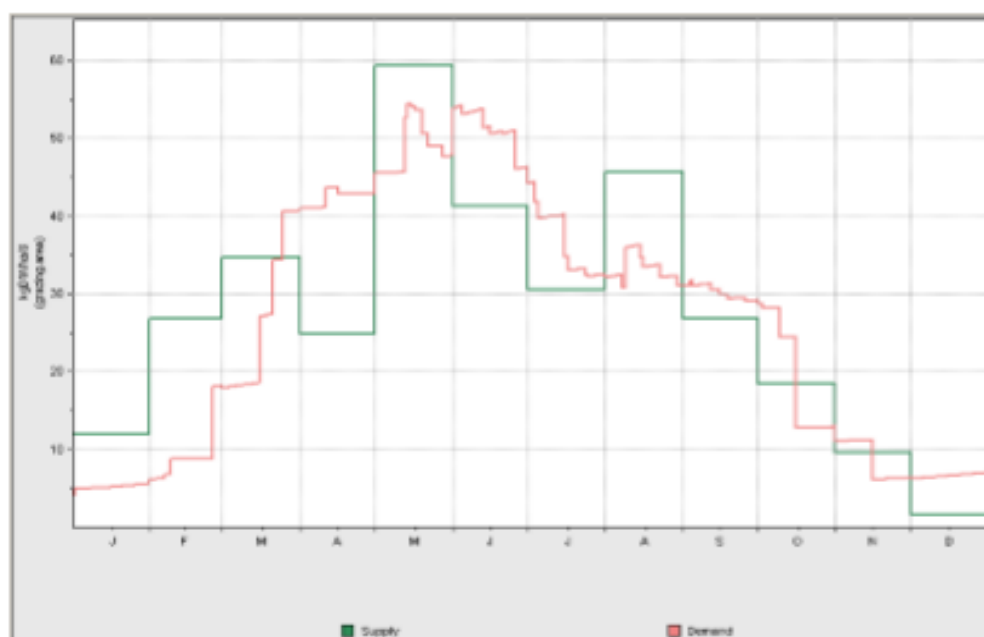
### **2.5.1 Grazed Grass**

Grass is the most important resource in sheep production and can provide 90 to 95% of energy requirements in sheep systems (Davies and Penning, 1996), but its management is often overlooked. Grassland which is well managed can provide high yields of high digestibility dry matter per hectare. Grass is the most

economic feed throughout the year and it can typically supply ME of 11.5MJ/kg DM and crude protein of 17%.

Johnson and Evans (1987) and Speedy and Bazely (1987) reviewed grass production for sheep. They demonstrated the patterns of grass growth and how that compliments ewe grazing and the times when ewe requirements cannot be met from grass. Grass growth compared to flock requirements are shown in Figure 3.

Figure 3. An example supply and demand curve for grass generated by Farmax. (Farmax Phase 1 Report 2013). Red = demand, green = supply.



The figure shows that for a typical March lambing flock, traditional grass growth cannot support ewes in late pregnancy, as grass has not started growing and in the summer months at weaning, when there is a reduction in grass growth before an autumn flush, and there are plenty of lambs on the farm. Mixed swards, grass and clover or herbs (see Section 2.5.2) and other forage crops have been developed to fill the gap in grass growth in the summer.

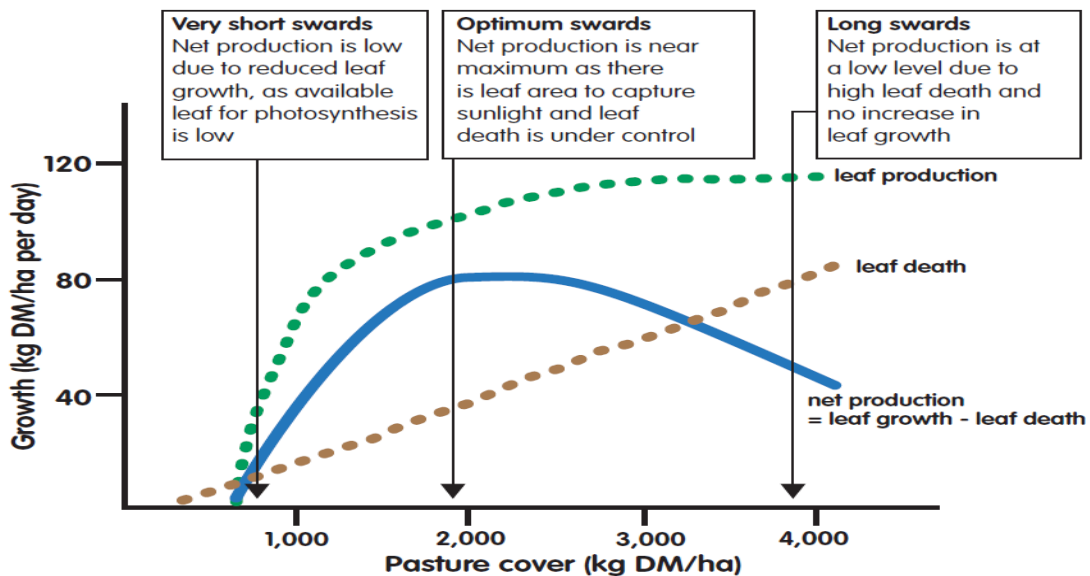
Grass management and supplementation for the lowland sheep flock was reviewed by Treacher (1990). The review suggested that optimum sward height of 6cm maximises production from lactating ewes with concentrate supplementation offered below a sward height of 4 cm. Target sward heights for sheep are shown in Table 8.

Table 8. Sward height targets for sheep (AHDB, 2016d - Planning grazing strategies for Better Returns. BRP Manual 8).

| Class of stock        | Grazing period | Rotational grazing |                          | Continuous grazing (cm) |
|-----------------------|----------------|--------------------|--------------------------|-------------------------|
|                       |                | Pre-graze (cm)     | Post-graze/residual (cm) |                         |
| Ewes and lambs        | Turn-out - May | 8-10               | 4-5                      | 4                       |
|                       | May - weaning  | 8-10               | 4-6                      | 4-6                     |
| Pre-tupping           | Sep - Nov      | 8-10               | 4-5                      | 6-8                     |
| Weaned finishing lamb | July - Sep     | 10-12              | 5-7                      | 6-8                     |

The optimum daily grass growth is reached when the total growth is between 2,000-2,500kg DM/ha, which equates to a height of around 8-12cm. Beyond this, the dying leaves deprive the new leaves of sunlight, leading to more leaf death and a decline in overall production. Grazing at the ideal point and resting swards when total grass falls below 1,250-1,500kg DM/ha (3-4cm) can improve grass utilisation, sustain sward quality and optimise performance, as shown in Figure 4.

Figure 4. Grass production at different growth rates (AHDB, 2016d - Planning grazing strategies for Better Returns. BRP Manual 8).



There is a fine balance between stocking rate and productivity, Earle *et al.*, (2016) found that pre weaning daily weight gain of lambs was significantly ( $P<0.001$ ) higher when ewes were grazed at a low (10 ewes per hectare) stocking rate compared to grazing at high (14 ewes per hectare) stocking rate. However, the results showed higher carcass output per hectare ( $P<0.001$ ) for grazing on high compared to low stocking rate pastures.

The nutritional quality of grass varies with season, age of sward, grass variety, management and fertiliser use, as shown in Table 9.

Table 9. Grazed grass yield and quality (AHDB 2014a, BRP Home Grown Forages Directory)

| Forage                      | Target DM Yield (t/ha) | Utilisation (%) | Dry Matter (%) | ME (MJ/kg DM) | CP (% in DM) |
|-----------------------------|------------------------|-----------------|----------------|---------------|--------------|
| Grazed grass                | 11.1                   | 65              | 17             | 11.5          | 17           |
| Grazed grass & white clover | 10.4                   | 65              | 16             | 12            | 19           |
| Grazed grass, low nitrogen  | 10.3                   | 65              | 17             | 11.5          | 18           |
| Poor quality sward          | 7.2                    | 55              | 18             | 10.5          | 15           |

The difference in quality between well managed pasture and poor quality swards is about 4t/ha yield, 10% in utilisation (65 to 55%), 1 MJ/kg DM of ME and 2% crude protein in DM. Therefore, it is important to maximise the quality and yield of grass to maximise output and profitability from the system.

Coleman and Henry (2002) review the nutritive value of grass. The nutrient supply balance of grass as described by McDonald *et al.*, (2011) depends on the quantities of protein, fibre and carbohydrate which vary with stage of growth, soil type and grass species. Late stage growth, high in fibre has reduced digestibility in the rumen and lower energy value. At the other end of the growth stage, new lush grass has a high water soluble carbohydrate level which is rapidly fermented in the rumen which may depress pH and reduce fibre digestion. Conversely low levels of grass sugars can reduce microbial protein synthesis in the rumen. Grass tends to be low in DUP; hence ewes at stages of production with a high nutrient demand (e.g. late pregnancy and lactation) require supplementary feeds to meet their requirements.

AHDB Beef & Lamb publications give full information on grass growth and utilisation and planning year round grazing.:

AHDB 2016a, BRP Manual 1 – Improving pasture for Better Returns

There are two main types of grazing strategy, set stocking and rotational grazing. Close management of sward height is vital to optimise sward utilisation and quality. More recently, and following extensive work in New Zealand, the focus is now on grass dry matter yield per hectare and allocating ewes a set DMI from grazed grass in paddock and rotational grazing systems.

In recent years there has been an increased focus on grassland management concentrating on growing more grass of higher nutritional quality by attention to soil analysis, structure and re-seeding. On top of this the UK has been experiencing warmer and wetter winters giving a longer grass growing season. On the basis of this the AHDB commissioned work on the development of an 'All grass wintering system for breeding ewes' which was undertaken by SRUC. Full details are available in the AHDB research reports (73204 and 73209) All Grass Wintering Phase 1 and 2. (AHDB, 2013c and 2015d) respectively. A summary of the system is given by Jones *et al.*, (2014).

Current wintering systems have tended towards housing ewes through the winter months to rest grassland and control nutrition on lowland farms or set stocking and concentrate feeding on hill and upland farms. All grass wintering (AGW) is a system designed to meet the ewe's winter nutritional requirements by saving autumn pasture and careful paddock management. It is a form of rotational paddock grazing which relies on sufficient winter grass growth on the farm, robust ewe breeds in good body condition and free draining soils. The aim is to graze each paddock once per winter followed by a long recovery period to ensure there is good grass growth for ewes and lambs in the spring. The system relies on managing field conditions using electric fencing and moving the sheep regularly. An assessment of the farm conditions and ewe breed and health should be undertaken before considering the system.

Frater *et al.*, (2014) reported on a pilot study of five farms in Cornwall in winter 2013. They concluded that AGW is feasible in South West England with free draining soils but adjustments are required to prevent grass shortfalls at lambing. The system must be flexible to cope with extreme weather conditions and must have contingency forage available. It can also be a labour intensive system with time needed each week to move electric fencing and shift groups of sheep.

Another grass management option is deferred grazing (or extended grazing) (AHDB, 2016d. Planned grazing strategies for Better Returns). Deferred grazing is where stock is removed from a field in early September so a wedge of grass is built up which can then be fed back by strip or block grazing in the spring. This system needs careful management and timing not only when shutting up the grass in the autumn but also when feeding in the spring.

Keady and Hanrahan (2012) reported on a study on the effects of allowance and frequency of allocation of autumn saved pasture, when offered to spring lambing ewes in mid pregnancy. The results showed that increasing the daily herbage allowance from 1.0 to 1.8kg per ewe increased ewe BCS and live weight at the end of the deferred grazing period. Reducing the frequency of herbage allocation from daily to twice weekly increased lamb birthweight, but otherwise did not affect ewe and lamb performance. They concluded that to maximise stock carrying capacity and reduce labour requirement a daily allowance of 1kg of herbage DM, allocated twice weekly, is sufficient for ewes on deferred grazing in mid pregnancy.

### **2.5.2 Grazing Other Crops**

Other grazed forages include clover, chicory, lucerne and plantain, which are usually combined with grass in mixed pastures. There is also a wide range of roots and brassicas. Details of all crops can be found in the AHDB 2014a, Home Grown Forages Directory.

Details of growing and efficient utilisation of pastures including clover and chicory are given in the following AHDB Better Returns Programme manuals:

AHDB 2016a, BRP Manual 1 – Improving pasture for Better Returns

AHDB 2016b, BRP Manual 4 – Managing clover for Better Returns.

Growing pastures including clover and chicory improves the nutritional content, especially protein content of the sward, but needs good management to get full potential. There is evidence that mixed swards are beneficial to productivity in sheep. Rutter (2010) reviewed grazing preferences of sheep and confirmed that they have clear diet preferences that change over the course of the day with changes in physiological state. Sheep have a partial preference for white clover (70%) when it forms part of the sward, possibly due to being able to eat clover more quickly than grass. The dry matter intake of clover is typically 1.5 times higher than dry matter intake of grass. There is a consistent diurnal pattern of preference, with clover strongest in the morning and with the proportion of grass in the diet gradually increasing through the day. The use of white clover in pastures for sheep was reviewed by Newton and Davies (1987) who found nitrogen fertiliser could be reduced and higher yields and performance was achievable from grazing mixed clover and grass swards. In practice if clover content of the sward exceeds 60%, DMI falls due to a lack of structural fibre in the rumen.

Clover particularly white clover which is more tolerant to grazing than red clover, can improve pasture protein content by 2% (see Table 10).

Table 10. Grazed crops yield and quality (AHDB 2014a, BRP Home Grown Forages Directory and AHDB 2016h, BRP plus – Using Chicory and Plantain in Beef and Sheep Systems)

| Forage                                       | Target DM Yield (t/ha) | Utilisation (%) | Dry Matter (%) | ME (MJ/kg DM) | CP (% in DM) |
|--|------------------------|-----------------|----------------|---------------|--------------|
| Chicory, white clover, ryegrass (grazed)     | 10                     | 65              | 15             | 11            | 18           |
| Chicory (40%), red and white clover (grazed) | 10                     | 70              | 12             | 12            | 20           |
| Lucerne (grazed)                             | 10-12                  | 80+             | 12-18          | 10            | 17-22        |
| Chicory                                      |                        |                 |                | 11            | 18           |
| Plantain                                     |                        |                 |                |               | 20-28        |

Clover and lucerne are legumes and they grow in a symbiotic relationship with nitrogen fixing bacteria. They are superior to grasses in their protein and mineral content. Mixed pastures of grass with clover are found to promote higher dry matter and protein intakes than grass alone. However, there are some nutritional and reproductive disorders associated with grazing pastures containing legumes:

- Bloat - the retention of fermentation gases, caused by the rapid breakdown of clover protein (particularly white clover).
- Tannins - cause poor protein digestibility in the rumen, moderate to high levels of non-hydrolysable tannins in the crop can bind protein so it is not digested in the small intestine.
- Oestrogenic activity - leading to infertility and postnatal death in lambs. Clover (particularly red clover) can contain high levels of phyto-oestrogens which damage the reproductive tract.

A review completed by Marley *et al.*, (2011) for the AHDB and other levy boards looked at the effect of grazed legume forage on ewe and cow fertility. The phyto-oestrogen levels in red clover are affected by soil status and type, weather, environment and clover variety. It is well documented that grazing swards containing red clover around mating time can affect fertility either permanently or temporarily. White clover also contains phyto-oestrogens but different and lower levels compared to red clover. The impact of white clover on ewe fertility is thought to be less severe. Lucerne is also thought to have a lower impact on fertility than red clover as it has similar phyto-oestrogens to white clover. The review concluded that from the work undertaken in the UK and abroad, it is still not possible to provide guidance on the effective use of



forage legumes whilst guaranteeing to protect the fertility status of ewes (Marley *et al.*, 2011). Therefore, legume forages or silages should not be offered to ewes for at least four weeks pre mating and eight weeks post mating.

Ewes should be introduced gradually to clover rich pastures and hay or straw should be available to provide fibre (AHDB 2016b, BRP Manual 4 – Managing Clover for Better Returns).

There is growing interest in herbs, such as chicory and plantain. They are high yielding, palatable and nutritious for grazing with clover or within a grass sward. They are not legumes and therefore require a source of nitrogen. They both have long tap roots so are more tolerant to drought conditions than grass, but better suited to light well drained soils. Cranston *et al.*, (2016) found that plantain was more productive under moderate drought due to its greater shoot mass whilst chicory was more productive and persistent under severe drought due to its greater root mass. Due to the deep roots they are a good source of the main macro minerals (e.g. calcium, potassium and magnesium) as shown in Table 11. They also contain high levels of some trace elements.

*Table 11. Mineral content of chicory and plantain (AHDB 2016h, BRP plus – Using Chicory and Plantain in Beef and Sheep Systems).*

| <b>Mineral Content (g/kg)</b> | <b>Chicory</b> | <b>Plantain</b> | <b>Perennial Ryegrass</b> |
|-------------------------------|----------------|-----------------|---------------------------|
| Calcium                       | 14.9           | 16.6            | 6.6                       |
| Phosphorus                    | 3.4            | 2.8             | 3.6                       |
| Sodium                        | 2.1            | 8.1             | 4.3                       |
| Potassium                     | 36.4           | 16.1            | 25.5                      |
| Magnesium                     | 2.8            | 3.2             | 1.8                       |

Due to the high calcium content of chicory and plantain, an assessment of the forage and the potential calcium supply must be done if this type of forage is offered to pregnant ewes due to the risk of hypocalcaemia (see Section 3.3.8).

Both crops require different management to grass as their growth pattern is very different. They tend to have a short but intense growing period and can therefore suit lactating ewes and their lambs in the right conditions.

Grazing chicory has been found to reduce lamb parasitism and improve lamb performance in some studies. Kidane *et al.*, (2010b) reported an experiment comparing lambs challenged with *Teladorsagia circumcincta* grazed on newly

established clean pasture sown with chicory or grass and clover. Lambs grazing the chicory had significantly lower ( $P<0.001$ ) faecal egg counts and grew faster ( $P<0.05$ ) than lambs grazing the grass and clover pasture. Pasture larvae counts were decreased ( $P=0.07$ ) for the chicory compared with the grass/clover plots.

Ewe and lamb performance was improved when grazing a herb sward mix compared to a ryegrass dominant sward (Hutton *et al.*, 2011). A total of 86 twin and triplet bearing Romney ewes were allocated to either a ryegrass dominant sward or a mixture of chicory, plantain, white and red clover. Ewes grazing the herb sward had significantly ( $P<0.05$ ) heavier body weight, better body condition, produced more milk, heavier lambs at birth and faster lamb growth rate compared to ewes offered the ryegrass sward.

Brassica crops such as kale, forage rape, grazing turnips, stubble turnips, swedes and new rape/kale hybrids are nutritious cost-effective feeds. The crops can be used for out-wintering to extend the grazing season or to help fill a forage gap in dry summers. They can also be used in both arable and grazing rotations, and make a good break crop between grass and cereals or grass re-seeds. Details of growing and feeding brassica crops can be found in AHDB 2016c, BRP Manual 6 – Using brassicas for Better Returns.

The nutritive value of brassica crops is shown in Table 12 and Appendix 1.

*Table 12. Brassica crop yields and quality (AHDB 2014a, BRP Home Grown Forages Directory)*

| <b>Forage</b> | <b>Target DM yield (t/ha)</b> | <b>Utilisation (%)</b> | <b>Dry matter (%)</b> | <b>ME (MJ/kg DM)</b> | <b>CP (% in DM)</b> |
|---------------|-------------------------------|------------------------|-----------------------|----------------------|---------------------|
| Kale          | 8-9                           | 80+                    | 15-17                 | 10-11                | 14-17               |
| Forage rape   | 4-5                           | 80+                    | 10-12                 | 10-11                | 19-20               |
| Turnips       | 5-6                           | 75-85                  | 10-15                 | 10-11                | 17-18               |
| Swedes        | 8                             | 80+                    | 9-13                  | 12-13                | 10-11               |
| Fodder beet   | 15                            | 80+                    | 12-19                 | 12-12.5              | 6-8                 |

Forage rape is a fast growing leafy catch crop with high protein content. It provides summer and autumn feed for lactating ewes or ewes pre-tupping. Kale is a late summer catch crop which can provide high yields of forage through the winter for pregnant ewes. Turnips (summer/grazing or stubble) are fast growing and are good autumn and early winter feed for pre-tupping or pregnant ewes.

Swedes and fodder beet are high energy winter feeding crops for pregnant ewes.

AHDB commissioned a research project, 'Maximising forage and grassland utilisation through, out wintering in-lamb ewes on swedes', (AHDB, 2015c) project number 73205. The key messages from the research were that a crop such as swedes provides a cost effective alternative to housing sheep, provided the crop is grown on relatively free draining ground and the weather is not too extreme. The mixture of swedes in mid pregnancy and grass in the last three to four weeks of pregnancy provides adequate nutrition to in lamb ewes provided that lambing is timed to coincide with reliable grass growth.

There are possible health issues associated with feeding some brassica crops (see AHDB 2016c, BRP Manual 6 – Using Brassicas for Better Returns):

- Bloat, due to rapid degradation of fresh crops in the rumen.
- Goitre, iodine deficiency caused by glucosinolates especially in root crops which block the uptake of iodine or low iodine crops. This can cause stillbirths, pre-natal mortality and can affect fertility.
- Kale anaemia - due to excess levels of S-methyl cysteine sulphoxide, causing loss of appetite, weakness, red urine, low fertility and goitre.
- Nitrate poisoning - due to high nitrate accumulation in the leaves when the crop is grown in soil with high nitrate levels or there is a high use of nitrogen fertiliser. The symptoms include scour, weakness, muscle tremors, poor breathing and death if not treated.
- Photo-sensitisation compounds in the brassicas cause the skin to be sensitive to sunlight causing pigment and skin damage.

Ewes must be introduced slowly to these types of crop to minimise the risk of health and digestive problems as they are a good source of readily fermented carbohydrate. The crops are best utilised if they are strip grazed and a grass runback or dry lying area must be provided. Brassica crops are low in fibre; therefore, an alternative fibre source should be available to the sheep, e.g. good quality hay or straw. Fresh water must also be provided at all times. Consideration should be given to mineral supplementation to balance the mineral and trace elements to minimise risk of goitre and anaemia.

When grazing mid and late pregnancy and lactating ewes on grass or other grazing crops, including brassica crops, the ewe's requirements must be balanced with the potential supply from the crops based on estimated intake. Most grass and brassica crops lack sufficient DUP, so that the microbial protein needs of the ewe cannot be met without concentrate supplementation.

### 2.5.3 Conserved Forages

Conserved forages, such as grass and maize silage and hay can produce high quality forage for winter feeding. Making high quality stable silage is important to maximise forage intake and minimise supplementary feed required and forage substitution (see Section 3.4.6). Forage quality can greatly affect intake and performance and this was shown in an experiment reported by Orr and Treacher (1990b). When ewes in mid pregnancy (weeks 11 to 15) were offered silage, hay or straw based diets the better quality forages (silage and hay with higher digestibility and ME) allowed ewes to maintain or improve their weight and condition compared to lower quality forages (poor hay and straw). They concluded that to maintain ewe performance in this period of pregnancy the ewes offered the poorer quality forages required more supplementary feeding.

The following AHDB publications detail making and feeding grass and maize silage respectively:

AHDB 2015b, BRP Manual 5 – Making grass silage for Better Returns

AHDB 2016e, BRP Manual 10 – Growing and feeding maize silage for Better Returns.

Grass silage can provide high feed value forage, but its quality is directly related to the grass growth stage at harvest and the success of the ensiling process. Silage can be stored as short chop in a clamp or long chop in big bales. Intakes of short chop silage are highest and intake will also depend on the nutritional and fermentation characteristics of the silage. When offered to pregnant ewes, reducing silage chop length by use of a precision chop harvester relative to single chopping, increased silage dry matter intake and consequently increased lamb birth weight by 0.25kg and reduced weight loss in ewes during pregnancy by 4.9kg (Chestnutt, 1989).

In a more recent study (Keady and Hanrahan, 2008) forage intake and lamb performance of ewes offered big bale or precision chopped silage were compared. The results showed little impact on silage dry matter intake or lamb birth weight but weaning weights were higher suggesting the ewes had milked better on the precision chopped silage.

Among the other characteristics that have been shown to be related to silage intake are; pH, buffering capacity, volatile fatty acid levels, ammonia nitrogen, digestible organic matter, rate of digestion and fibre content (McDonald *et al.*, 2011). Considerable research has been undertaken to predict the effect of silage quality on intake, particularly in dairy cows. The results are used in silage analysis reports which include an estimate of intake potential.

The production and utilisation of ensiled forages was reviewed by Keady *et al.*, (2013). It concluded that evidence from Ireland and UK shows that in relation to grass silage, digestibility is the most important factor influencing feed value

and consequently animal performance. Most factors affecting silage digestibility can be controlled by the producer and these are:

- Harvest date - a one-week delay in harvest reduces digestibility by 3.3% and requires an additional 12.7kg concentrate DM per ewe in pregnancy.
- Sward type - perennial ryegrasses need to be carefully managed to ensure silage is harvested at the correct stage by heading date.
- Silage fermentation - poorly preserved silage with low lactic acid concentration and high ammonia has poorer digestibility compared to well preserved silage.
- Fertiliser application - increased fertiliser use increases herbage yield but may reduce digestibility.
- Wilting - reduces silage digestibility - every 24 hours of wilting reduces digestibility by between 6 and 22 g/kgDM<sup>-1</sup>.

Each 10g/kg<sup>-1</sup> increase in digestible organic matter in the dry matter increases lamb birth weight by 52.3g and ewe weight post lambing by 1.3kg. Alternatively, each increase of five percentage units in silage digestible organic matter in the dry matter enabled a reduction in concentrate intake of 19.2kg for ewes during late pregnancy.

Poorly preserved, unstable silage should not be fed to ewes in pregnancy or lactation. A reduction in intake due to foul smelling, rancid silage can lead to loss of appetite and metabolic disease e.g. twin lamb disease. *Listeria* are bacteria found in soil and therefore can be found in silage where there has been soil contamination at harvest. Sheep are susceptible to small doses of *Listeria* bacteria and affected ewes have drooping faces and drool, and walk in circles as a result of abscesses in the brain. Listeriosis also causes abortion in pregnant ewes. Most cases occur four to six weeks after eating affected silage, so care is needed to ensure silage is stable and of good quality for feeding at critical times in the production cycle (McDonald *et al.*, 2011).

Maize silage provides a high energy (due to the starch content of the maize kernels), but low protein forage compared to grass silage. Early maturing varieties now allow maize to be grown over most parts of lowland UK. It has good intake potential which increases when mixed with grass silage. Keady *et al.*, (2013) reviewed the feeding of maize silage to pregnant ewes and concluded that it could partially or totally replace grass silage in diets. Maize silage can be offered as the sole forage without protein supplementation until late pregnancy (six to seven weeks pre lambing). Due to the low protein content Keady *et al.*, (2013) recommend feeding soya bean meal in late pregnancy to achieve the same performance as grass silage. Increasing the maturity of maize at harvest (higher starch) tended to increase lamb weaning weight by 1kg.

A LINK (2012) project (LK06894) on the estimation of energy value for maize silage concluded that there was a large variation in the 90 samples collected from commercial farms over two years with predicted ME contents ranging from 9.1 to 12.0 MJ/kg DM.

Keady *et al.*, (2013) reviewed the advances in silage technology with the opportunity for ensiling whole crop wheat and also high protein legume based forages such as clover, lucerne and kale. It was concluded for each silage type:

- Whole crop wheat silage, (from a review of 20 cattle studies using whole crop wheat silage compared to grass silage) whilst partially or totally replacing grass silage with whole crop wheat increased forage dry matter intake but it had no beneficial effect on milk yields or carcass gain. There has been no work with whole crop wheat silage feeding to pregnant or lactating ewes although it is successfully used on farms in the UK.
- Red clover and lucerne silage - these forages were thought of as unsuitable for ensiling due to their low sugar and high buffering capacity. Advances in technology have enabled good quality forages to be produced which have promoted significantly higher performance in growing lambs compared to ryegrass silage. There has been little work in pregnant and lactating ewes, probably due to the concern over high levels of phyto-oestrogen compounds which lead to fertility problems. Ensiling does not affect the level of phyto-oestrogens in the resulting silage.
- Kale silage - ensiling kale in big bales has provided a successful method of making silage of this crop. Ensiling has been shown to effectively reduce the potential toxicity of the metabolites (e.g. glucosinolates and S-methyl cysteine sulphoxide) found in fresh brassicas in studies using growing lambs (Keady *et al.*, 2013).

The effect of ensiled forage legume silages (lucerne and red clover) on the performance of twin bearing ewes was reported by Speijers *et al.*, (2005). Ewes offered the legume silages had significantly higher intakes of DM, ME and protein than ewes fed ryegrass silage up to lambing and this was reflected in significantly higher ewe live weight gains but not in lamb birth weights. Lambs born to ewes offered legume silages up to lambing had higher growth rates to 3 and 12 weeks of age. The trial demonstrated that lucerne and red clover silages can outperform grass silage for pregnant ewes. A recent trial at Harper Adams University funded by AHDB concurs with this (to be published in 2016).

Offering silages of mixed grass and white clover is well documented, Orr and Treacher (1990a) offered diets containing different proportions of perennial ryegrass and white clover silage to ewes in late pregnancy. White clover formed 0, 20, 40 and 60% of the grass/clover silage, and forage intake was significantly higher with increasing proportion of clover. Ewes gained more

weight and had lower BCS losses with increasing inclusion of white clover in the silage.

Feeding silages as part of a TMR diet is ideal, so long as the farm has the machinery, space and capacity to manage the system. The concentrates are mixed with the silage(s) in a forage/feeder wagon so there is a uniform mix of feeds presented to the ewes, which avoids selection and prevents large shifts in rumen pH associated with meal feeding of concentrates (see Section 2.3).

Hay is a higher risk option for conserving grass as it requires dry conditions and is cut later so is generally lower quality than silage. It is cheaper to produce and potentially easier to store and handle. However, like silage, to get the best response from ewes at key stages of production the higher the quality the better (Orr and Treacher, 1984).

Straw (wheat or barley) is a useful fibre source and can also be used as the main forage for ewes in late pregnancy. There are differences between varieties in intake and nutritive value, with spring crops having higher nutritive value than winter crops (Robinson, 1990). Due to its low protein and energy content, the quality and rate of concentrate feeding is high to ensure the ewe's requirements are met. Prior to lambing ewes which are bearing multiple lambs may need to be fed three times a day. Consideration also needs to be given to mineral and vitamin supplementation when straw is used as the main forage. At least 50% extra straw must be offered to sheep to allow them to select the most digestible parts and leave the hard stems. The wasted straw can be used as bedding. (See MAFF/ADAS (1986) technical note P3016 – Feeding straw to housed ewes).

Ammonia treatment of straw improves its RDP content and digestibility, reducing wastage and increasing intake (Robinson, 1990). However, treating, handling and storing treated straw needs careful management. Orr *et al.*, (1985) found ammonia treatment of barley straw increased digestibility from 42 to 58% and nitrogen content from 7 to 18%. When offered to ewes in late pregnancy ammonia treatment increased intake and reduced substitution rate of concentrate feeding. (See ADAS (1987) technical note P618 – On-farm treatment and feeding of straw).

Table 13 shows the nutritive quality and yields of different grass silages, maize silage and hay.

Table 13. Silages and hay yield and quality (AHDB, 2014a, BRP Home Grown Forages Directory and AHDB, 2015b and FIM Database, 2004)

| Forage                           | Target DM yield (t/ha) | Utilisation (%) | Dry matter (%) | ME (MJ/kg DM) | CP (% in DM) |
|----------------------------------|------------------------|-----------------|----------------|---------------|--------------|
| 1 <sup>st</sup> cut grass silage | 5.7                    | 87              | 25             | 11.2          | 14           |
| Ryegrass silage                  | 14                     | 87              | 27             | 11            | 13           |
| Ryegrass & red clover silage     | 13                     | 87              | 27             | 10.8          | 17           |
| Maize silage                     | 13.5                   | 87              | 28-35          | 10.8-11.7     | 8-9          |
| Hay                              | 5                      | 85              | 85             | 8.5-9.5       | 9            |
| Straw (barley)                   |                        | 50              | 86             | 6.5           | 4            |

## 2.6 Concentrate Feeding

At stages of high nutrient demand, e.g. late pregnancy and lactation or if forage quality is poor, then forage fed alone may not be adequate to meet the ewe's requirements for energy and protein. Concentrate supplementation can be in different forms:

- Straight raw materials, fed on their own or in a mix on farm, e.g. cereals, soya bean meal, distillers grains, beans.
- Compound feed manufactured to supply a balanced mix of energy, protein, minerals and vitamins.

A summary of common feeds can be found in AHDB, 2013b The Mini Feeds Directory. The AHDB publication gives information on nutrient analysis, palatability and inclusion rates.

The commonly used raw materials in ewe rations are shown in Table 14.

Cereals are generally fed whole, not rolled or ground, as this slows the rate of fermentation in the rumen and is more conducive to the growth of cellulolytic rumen bacteria that break down fibrous plant materials (Robinson, 1990). About 5% of whole grains are found in the faeces when ewes are fed hay and root based diets but this can increase to over 10% when ewes are offered silage. Robinson (1990) concluded that when feeding high quality silage diets, it was economic to process the grains which, when mixed with forage, will reduce the detrimental effects of rapid fermentation.



Table 14. Common raw materials used in ewe rations

| Category            | Raw Materials  | Nutrient Supply  |
|---------------------|--|--|
| Cereals             | Barley, wheat, oats, maize                                   | High in energy and starch, low in fibre and protein.   |
| Cereal co-products  | Wheatfeed, maize gluten, wheat distillers                    | Moderate to high energy, protein and fibre. Can be variable in quality depending on source.  |
| Pulses              | Peas, beans and lupins                                       | High in protein, high energy and starch, low in fibre.   |
| Oilseed co-products | Soya bean meal, rapeseed meal, linseed meal, sunflower meal. | High in protein, moderate/high energy, low in starch.  |
| Sugar co-products   | Molasses, sugar beet pulp                                    | Molasses is high in sugar and used to aid palatability and reduce dust. Sugar beet pulp is high in fermentable fibre and energy, low in protein. |

Traditionally wheat and barley distiller's products from the whiskey industry have not been advisable in sheep diets due to the variable quality and high level of copper. Wheat distiller's dark grains is now produced as a by-product of the bioethanol industry from two plants in the north of England. AHDB (2014b) predicted that the plants account for two million tonnes of wheat being processed with an output of 600,000 tonnes of wheat distillers produced per annum. The majority of this is going into dairy diets. Due to the production process, high levels of copper are not an issue, so potentially it could be a good protein source for ewes.

Diets for pregnant and lactating ewes generally rely on soya bean meal to provide the high quality protein needed to meet DUP requirements. Soya bean meal is superior in terms of crude protein and DUP content as shown in Table 15.

However almost all soya bean meal used in the UK is imported from South America. This may not be sustainable in the long term, so home grown protein sources have been assessed to reduce reliance on soya bean meal. There have been a number of studies which compare diets formulated to the same energy and protein content, using different protein sources. Due to the difference in DUP level of soya bean meal, most studies have compared diets of different MP or DUP rather than protein source.

Table 15. Energy and protein content of alternative protein sources (AFRC, 1993)

| Protein Source               | ME (MJ/kg DM) | Crude Protein (%) | DUP (% @ 5% outflow) |
|------------------------------|---------------|-------------------|----------------------|
| Soya bean meal               | 13.3          | 50                | 14.6                 |
| Rapeseed meal                | 13.3          | 38                | 5.5                  |
| Wheat distillers dark grains | 12.4          | 30                | 1.2*                 |
| Beans                        | 13.1          | 30                | 3.9                  |
| Peas                         | 13.5          | 25                | 3.2                  |

\*known to be variable quality, new supplies from bioethanol production thought to be higher.

AHDB (2014b) looked at sustainable protein sources for pregnant ewes, comparing ewe and lamb performance when ewes were offered soya bean meal, rapeseed meal, wheat distillers grains or field beans with cereals or fodder beet in late pregnancy. The results showed that ewe live weight, condition score, lamb birth weight and daily live weight gain did not differ between the groups offered the different protein sources/ levels of MP. They concluded that rapeseed meal, wheat distiller's grains and beans could substitute for soya bean meal in the diets of twin bearing ewes on complete diets based on good quality silage (around 10.8 MJ/kg DM). In this trial good quality silage was offered and ewes were in good condition throughout the study.

Protecting protein by heat treating in the presence of xylose or formaldehyde treatment of soya bean meal or rapeseed meal has been found to increase DUP to almost double normal levels (Houdijk and Vipond, 2014) as shown in Table 16.

Houdijk and Vipond (2014) concluded from this desk study that protected home grown protein sources, subject to availability and palatability can potentially reduce the reliance on soya bean meal to satisfy pregnant ewe MP requirements. A protected rapeseed meal was successfully used in trials reported by Wilkinson *et al.*, (2014) and Houdijk *et al.*, (2015). In these studies, standard ewe and lamb performance was reported when ewes were offered diets containing protected rapeseed meal.

Table 16. Crude protein and DUP levels of untreated and treated protein sources (Hazzledine, 2008)

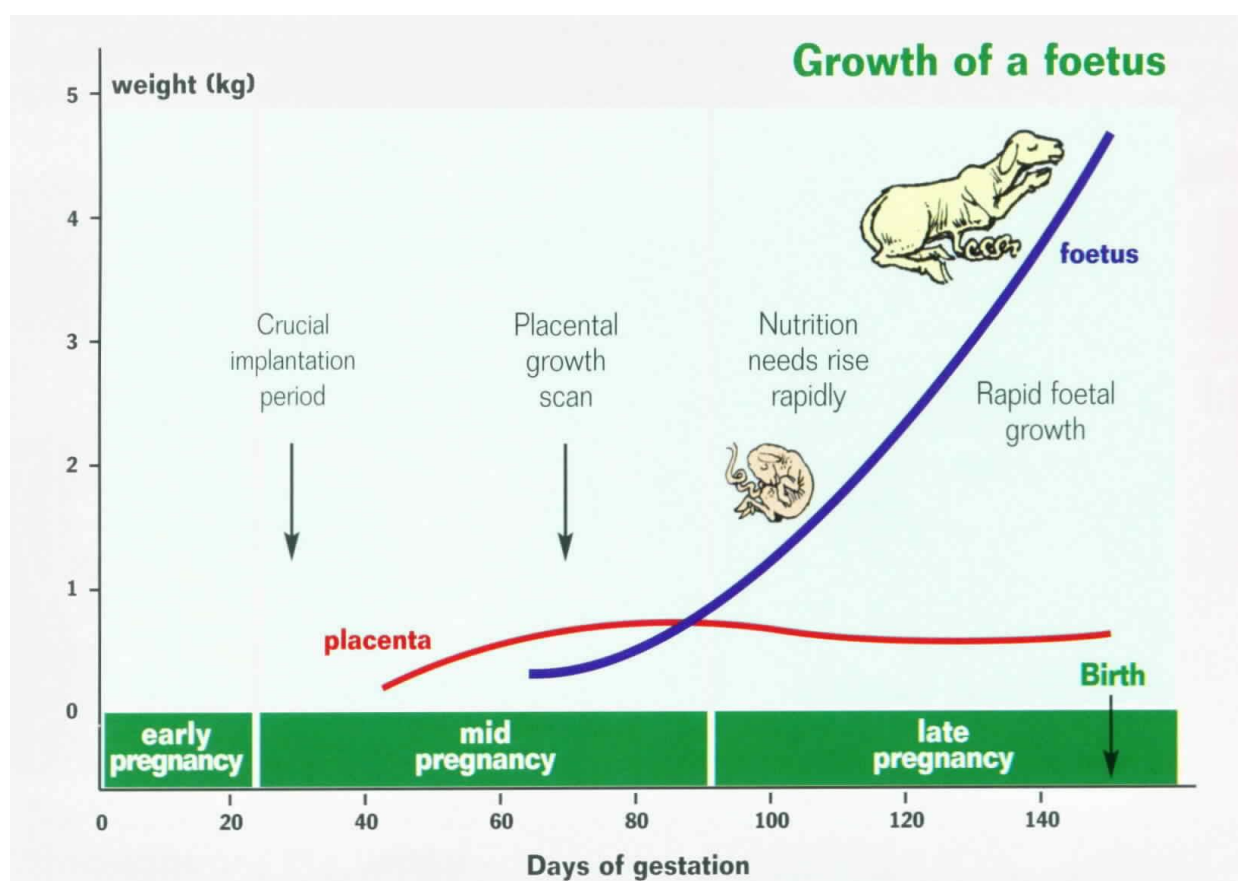
| <b>Protein Source</b> | <b>Crude Protein (% DM)</b> | <b>DUP (% of protein pre-treatment)</b> | <b>Treatment</b>      | <b>DUP (% of protein post treatment)</b> |
|-----------------------|-----------------------------|---|-----------------------|--|
| Soya bean meal        | 51                          | 33                                      | Heat and formaldehyde | 62                                       |
| Rapeseed meal         | 35                          | 17                                      | Heat                  | 70                                       |
| Lupins                | 37                          | 24                                      | Pressure toasting     | 55                                       |
| Faba beans            | 28                          | 30                                      | Pressure toasting     | 63                                       |
| Peas                  | 24                          | 27                                      | Pressure toasting     | 57                                       |

### 3 Feeding the Ewe During the Production Cycle

Correct feeding of the ewe is important throughout the production cycle, starting at weaning, continuing through gestation and then lactation. Nutrition pre and post tupping influences the number of foetuses established including oocyte/follicular maturation, ovulation, embryo development and implantation. As gestation progresses, this extends to foetal survival, birth weight, vigour and colostrum production. In lactation a high level of nutrition combined with the utilisation of body reserves is required to maximise milk production and consequently lamb growth (Robinson *et al.*, 2002; Robinson *et al.*, 2005).

The key stages of foetal growth through gestation are shown in Figure 5. During the first month, the embryo is formed and implantation takes place. The placenta grows to full weight and the foetuses start to grow during mid pregnancy (months 2 and 3). In the final two months, the foetuses grow rapidly and the nutrient needs of the ewe increase correspondingly.

Figure 5. Key stages of foetal growth through gestation (AHDB, 2016f - Manual 12 – Improving ewe nutrition for Better Returns)



A recent review by Fthenakis *et al.*, (2012) stated that nutritional management of pregnant ewes should be planned to:

- Prevent pregnancy toxæmia and other metabolic diseases in the pre-lambing period.
- Produce colostrum in appropriate quality and quantity.
- Produce lambs with normal birth body weight, not too heavy or too light.
- Support subsequent milk yield during lactation.

An Australian review of neonatal lamb mortality undertaken by Refshauge *et al.*, (2015), see Table 17, concluded that the nutrition of the ewe prior to and during pregnancy has an effect on almost all the factors associated with mortality, particularly starvation, still birth, foetal death and dystocia. The review concluded that single born lambs are more likely to die from dystocia and still birth, while twin born lambs are more likely to die from birth injury, starvation, mis-mothering or from undiagnosed causes. Triplet born lambs were most likely to die from starvation, mis-mothering or premature death *in utero*.

Table 17. Factors associated with neonatal death in lambs (Refshauge *et al.*, 2015)

| Factor Affecting Lamb Mortality   | % of Lambs Died from Factor |
|-----------------------------------|-----------------------------|
| Starvation – mis-mothering        | 25                          |
| Stillbirth                        | 21                          |
| Birth Injury                      | 18                          |
| Dystocia                          | 9                           |
| Premature death <i>in utero</i> p | 10                          |
| Predation                         | 7                           |
| Cold exposure                     | 5                           |
| Undiagnosed                       | 4                           |
| Infection                         | 1                           |
| Misadventure                      | 1                           |

The timetable of key events of pregnancy are shown in Table 18:

The ewe cannot meet the nutrient demands for lamb growth, colostrum and milk production from her diet alone and therefore draws on her own body reserves. Hence management of ewe body reserves (BCS) is important at all stages of the production cycle.

Table 18. Timetable of key events through pregnancy for a 75kg ewe (adapted from SAC, 2009a)

| Day of Pregnancy | Key Event                                  | Key Stages          |
|------------------|--|---------------------|
| 0                | Mating                                     | Pre-implantation    |
| 3                | Fertilisation                              |                     |
| 15               | Migration                                  | Implantation        |
| 34               | Implantation                               |                     |
| 40               | Foetus weighs 5g                           | Placental growth    |
| 90               | Placenta weighs 1kg and Foetus weighs 700g |                     |
| 110              | Foetus weighs 1.5kg                        | Foetal growth       |
| 139              | Foetus weighs 3.75kg                       |                     |
| 145              | Foetus weighs 5kg                          | Full term - lambing |

### 3.1 Nutritional Management of the Ewe Up to Mating

Nutrition up to mating is important as this affects whether the ewe gets pregnant, how quickly the ewe conceives and how many embryos successfully implant.

Robinson *et al.*, (2005) summarised the critical times in the life of a ewe when ovulation rate is particularly sensitive to nutrition, shown in Table 19.

Table 19. Critical periods during which ovulation rate in ewes is particularly sensitive to nutrition (Robinson *et al.*, 2005).

| Life Stage | Nutrition Sensitive Window      | Target Tissue / Organ   | Mechanism  |
|------------|---------------------------------|-------------------------|--|
| Foetus     | Days 50 to 65                   | Foetal ovary            | Alteration in germ cell meiosis  |
| Neonate    | Pre-weaning                     | Not determined          | Not determined   |
| Adult      | 6 months prior to ovulation     | Ovary                   | Alteration in follicle numbers leaving pool                                |
| Adult      | 10 days preceding ovulation     | Hypothalamus, pituitary | Changes in follicular growth and survival, oocyte quality, ovulation rate. |
| Adult      | Days 8 to 4 preceding ovulation | Ovary                   | Changes in follicular growth and survival, oocyte quality, ovulation rate. |

### **3.1.1 Energy and Protein Requirements Up to Mating**

The energy and protein requirements up to mating are suggested to be maintenance levels for a ewe in the required condition i.e. no gain in weight is required (MLC, 1988, Robinson, 1990 and Robinson *et al.*, 2002). However, in most cases, ewes need to gain body condition and hence weight after losses during lactation. Therefore, requirements depend on the weight of the ewe, the gain in weight and condition required and the time available before mating to achieve this. It is recommended that energy and protein requirements detailed in AFRC (1993) are used, Cottrill *et al.*, (2009) confirmed this.

### **3.1.2 Effects on the Foetus and Neonate**

The ability of ewes to ovulate and produce viable embryos is thought to start when the ewes are foetuses themselves. Nutrition affects the formation of foetal reproductive organs, their post-natal development, timing of puberty and the rate of ovulation (Robinson *et al.*, 2002 and 2005). Robinson *et al.*, (2005) produced a comprehensive review on nutrition and fertility in ruminant livestock, focusing on foetal and early life of the ewe and up to mating. More recently, Kenyon and Blair (2014) have reviewed foetal programming in sheep and the effects on production in adult life.

Observations of reproductive performance of sheep conceived, born and reared under different degrees of nutritional adversity provided evidence that inadequate or inappropriate foetal and/or post-natal nutrition reduces their adult reproductive performance. Robinson *et al.*, (2002) reviewed the effect of undernutrition in early post-natal life from nutritional inadequacy of the ewe in late pregnancy and lactation and found impaired adult reproductive performance. Puberty is delayed by feed intake that restricts growth rate to 50% of the lamb's potential and the effects are more pronounced when feed restriction is applied in the early post-natal rather than the immediately pre-pubertal phase. For further information, see Section 4 on Managing Replacements.

### **3.1.3 Effects Six Months Preceding Mating**

In mature ewes, preparation for mating on farm tends to start once the ewes are weaned and dried off. However, Robinson *et al.*, (2002) suggested that the nature of the ewe's long term nutritional regime has a huge impact on the number of ova released at mating time. Robinson *et al.*, (2012) suggested that ovulatory responses to improved nutrition in the few weeks before mating may be influenced by the plane of nutrition during the previous six months from when the ovarian follicles that go on to ovulate leave the primordial pool and commit to growth. The review concluded that adequate nutrition throughout this six-month period led to increased ovulation rate, although the mechanisms

dictating this nutrition dependent response is not fully understood. It is thought to be due to nutrient sensitive hormone mechanisms with the ewe's body condition and nutrient supply affecting hormone release from the ovary, pituitary and hypothalamus. Ewes are generally lactating six months before mating and experiencing negative energy balance at this time. In order to overcome this, it is advised that pre-ovulatory 'flushing' is made an integral part of pre-mating management.

More recently, Kenyon and Blair (2014) reviewed the effect of maternal nutrition on foetal growth and subsequent lamb birth weight. They found consistently that underfeeding below maintenance requirements in the pre-mating phase led to lower foetal and lamb birth weights.

Preliminary data from the AHDB KPI project (AHDB, 2014c) supports this. Data suggests that ewes need to carry a minimum, but as yet not fully determined, level of BCS from mating through to lambing in order to ensure maximum weight of weaned lamb per flock (i.e. litter size x lamb growth).

Where ewes are managed to gain BCS from weaning to mating, those that were in very low BCS at weaning, have a carryover in terms of poorer output the following year (scan % and lamb growth rates) even if they managed to get to the target range in BCS at mating.

### **3.1.4 Nutrition Weaning to Mating**

In practice on commercial farms, preparation for mating starts at weaning, which normally takes place three to four months post lambing, though in early lambing systems may be only 2 months. Significantly, some farmers like to leave it until 5 months. The consequences of this decision on future performance are discussed since this allows the ewe a dry period of about three months (range 2 to 5 months) during which her body reserves (body condition) have to recover ready for a successful mating and subsequent pregnancy.

Robinson (1983, 1990) and Robinson *et al.*, (2002) support the view that at drying off (weaning), ewes must be assessed for BCS and then fed to gain weight to achieve target condition and be on a rising plane of nutrition at mating. Based on numerous papers and studies including Gunn *et al.*, (1991), AHDB (2016f) recommends BCS for optimal performance at tugging of:

- Hill breeds – 2.5
- Upland breeds – 3.0
- Lowland breeds – 3.5

Recently reviewed by Fthenakis *et al.*, (2012) they concluded that ewes at optimum body condition at mating with a good energy supply will have increased ovulation rate, leading to an increased number of lambs born per



ewe. Conversely an inadequate energy intake and low body condition leading up to mating leads to reduced cyclic activity, reduced ovulation rate and suboptimal ova survival, as well as a higher risk of early embryonic death.

Ewes must be grouped by condition score at weaning and allocated to an appropriate feeding regime. At this stage feed restriction may also be necessary for ewes in BCS greater than 3.5 that have lost their lambs or reared a single lamb. Ewes that reared multiple lambs are likely to have lost at least one condition unit through lactation. A ewe in poor condition, (1.5 units below target) will first need to replace body protein and then put on body fat to increase the body condition over the loin. Robinson *et al.*, (2002) calculated that in a 70kg ewe this equates to 8kg of body fat. At energy levels equivalent to twice maintenance replacing this level of fat will take about 90 to 65 days in ewes offered forages of ME 8 and 12 MJ/kg DM respectively.

AHDB (2015a), based on Russell (1984) recommends that it takes six to eight weeks on good grass to gain one BCS. As a guide MLC (1988) suggests that each change of 1kg in bodyweight is equivalent to 0.1 unit change in BCS. SAC (2009a) predicts that one unit of condition score is about 13% of body weight. Therefore, for a 65 kg ewe in condition score 2 at weaning, to be at condition score 3.5 at mating she needs to gain about 13kg mainly as fat. The energy content of the weight gain is 24MJ/kg, but with an efficiency of gain of about 45%, the ewe needs to eat about 55MJ/kg of gain, about 700MJ in total to go from condition score 2 to 3.5. Over 10 weeks this 10MJ per day, which is equivalent to an extra kg of DM of best quality grass.

The AHDB KPI project (AHDB, 2014c) implemented previous advice to allow 6 to 8 weeks to regain one unit of BCS in a dry ewe post-weaning (Russell,1984). The nutritional 'cost' of regaining BCS from weaning has been quantified in terms of MJ ME and subsequently kg dry matter of grazing. Using ARC (1993), a ewe will need approximately 500MJ ME/unit of BCS to be gained over her maintenance requirement, approximately 50kgs of grass dry matter. This has largely been borne out on the KPI farms. However, with the data the project has generated on the weight differential between BCS units we will be able to refine this. The implications for the management of nutritional resources in the late summer months on sheep farms in this period are clear. Grass quantity (dry matter) and quality available must be assessed and supplements or other crops offered as required.

Robinson *et al.*, (2002) found that when allowed free access to food, thin ewes eat more than fat ewes and partition the extra energy to maternal rather than conceptus tissues. (Gunn *et al.*, 1991) - Table 20 illustrates this. Where leaner ewes are allowed to eat to appetite, DMI intakes are approximately 30% higher than ewes in higher BCS. Harnessing this innate ability of the thinner ewe to eat more dry matter allows us to not only plan ahead for groups of ewes, but

prompts prioritisation of ewes versus lambs during the weaning to mating period.

Table 20. DMI of ewes pre-mating according to BCS and pasture availability. (Gunn *et al.*, 1991).

| BCS 5 Weeks Pre-mating | Feeding Level | BCS at Mating | Pasture Intake (g DM/ewe/day) |
|------------------------|---------------|---------------|-------------------------------|
| >3                     | H             | 3.18          | 722                           |
|                        | L             | 2.96          | 728                           |
| 2.5/2.75               | H             | 3.05          | 829                           |
|                        | L             | 2.78          | 746                           |
| 2.25 or less           | H             | 2.86          | 1101                          |
|                        | L             | 2.46          | 778                           |

H = unrestricted access to feed

L = restricted access to feed

Hickson *et al.*, (2012) reported on a study to determine the effect of live weight and live weight gain of ewes immediately post –weaning on the live weight and survival of subsequent lambs. The study used a total of 1367 mixed age Romney ewes allocated to grazing paddocks designated as high plane of nutrition or maintenance nutrition for seven weeks from weaning until 71 days pre- mating. The aim of the study was to determine the effect of ewe live weight and live weight gain (no account was taken of ewe BCS in this study). Live weight gain during the 42-day period was significantly ( $P<0.05$ ) greater in ewes offered the high plane of nutrition compared to the maintenance group of ewes. They found this did not influence number of foetuses, lambs born or reared per ewe or the total weight of lambs born per ewe. This study indicated that live weight and weight gain from weaning only had a minor influence on lamb production and there was little advantage in specifically managing ewes during this period. However, they did not use BCS in the work so we cannot know whether the ewes were already in good BCS at the start and this underlines the need for there to be recognition of BCS as the main indicator in the management of ewe.

However, it is suggested that BCS is a better measure of ewe nutrient supply and if ewes are in poor condition at weaning then it will potentially be too little time to increase BCS if an increased plane of nutrition does not start until six to eight weeks pre-mating.

### 3.1.5 Flushing – Just Prior to Mating

There are varying recommendations on when to start flushing ewes i.e. how many weeks before tupping should the rising plane of nutrition start for optimal results. Robinson *et al.*, (2002) suggest a 10 to 14 day flushing period before ovulation following a review of research, however it was found that ewes that were previously restricted in nutrition may not respond in this short time period. Ewes in good condition that have been on a rising plane of nutrition may not respond to flushing in the 10 days prior to tupping, showing good ovulation rates that cannot be improved. For a one unit reduction in BCS of the ewe it was anticipated that ovulation rate may drop by 0.45. Robinson *et al.*, (2002) showed that ewes in sub optimal body condition responded to just four days of feeding although this approach is not recommended. Sudden changes in nutrition can cause metabolic acidosis which can be counter-productive.

More recently a rising plane of nutrition has been recommended for the five to six weeks pre mating, to correspond with two full oestrus cycles (Fthenakis *et al.*, 2012). There is evidence (Hernandez *et al.*, 2010) that starting an increasing plane of nutrition 60 days (eight to nine weeks) prior to mating has the potential to influence foetal growth and performance of lambs post birth.

### 3.1.6 Prolific and Super Ovulated Ewes

In farm circumstances where there is no intervention with the reproductive cycle, ewes spontaneously ovulate, but for embryo transfer programmes donor ewes are super ovulated. Research has found that these ewes respond differently to plane of nutrition and diet type (Robinson *et al.*, 2005). Studies show that a high plane of nutrition is detrimental to oocyte production and this is accentuated if the ewes are in good body condition or given diets with high starch content. Lozano *et al.*, (2003) and Grazul-Bilska *et al.*, (2012) reported that both over and under nutrition had a negative effect on oocyte quality and implantation rates. They concluded that over nutrition of super ovulated ewes decreased the quality of the oocytes and undernutrition affected the uterine environment compromising the development of the embryo. Robinson *et al.*, (2002) recommends a maintenance level of feeding for super ovulated embryo donor ewes leading up to artificial insemination and embryo collection.

In ewes that have prolificacy genes (e.g. Booroola or Inverdale) such as the Cambridge, Belclare, Aberdale and Lleyn, high feed intake around mating should be avoided to limit the number of ovulations and to maintain good levels of progesterone to help maintain pregnancy.

A study by Demmers *et al.*, (2011) aimed to determine whether ewes heterozygous (I+) for the Inverdale gene with high natural ovulation rate (OR) show similar sensitivity to nutritional manipulation as non-carriers (++). Over

two years, I+ or ++ ewes were given high (*ad libitum*) or control (maintenance) pasture allowances for six weeks prior to mating at a synchronised oestrus, with OR measured eight days later. The high group increased in weight compared with controls (+5.84kg;  $P<0.01$ ), accompanied by increased OR (+19%;  $P<0.01$ ). As well as having higher OR (+45%;  $P<0.01$ ), I+ ewes responded to increased feed with a larger proportional increase in OR (+27%;  $P<0.01$ ) compared with the response in ++ ewes (+11%;  $P<0.05$ ), suggesting an interaction between the Inverdale gene and nutritional signals in the follicle to control OR. Although litter size increases only tended to significance (+12%;  $P=0.06$ ), extra feed resulted in over 50% of I+ ewes giving birth to more than three lambs, compared with 20 to 31% of I+ ewes on maintenance rations.

In practice prolific ewes should not be 'flushed' but should be held at condition score 2.5 to 3.0 over mating to avoid excessive litter size. This is further described in the SAC publication (2009a).

### **3.1.7 Effect of Dietary Components on Fertility**

Throughout the period of nutritional control for optimum ovulation and immediately thereafter, care must be taken to ensure other dietary factors do not impair ovarian function. Most notable are the phyto-oestrogens found in clover, trefoil and lucerne, thought to have caused permanent subclinical infertility in about four million ewes in Western Australia alone (Robinson *et al.*, 2002). Breeding is impaired by the effects of secondary plant metabolites which have similar structures to the hormones that control reproduction.

A recent review completed by Marley *et al.*, (2011) for the AHDB and other levy boards looked at the effect of grazed legume forage on ewe and cow fertility. The phyto-oestrogen levels in red clover are affected by soil status and type, weather, environment and clover variety. It is well documented that grazing pastures containing red clover around mating time can affect fertility either permanently or temporarily. White clover also contains phyto-oestrogens but different and lower levels compared to red clover. The impact of white clover on ewe fertility is thought to be less severe. Lucerne is also thought to have a lower impact on fertility than red clover as it has similar phyto-oestrogens to white clover. The review concluded that from the work undertaken in the UK and abroad, it is still not possible to provide guidance on the effective use of forage legumes whilst guaranteeing to protect the fertility status of ewes (Marley *et al.*, 2011). Therefore, it has been recommended that legume forages or silages should not be offered to ewes from at least four weeks pre mating to eight weeks post mating.

### 3.1.8 Worm Burden in Ewes Pre-mating

Mature ewes, in common with most adult ruminants have an acquired (adapted) immunity to endemic gastrointestinal nematodes (GINs). This immune response involves the rejection of incoming immature larvae from the gut and a reduction in the fecundity of the worms that are allowed to develop to maturity in the gut. The trigger for the immune response is incoming larvae of a species previously encountered. The speed of this response is also influenced by how recently the animal was exposed. If within 7 weeks it is rapid; longer and it may take 5 to 14 days (McClure, 2000). The ability to mount the immune response is also affected by nutritional status and is likely to be less effective if the ewe is having to partition nutrients between her own requirements when she is below ideal condition and the needs of her immune system (Houdijk *et al.*, 2001).

It has been long accepted practice for sheep farmers to de-worm ewes at the start of the flushing period in the belief that this would improve lambing % as it removed their worm burden. SCOPS (2012) have advised against this practice since 2004 because such treatments are now deemed unnecessary for fit, adult ewes. Only immature (in this context this means females up to about 18 months of age with incomplete acquired immunity), ewes that are naïve despite age due to lack of exposure and those that are in poor condition are recommended as needing treatment. These animals will not be able to mount a full immune response to GINS. Indeed, given the review of McClure (2000) the removal of the parasites that are providing the constant status to the immune system may be in itself detrimental. This is supported by West *et al.*, (2009) who demonstrated that mature sheep given a continuous slow release anthelmintic bolus and then exposed to larvae had a 3 to 5Kg weight disadvantage and 8 less lambs/100 ewes compared to untreated ewes which had maintained their immune status. In NZ, trials on farms report a difference of -11 to + 20% in lamb numbers conceived when treated and untreated ewes are compared (West *et al.*, 2009). This underlines the need for guidance on which animals require treatment versus those that do not.

As yet unpublished preliminary data from a VMD funded project (2013-2016) carried out by APHA (formerly FERA) supports this in practice. Flocks following SCOPS recommendations using on average 0.5 targeted ewe treatments per year compared to 2 to 3/ewe per year in flocks using a conventional approach. Ewe performance was at least as good in the SCOPS flocks as those using 5 to 6 times the number of ewe doses.

## **3.2 Nutritional Management of the Ewe in the First to Third Months of Pregnancy**

### **3.2.1 Embryo Implantation and Survival - First Month of Pregnancy**

During the first month of gestation foetal growth is minimal. Embryo implantation into the lining of the uterus takes place two to three weeks post mating. In that time the fertilised embryo has to develop into a morula and then a blastocyst before implantation takes place. Nutrition at this time has an influence on the composition of the oviductal and uterine secretions that nourish the embryo in its early cell divisions. Robinson *et al.*, (2002) reviewed the plane of nutrition post mating and demonstrated that high feeding levels at this stage can decrease pregnancy rate and litter size by inhibiting placental growth and function. This is caused by reducing blood progesterone to levels that compromise embryo survival, with 11 to 12 day old embryos being the most vulnerable.

The review explored the role of progesterone in the very early stages of pregnancy. Excess levels of nutrition cause shifts in progesterone concentration resulting in alteration of placental function and/or the expression of genes within the embryo that control subsequent foetal growth. The nutritional environment of the pre-implanted embryo can also alter gene expression and distort the relationship between the size of the foetus and the placenta. More recently, Addah *et al.*, (2012) also concluded that higher energy intake during the first trimester has deleterious effects on oocyte quality and embryo survival through its effects on progesterone concentration and uterine pH.

Robinson *et al.*, (2005) concluded that the impact of nutrition on embryo survival extends beyond the supply of essential nutrients and the modifications of the hormones and growth factors that influence embryo development. Abrupt changes in diet composition or rapid fluctuations in feeding level and pattern of feeding can disrupt rumen function and metabolic homeostasis with adverse consequences for embryo survival.

Kenyon and Blair (2014) and Rooke *et al.*, (2015) have completed extensive reviews of the factors affecting foetal development through gestation, which includes under and over nutrition of the ewe. They also conclude that both excessive over feeding or under feeding compared to maintenance in early gestation can have a detrimental effect on lamb survival and birth weight at lambing time.

Rooke *et al.*, (2015) reviewed the effects of over nutrition in pregnancy but most studies are not specific to the first month of pregnancy and the embryo implantation stage. However, they report differences in response depending on the age of the ewe. Over feeding of ewe lambs (under one year of age at mating) has produced mixed results with one experiment showing the young

ewe partitioning food to maternal growth at the expense of lamb birth weight, when fed at twice energy requirements, while in another study offering the same feeding level, the ewe lambs produced lambs of higher birthweight when overfed between days 0 and 39 of pregnancy.

A study to compare age of ewe and level of feeding during the first month of pregnancy was reported by Annett and Carson (2006). Conception rate, foetal development and lamb output were compared in adult ewes and ewe lambs offered diets designed to supply 2.0, 1.0 and 0.6 of maintenance levels from day 0 to 31 of gestation. Nutrition level had no effect on conception rates in adult ewes, while the ewe lambs had lower conception rates on the 2.0 and 1.0 times maintenance diet compared to the 0.6 rate. But as a result more ewe lambs on the low feeding level conceived and they had higher mean total lamb birth weight. However, they concluded that the proviso on this strategy is that food restricted ewe lambs are less capable of sustaining high levels of lamb performance from birth to weaning, thus offsetting some of the fertility benefits.

Undernutrition in this early stage of pregnancy is thought to have a larger detrimental effect on embryo development than over nutrition (Addah *et al.*, 2012 and Rooke *et al.*, 2015). Addah *et al.*, (2012) concluded in a review of under nutrition of the ewe that at this stage of pregnancy, low energy levels may 'programme' poor adult growth and productivity of the progeny. Although overall they advised that under nutrition at this stage had less effect on lamb birth weight than if the under nutrition was at later stages of pregnancy.

Kenyon and Blair (2014) reviewed the effect of below maintenance feeding in the first month of pregnancy on lamb birth weight and found that undernutrition could lead to reduced birth weight especially in ewes rearing multiple foetuses. However, they also concluded that the effect of undernutrition was greater in late pregnancy than very early pregnancy.

Robinson *et al.*, (2002) Annett and Carson (2006) and Rooke *et al.*, (2015) concluded that for ewes of the target condition score at mating (3 to 3.5 for lowland ewes), the optimum feeding level during the first month of pregnancy for maximum embryo survival is maintenance level, thereby ewes maintain live weight and BCS.

Numerous micronutrients are involved in embryo development and survival. The key ones linked to impaired embryo development and survival are shown in Table 21, along with their functions and modes of action. For a comprehensive review, refer to Suttle (2010).

Table 21. Micronutrient involvement in embryo development and survival (modified from Robinson *et al.*, 2005)

| Micronutrient                          | Function  | Mode of Action   |
|--|---|--|
| Vitamins and trace elements in general | Deficiency- steroid hormone synthesis, expression of growth factors, gene transcription | Embryo cell proliferation and differentiation                    |
| Vitamin A                              | Deficiency – disruption of the retinoic acid receptor                                   | Failure of embryo growth, disrupted organ growth and embryo loss |
| Vitamin A                              | Excess - disruption of the retinoic acid receptor                                       | Disruption of the embryos nervous system                         |
| Vitamin E and selenium                 | Deficiency - antioxidants   | Embryo loss at implantation                                      |
| Cobalt                                 | Deficiency - inadequate folate  | Impaired embryo development, neural pathway defects              |

Ewe diets need to supply minerals and trace elements at recommended levels throughout pregnancy, avoiding excess or deficiency to optimise foetal growth (Robinson *et al.*, 2005). For further details on the effect of trace elements and vitamins on the pregnant ewe, refer to Section 2.4.3.

### 3.2.2 Placental Growth – Second and Third Months of Pregnancy

During the second and third months of pregnancy the placenta grows to its full weight of about 1kg and the foetus develops to about 15 to 20% of its birthweight (Fthenakis *et al.*, 2012). The placenta plays a key role supplying nutrients to the developing foetuses which determines foetal survival and lamb birth weight. If it does not fully develop there can be a detrimental effect on foetal growth and lamb birthweight (Sen *et al.*, 2013). By day 90 the placenta has fully developed to about 1kg in weight and the foetus has grown to 15 to 20% of its final birthweight. Therefore, the objective of ewe nutrition at this stage is to optimise placental growth and the most sensitive period is between 50 and 90 days of gestation.

BCS affects the nutrition response of ewes in mid-pregnancy. Robinson (1990) and Robinson *et al.*, (2002) summarised that ewes in good body condition (score 3.5), could adjust to a mild degree of undernutrition with a loss of condition of up to 0.5 BCS without detrimental effect on the placenta and lamb growth in the second and third months of pregnancy. There is some evidence that placental growth and lamb birth weights are enhanced with a loss of up to



0.5 BCS in mid pregnancy as long as feeding is good in late pregnancy (months four and five). However more severe feed restriction can lead to a reduction in placental size. For ewes in poorer body condition (2 to 2.5) at the start of this phase, a reduction in feeding has a detrimental effect on placental growth and subsequent lamb birth weight.

### **3.2.3 Energy and Protein Requirements in Early and Mid-Pregnancy**

Evidence supports the view that the energy and protein requirements for a ewe in the first 90 days of pregnancy are those sufficient for maintenance of the ewe in the target body condition (and hence weight), the developing foetus and placenta have a minute requirement above maintenance levels (Robinson *et al.*, 2002). More evidence has been reviewed in previous sections that supports the view that both under and over feeding could present short and/or long term production problems. This underlines the need for ewes to be in the target BCS at mating, not simply in terms of ovulation rate and litter size, but because of its effects in mid pregnancy.

As detailed in section 2, it is recommended that energy and protein requirements for maintenance detailed in AFRC (1993) are used, confirmed by Cottrill *et al.*, (2009).

Robinson (1990) concluded that the degree of maturity of the ewe also interacts with plane of nutrition in mid pregnancy. Young ewes, ewe lambs or shearlings are more susceptible to a loss in condition in mid pregnancy especially if they are poorer in body condition, leading to reduced placenta weight, foetus weight and lamb survival. Therefore, it is advised that young ewes maintain their weight and condition through mid-pregnancy. These reviews recommended using the interaction between age and condition score of the ewe with feeding level in mid pregnancy to manage feeding strategies on farm. In practice, a flock of ewes will have varying condition score, so management in groups within a tight range of BCS and age is ideal.

An experiment to identify metabolic changes in the ewe and assess placental development was reported by Clarke *et al.*, (1998). The results showed that restricted maternal nutrition between days 30 and 80 of gestation led to a smaller placenta. The foetal weights were not affected and this was thought to be due to higher haemoglobin and thyroid hormone levels in the foetal cotyledons and umbilical cord plasma respectively. This hypothesis of increased blood flow between the placenta and foetus when placental development has been reduced by maternal undernutrition was confirmed by Addah *et al.*, (2012).

Although this research suggests ewes can compensate for undernutrition in mid pregnancy there is a suggestion that there are effects on the long term productivity of the lamb. Rae *et al.*, (2001) found that maternal undernutrition

between mating and day 110 of pregnancy led to significantly delayed foetal follicular development which would have a long term effect on the breeding capacity of the lamb. Maternal undernutrition also altered foetal development when ewes were under fed between days 30 and 80 of gestation (Sen *et al.*, 2013). Single bearing ewes showed lower placenta weight, cotyledon weight and lamb birth weights when offered a diet 50% of daily requirement compared to 100% of requirements.

Recent reviews (Addah *et al.*, 2012, Fthenakis *et al.*, 2012, Kenyon and Blair, 2014 and Rooke *et al.*, 2015) concluded that results were very variable and inconsistent and that maternal responses to under nutrition in mid pregnancy are not as severe as when the restriction is in late pregnancy. Rooke *et al.*, (2015) found that undernutrition up to day 100 of gestation reduced lamb birthweight in four out of ten studies reviewed. They concluded that when birth weight reductions were observed they may have resulted from differences in ewe breed, age of the ewe or environment. During most studies reviewed, ewes were offered diets at maintenance or above after day 100 of gestation which enabled compensatory growth of the foetus during late pregnancy.

Many studies focus on lamb birth weight, Rooke *et al.*, (2015) and Dwyer *et al.*, (2016) also reviewed the impact of maternal undernutrition in mid pregnancy on lamb mortality, maternal and lamb behaviour. Lamb mortality was increased with reduced lamb birth weight, but some reports show reduced mortality when lamb birth weights were not affected by maternal undernutrition in mid pregnancy. There is evidence that under nutrition affects the establishment of the ewe and lamb bond and this effect is greater in younger ewes with less previous experience of lambing. The breed of the ewe was also found to have an effect on the ewe – lamb bond when ewes were under fed in mid pregnancy (Rooke *et al.*, 2015). Lambs from under nourished Suffolk ewes took longer to progress through behavioural milestones than Blackface ewes fed levels of under nutrition between days 0 to 90 of gestation. Lambs from under nourished ewes of both breeds took longer to suck from their mothers. Also undernourished ewes from both breeds displayed poor maternal behaviour, were more likely to prevent lambs from sucking, and were less likely to approach or interact with their lambs.

Early work by Orr and Treacher (1990b) suggested that although lamb birth weights were unaffected when ewes had a period of undernutrition in mid pregnancy, the ewes were of lower weight and condition post lambing. Ewes in poorer condition then took longer to recover at weaning.

Current industry guidance recommends that ewes in good condition (3.5 for lowland ewes) at the start of the mid pregnancy period can lose up to 0.5 units of condition score in mid pregnancy. However there appears to be growing evidence that although lamb birth weight may not be affected by the loss of condition as the ewe compensates with foetal blood flow, there may be

undesirable long term effects on lamb mortality and future reproductive ability of the lamb. There may also be longer term effects on the reproductive ability of the ewe if she takes longer to regain condition before the next mating.

Over nutrition of ewes in mid pregnancy does not generally affect lamb birth weight. Rooke *et al.*, (2015) concluded there is no clear evidence indicative of improved lamb welfare of feeding ewes during pregnancy more than required for maintenance of growth of the foetus. Some studies show there may be disadvantages such as increased dystocia, reduced lamb vigour and reduced lamb survival, although over feeding is more likely to cause these problems when it occurs in late pregnancy.

With the advent of EID we can now monitor large cohorts of ewes on an individual basis. These data allow for a more in depth look at the effects of BCS and weight both as measures at specific times but also the changes over time.

Preliminary data from the AHDB KPI project (AHDB, 2014c) suggests that there is a positive relationship between weight gain from mating through to scanning on both scanning % and the weight of twin lambs at eight weeks of age. This is further supported by data from six farms in Wales involved in a similar project in 2014/15. This is in contrast to current advice which has for many years suggested that ewes can lose body condition (and hence weight) in this period without any effect on productivity. This is of course providing they are in the target BCS at mating (see earlier refs) and in practice amounts to 0.5 BCS units of around 5 to 6% of live weight.

It is too early to say what the final outcome will be, but it is likely that the results will support advice that ewes must be on at least a maintenance diet up to mid pregnancy so as not to lose weight and possibly to gain a small % for optimum performance in that production year.

The importance of the relationship between nutrition and final reared output per ewe is an underlying premise to ewe management. Attempts to by-pass this relationship by increasing fertility through either genetic or exogenous treatments have had mixed results. Fecundin™ was developed in the 1980's and involved the immunisation of ewes against androstenedione, a steroid which normally limits ovarian follicle production. Treatment resulted in an increased ovulation rate and litter size, overriding the nutritional effects of body condition and flushing around the mating period. However, trials both in the Antipodes and the UK (Stubbings and Maund, 1988) demonstrated that while litter size could be increased significantly, the resulting rearing % was rarely improved and in some cases lower than untreated ewes. The conclusion is that nutritional restriction applies during the whole production cycle as do any other management issues which are amplified by increasing litter size. West *et al.*, (2009) review the current recommendations for this approach in NZ where commercial products are available and also conclude that they pose significant management and nutritional challenges.

Similarly, the Inverdale, Booroola and other genes (Davies, 2004) have been proposed as genetic solutions to the limit on productivity that ovulation rate poses. However, the reasons for using such genes in breeding programmes is often overlooked. Davies (2004) outlines the incorporation of a major gene for prolificacy into a flock using marker assisted selection which allows increased selection pressure on other traits leading to increased genetic gain without losing the new breed's characteristics.

The Inverdale (INX) gene is currently in limited use in the UK in the 'Aberdale'™ (Innovis see website). The gene has been incorporated into a Texel breeding line and the carrier rams are then crossed to less prolific breeds to produce a gene carrying F1 female. These are capable of very high levels of prolificacy without the need for higher levels of nutrition in the pre-mating/mating period.

An evaluation of these ewes on commercial and college farms was undertaken by IBERS (as yet unpublished). The conclusion was that the Aberdale had a limited place on farms where poor quality grazing was available in the autumn that would restrict the performance of non INX carrying ewes. However, this requires a significant management effort to ensure that they are in good BCS pre-mating, are negatively flushed and then are not allowed to lose condition through early/mid pregnancy. This is a further illustration of how nutrition management affects the potential benefits of the gene.

Clear effects of foetal nutrition on subsequent reproductive performance are also reported. Robinson *et al.*, (2002) in their review conclude that where there is inadequate nutrition in early pregnancy there is a lasting detrimental effect on the foetal ovary. Rae *et al.*, (2016) having looked at various stages of foetal development, conclude that undernutrition before and during folliculogenesis can delay foetal follicular development and this has lasting effects on future productive potential.

### **3.3 Nutritional Management of the Ewe in the Fourth and Fifth Months of Pregnancy**

During the fourth and fifth months of pregnancy 80 to 85% of foetal growth takes place, placing a huge nutrient demand on the ewe (see Figure 5 and Table 18). It has been long recognised that there is a strong correlation between ewe nutrition in late pregnancy and lamb survival and birth weight. The ewe's udder also develops in preparation for lambing and production of colostrum and milk in the last 4 weeks of gestation which is important to ensure good quality and adequate supplies of colostrum in the first two to three days post lambing together with overall lactation yield (Robinson, 1983 and 1990).

The review of Fthenakis *et al.*, (2012) summarised that good nutritional management of ewes in this period should:

- Prevent pregnancy toxæmia and other metabolic diseases (e.g. hypocalcaemia, hypomagnesaemia)
- Produce lambs of normal birth weights and of good vigour
- Produce colostrum in appropriate quality and quantity
- Support increased milk yield during lactation.

The preliminary results of the AHDB KPI project (AHDB, 2014c) concur with previous work in that ewes need to start the final trimester in good BCS (score 3 or above) and that the loss in BCS up to lambing should be minimal. As yet it is not clear if there are any direct effects of BCS in late pregnancy *per se* on ewe performance up to lambing (except in extreme BCS scores for example where ewes are thin and lame). Analysis of the full dataset is required to demonstrate any relationship. The effect of BCS in late pregnancy is more evident when lamb performance (linked to milk yield, lamb viability) is considered

### **3.3.1 Energy and Protein Requirements in Late Pregnancy**

Based on the current information and the consensus of a workshop attended by a group of industry experts (April 2016), it is suggested that the energy and protein requirements published in AFRC, (1993) for late pregnant ewes continue to be used, as a minimum requirement. However, they also emphasised the need to consider their live weight and body condition, the predicted lamb birth weight and number of lambs and also the potential level of parasitic infection the ewe is exposed to when applying these recommendations. The group agreed that current ME and MP requirements for sheep worked satisfactorily on UK farms with 'practical adjustment' and there is insufficient evidence to support any adjustment given the potential costs relative to the unpredictable benefits.

However, there are clearly many questions surrounding this. Robinson *et al.*, (2002) noted the evidence that in the absence of any alteration in the composition and intake of a diet, pregnancy *per se* causes approximately a 15% increase in the amount of amino nitrogen reaching the duodenum and therefore available for absorption in the small intestine. It is thought that ewes in late pregnancy have a modified maternal digestive system and the source of the extra protein reaching the small intestine is increased undegraded protein. Cottrill *et al.*, (2009) confirmed this concept was still an omission in all current feeding systems.

As detailed in Section 2, it is recommended that energy and protein requirements for pregnancy detailed in AFRC (1993) are used (Cottrill *et al.*, 2009). Demands for energy and protein increase rapidly in the last two months

of pregnancy for the development of the foetus and mammary gland. The calculated ME requirements for housed pregnant ewes are shown in Table 22.

*Table 22. Metabolisable energy (MJ/day) requirements of housed pregnant ewes (based on a diet with ME of 11MJ/kg DM, assuming no ewe weight loss) (AFRC, 1993)*

| <b>Ewe Live Weight (kg)</b> | <b>Number of Lambs</b> | <b>7 Weeks to Lambing</b> | <b>5 Weeks to Lambing</b> | <b>3 Weeks to Lambing</b> | <b>1 Week to Lambing</b> |
|-----------------------------|------------------------|---------------------------|---------------------------|---------------------------|--------------------------|
| 50                          | 1                      | 7.9                       | 8.7                       | 9.8                       | 11.2                     |
|                             | 2                      | 8.8                       | 10.1                      | 11.9                      | 14.2                     |
| 60                          | 1                      | 9.1                       | 10.0                      | 11.2                      | 12.8                     |
|                             | 2                      | 10.1                      | 11.6                      | 13.7                      | 16.3                     |
| 70                          | 1                      | 10.2                      | 11.2                      | 12.6                      | 14.4                     |
|                             | 2                      | 11.4                      | 13.1                      | 15.3                      | 18.3                     |
|                             | 3                      | 12.0                      | 14.0                      | 16.7                      | 20.3                     |
| 80                          | 1                      | 11.3                      | 12.4                      | 13.9                      | 15.9                     |
|                             | 2                      | 12.6                      | 14.4                      | 17.0                      | 20.2                     |
|                             | 3                      | 13.3                      | 15.5                      | 18.5                      | 22.5                     |

The ewe's demand for ME increases with ewe live weight, the number of lambs carried and the closer to lambing. For a 70 kg ewe carrying twins there is a 60% increase in ME requirements between seven and one week pre lambing.

The calculated MP requirements for housed pregnant ewes are shown in Table 23. MP requirements rise during the last seven weeks of pregnancy with an increased demand in the last three weeks. For a 70 kg ewe carrying twins there is a 60% increase in MP requirements between seven and one week pre lambing.

*Table 23. MP (g/day) requirements of housed pregnant ewes (based on a diet with ME of 11MJ/kg DM, assuming no ewe weight loss) (AFRC, 1993)*

| <b>Ewe Live Weight (kg)</b> | <b>Number of Lambs</b> | <b>7 Weeks to Lambing</b> | <b>5 Weeks to Lambing</b> | <b>3 Weeks to Lambing</b> | <b>1 Week to Lambing</b> |
|-----------------------------|------------------------|---------------------------|---------------------------|---------------------------|--------------------------|
| 50                          | 1                      | 72                        | 76                        | 81                        | 88                       |
|                             | 2                      | 77                        | 83                        | 92                        | 103                      |
| 60                          | 1                      | 80                        | 84                        | 90                        | 98                       |
|                             | 2                      | 85                        | 92                        | 102                       | 115                      |
| 70                          | 1                      | 87                        | 92                        | 98                        | 107                      |
|                             | 2                      | 93                        | 101                       | 112                       | 126                      |
|                             | 3                      | 96                        | 106                       | 119                       | 136                      |
| 80                          | 1                      | 94                        | 99                        | 107                       | 116                      |
|                             | 2                      | 100                       | 109                       | 122                       | 137                      |
|                             | 3                      | 104                       | 115                       | 129                       | 148                      |

### **3.3.2 Factors Affecting the Interpretation of the Requirements**

The requirements for energy and protein are determined by ewe weight, number of lambs carried and whether the ewe is gaining, losing or maintaining her weight (AFRC, 1993). It is therefore important to know accurate body weights for the ewes, the number of lambs carried from scanning results and BCS. In practice, ewes should be fed according to the number of lambs carried and their condition from six weeks pre lambing. Thin single bearing ewes can be fed with the twin bearing ewes and thin twin bearing ewes can be fed with triplet bearing ewes to meet extra nutrient demands of low condition score ewes. Young first time lambers (ewe lambs or shearlings) should be fed in separate groups by litter size, to the adult ewes.

There are many other factors which need to be taken into account when preparing rations to ensure the diet offered meets the requirements of the ewe. Rumen function and maximising contribution from forage are key to maximise feed intake as described in Sections 2. The following factors affect intake and must be considered when preparing rations to ensure the required level of energy and protein are supplied.

- Correct weight and age of the ewes
- Known forage type and quality
- High quality concentrate fed to maximise forage intake and provide nutrients
- Fresh, accessible water at all times
- Frequency of feeding (once or twice a day feeding)
- Flat rate or step feeding
- Presentation of the food (e.g. TMR)
- Access and feeding space.

### **3.3.3 Effect of Under and Over nutrition in Late Pregnancy**

Considerable research has been undertaken on the effects of under nutrition of ewes in late pregnancy. While the ewe can compensate for mild undernutrition in mid-pregnancy by increasing blood flow across the placenta, this is not possible in the last two months of pregnancy when nutrient demand is very high (Addah *et al.*, 2012).

Dwyer (2014), Kenyon and Blair (2014) and Rooke *et al.*, (2015) demonstrate that ewes under nourished in the last eight weeks of pregnancy have:

- Lambs of lower birth weight with reduced survival rates
- A weaker ewe and lamb bond
- Reduced udder weight and mammary development
- Delayed onset of lactation
- Reduced colostrum and milk yield
- Long term performance of ewe and lamb.

The effect of feeding diets supplying inadequate energy in late pregnancy on fat and thin ewes was reviewed by Robinson *et al.*, (2002). He found that fatter ewes mobilise their energy reserves. Providing the energy deficit is not large or acute enough to induce pregnancy toxemia, they are better at sustaining foetal growth than thinner ewes. Thin ewes with free access to a low energy diet will eat more than fat ewes. The effect of body condition was tested by feeding fat and thin ewes to requirement in late pregnancy and they found that the fat content of the lamb was positively correlated to the fat content of the dam. Ewes in better condition produced lambs with higher adipose tissue (brown fat) which is critical in heat production and lamb survival.

There is also a positive correlation between energy under nutrition and intake of DUP and MP. Robinson (1990) showed that as the level of energy in the diet decreased the requirement for protein in the diet in the form of DUP or MP increased to meet the needs of the growing foetuses.

MP supply in late pregnancy has a direct effect on lamb birth weight but also on the nutrient partitioning in the ewe (Robinson *et al.*, 2002). Ewes on low levels of dietary protein in late pregnancy lose protein and fat from the carcass tissues and fat from the internal organs compared to ewes on adequate dietary protein diets. Ewes offered diets of adequate protein gain protein in both carcass tissues and maternal organs. Again this contributes to the future productivity of the ewe. This muscle proteolysis is only one of the many pregnancy induced metabolic adaptations in maternal tissues.

Fthenakis *et al.*, (2012) postulated that the negative effect of under nutrition on foetal growth in late pregnancy was as a result of an imbalance of glucose and insulin resulting in a decreased foetal insulin like growth factor. Foetuses are thought to swallow amniotic fluid which provides the nutrients and growth factors for their development. This hypothesis is also reviewed by Addah *et al.*, (2012) who also describe the foetal placental metabolism of glutamate and glutamine in response to under nutrition in late pregnancy.

McGovern *et al.*, (2015a; 2015b) reported on trials studying the ewe's response to increased energy and protein in the last four weeks of gestation. They concluded that ewes offered diets lower than recommendation in both energy and protein had lower live weight and BCS at lambing, lower colostrum and milk yield production and lower lamb growth rates to weaning.

Under nourished ewes in late pregnancy are found to have behavioural impairments at lambing, taking longer to interact with their lambs and displaying more aggression to the lamb, spending less time grooming and more time eating after birth than well fed ewes (Dwyer *et al.*, 2014 and Rooke *et al.*, 2015). This weak ewe and lamb bond is caused by changes in oestradiol and progesterone relative concentrations in undernourished ewes. Undernourished



ewes have increased progesterone level which depresses the ratio with oestradiol and this is thought to mediate maternal care in the ewe (Dwyer *et al.*, 2014).

Rooke *et al.*, (2015) showed a genetic difference in the ewe and lamb bond. Lambs from under fed Suffolk ewes took longer to progress through behavioural milestones compared to lambs born to undernourished Scottish Blackface ewes. Although lambs from both breeds took longer to suck their dams and there was less interaction between ewe and lamb compared to adequately fed ewes. Lower lamb birthweights were associated with decreased live weight gain to weaning in some studies, related to ability of the ewe to milk and environmental and husbandry factors. The difference between breeds was described by Dwyer (2014) who showed that Scottish Blackface ewes had higher levels of maternal care than Suffolk ewes, which was in common with other less domesticated breeds. The less domesticated Scottish Blackface was found to have higher circulating concentrations of oestradiol in late gestation and showed a greater pre-lambing surge of oestradiol compared to Suffolk ewes. Oestradiol is thought to regulate the oxytocin receptors in the brain resulting in increased expression of maternal behaviour.

The effect of ewe maternal nutrition in late pregnancy on the future reproductive performance of her lambs was reviewed by Kenyon and Blair (2014). They concluded that low maternal nutrition in ewes can affect the development of the ovaries in the foetus with lower levels of follicle production and also the structure of the foetal testis. However, the effects on the adult progeny's reproductive performance was not always present.

Trace elements and vitamins are reviewed in Section 2. Dwyer *et al.*, (2016) confirms that where the status of ewes was marginal, supplementation improved lamb survival, for cobalt, selenium and vitamin E. There is little evidence of any benefits to supplying trace elements in excess of requirements. Providing there are no chronic deficiencies in trace element and vitamin supply, under nutrition is the main nutritional risk to neonatal lamb survival in late pregnancy.

Dystocia can be due to excessive foetal-maternal disproportion (Fthenakis *et al.*, 2012), even thin ewes put energy into the growing foetus causing excessively large lambs which cause lambing difficulties. This is more likely to be a concern with single bearing ewes, as ewes bearing multiple lambs tend to struggle to achieve sufficient dry matter intake in late pregnancy.

Rooke *et al.*, (2015) also reviewed the effect of over nutrition of ewes in late pregnancy. There were generally no differences in lamb birth weight, lamb mortality or daily live weight gain in lambs born to ewes over fed in late pregnancy, but this depended on the BCS of the ewe. Although in some cases there may be disadvantages such as increased dystocia, reduced lamb vigour

and lamb survival. Ewes which are overfat at lambing can experience higher levels of prolapse and there is also a higher risk of pregnancy toxaemia (Robinson *et al.*, 2002).

Hosie *et al.*, (1991) reviewed the nutritional factors associated with vaginal prolapse and concluded that over feeding was the key cause, confirmed by BCS and beta hydroxyl-butyrate blood levels.

### **3.3.4 Lamb Birth Weight and Mortality**

Dwyer *et al.*, (2016) reviewed the effect of lamb birthweight on lamb mortality. In only half the studies reviewed was a decrease in birthweight accompanied by increased mortality. Low birthweight lambs tend to have lower glucose levels and brown adipose fat levels reducing their ability to keep warm and 'get up and go' (Robinson, 1990; Fthenakis *et al.*, 2012). Contributory factors were how much lower the birth weight was, along with physical environment and the amount and quality of husbandry given. The review (Dwyer *et al.*, 2016) confirmed that feeding the ewe in excess of requirements was not associated with improvements in lamb survival and negative outcomes were more common. They concluded there was a U shaped relationship between lamb birth weight and survival. For a Scottish Blackface, the optimal birthweight lies between 3 and 5 kg, with mortality increasing rapidly in lambs born at less than 3kg and greater than 5kg. For each breed of sheep, linked to their mature weight there will be an optimum birth weight range, outside of which mortality is likely to be higher.

Dwyer (2014) described the increased mortality of lambs that are too large at birth. Ewes which experience a prolonged or difficult lambing are slower to groom their lambs, show reduced bonding behaviour and fewer bleats and are more likely to reject their lambs. Also lambs can have less vigour due to a difficult birth, all of which are factors contributing to higher mortality levels in over size lambs.

### **3.3.5 Colostrum Production**

Lambs are born hypo immunocompetent, with only a small store of energy for heat production and metabolism and are therefore completely dependent on colostrum to supply immunoglobulins and energy (O'Doherty and Crosby, 1997).

Most mammary gland development takes place during the last month of pregnancy, but in the week before lambing, the gland markedly increases in size and this growth accompanies massive colostrum synthesis at the onset of milk production. Growth of the gland and mammary cell differentiation are both strongly influenced by nutrition of the ewe in late pregnancy (Robinson *et al.*,

2002; Nowak and Poindron, 2006; Banchero *et al.*, 2015). For a complete review of colostrum production in ewes refer to Banchero *et al.*, (2015). The review concluded that poor pre lambing nutrition reduced both colostrum and milk production, delayed the onset of lactation, changed the viscosity of the colostrum before lambing and reduced the quantity produced after lambing. Viscosity and volume of colostrum are inversely related, with colostrum becoming more viscous if lactation is delayed. When colostrum is very viscous this can be a problem for new born lambs as it is more difficult to withdraw from the teat.

Undernutrition in late pregnancy delays the fall in progesterone level which in turn delays the increase of blood flow to the udder, depriving it of important metabolic substrates for colostrum production (Robinson *et al.*, 2002; Banchero *et al.*, 2015). There is an immediate requirement at birth for 50ml of colostrum per kg of lamb birthweight, so any delay in its production can compromise lamb survival. Banchero *et al.*, (2015) suggest that a lamb requires 200ml of colostrum per kg of birth weight in mild weather conditions within the first 18 hours of life. This level of intake needs to be increased by 50% in wet and windy weather and again they suggest that 25% of colostrum intake needs to be available at birth to improve lamb survival.

The primary immunoglobulin in colostrum is immunoglobulin G (IgG) and its concentration decreases rapidly after parturition at approximately 3.3mg/ml/hour, diminishing to zero by 23 hours post lambing (Al-Sabbagh *et al.*, 1995).

A clear relationship between the ewe energy intake over the last three weeks of pregnancy and colostrum yield was confirmed by O'Doherty and Crosby (1997). The production of IgG during the first 18 hours after lambing was positively related to the amount of colostrum produced. There was a significant relationship between total amount of IgG ingested and the amount circulating in the lamb serum at 18 hours post lambing. They observed a significant ( $P<0.05$ ) increase in the efficiency of absorption of colostrum IgG by lambs when ewes were offered a pre lambing protein supplement of soya bean meal. Champion *et al.*, (2016) reported a response in lamb serum IgG at 24hour post lambing to increased energy and protein intakes in ewes, although there was no observed response in colostrum production or intake by the lambs.

Amanlou *et al.*, (2011) reported that supplementing ewes with high DUP (24% higher than requirement) during the last three weeks of pregnancy led to increased colostrum production. Ewes offered the high DUP diet produced colostrum of higher fat and protein compared to ewes offered diets formulated to meet requirements. Conversely, Ocak *et al.*, (2005) found that total colostrum yield was reduced for single bearing ewes supplemented with 1.4 times the protein requirement level for pregnant ewes compared to ewes fed protein at maintenance levels.

Banchero *et al.*, (2015) reviewed level of protein in late pregnancy diets and concluded that both deficits and excesses of dietary protein can impair the amount of colostrum produced at lambing. The level of protein required is dependent on the energy available to the ewe. High levels of RDP in the diets can lead to high levels of ammonia in the rumen if there is not sufficient energy in the diet. Conversely if low levels of protein are fed in pregnancy, this may reduce the utilisation of starch for colostrum synthesis in ewes supplemented with high energy diets, supplemented with cereal grains. The review concludes that if the pregnancy diet contains sufficient energy, then supplementing with high quality protein can increase colostrum production. However, this was less effective than supplementing with cereal grains in the last week of pregnancy.

The amount of energy, especially glucose, available at the end of pregnancy plays a major role in colostrum synthesis (Banchero *et al.*, 2015). Cereal grains such as maize, barley and sorghum are rich in ME and starch and when they are used to supplement in the last week of pregnancy, can double the production of colostrum. Different grains give varying responses dependent on the amount of starch digested post rumen. The amount of starch entering the lower digestive tract is 14%, 8.5% and 2% of grain DM intake for maize, barley and oats respectively. Supplementation with oats had little effect on colostrum production due to low starch levels but maize and barley supplementation produced an increase in colostrum production of 90 to 185% over that of un-supplemented ewes.

The effect of energy intake during the last five weeks of pregnancy on ewe live weight gain, lamb birth weight and colostrum production is shown in Table 24. The results show that ewes offered a high plane of nutrition gain more body weight have lighter lambs but produce more colostrum compared to ewes offered a restricted low plane of nutrition. The low energy diet offered to ewes led to reduced ewe weight, but high lamb birth weight with low colostrum yield. Ewes offered a low energy diet from day 110 to 135 days of pregnancy, then fed a high energy diet for the last 10 days of pregnancy showed high birthweight of lambs and moderate levels of colostrum. The results of this study should be treated with caution, because the low energy level is extremely low and the high energy level is below recommended levels in AFRC (1993).

High mineral intakes (above requirements) of ewes in late pregnancy led to lower absorption of IgG in the lambs (Boland *et al.*, 2005).

Nowak and Poindron (2006) reviewed lamb survival. They concluded that maximising lamb vigour at birth, colostrum production and the ewe and lamb bond through adequate feeding in late pregnancy was fundamental for lamb survival. Delayed lactation or insufficient colostrum yields may be fatal since suckling has strong properties in the establishment of the mother and lamb bond, without which survival is reduced.

Table 24. The effect of energy intake during the last 35 days of pregnancy (McDonald *et al.*, 2011)

| Energy Plane      | Energy Intake (MJ/day) | Live Weight Change in Ewes (kg) | Lamb Birth Weight (kg) | Colostrum in first 18 Hours (ml) |
|-------------------|------------------------|---------------------------------|------------------------|----------------------------------|
| High Plane        | 13                     | +6.5                            | 4.3                    | 2054                             |
| Low Plane         | 4                      | -2.5                            | 4.8                    | 994                              |
| Low / High Plane* | 4 / 13                 | +4.0                            | 5.0                    | 1315                             |

\*High plane for last 10 days of pregnancy.

Al-Sabbagh *et al.*, (1995) reported on a study to determine the effect of body condition at lambing on colostrum quality and lamb performance. They concluded that within the range of BCS 2.5 to 3.5 at lambing, BCS was not an important factor affecting the colostrum IgG concentration, total weight of lamb born, lamb mortality, or total weight of lamb weaned.

### 3.3.6 Pregnancy Toxaemia in Late Pregnant Ewes

During late pregnancy, rapidly increasing energy demands of the growing foetuses, combined with hormonal interactions (insulin, prolactin), have an impact on lipid metabolism, putting the ewe at risk of developing pregnancy toxaemia (also known as ketosis and twin lamb disease). It is a metabolic disease characterised by hypoglycaemia and hyperketonaemia resulting from the inability of the ewe to maintain an adequate energy balance in the last five to six weeks of pregnancy. Thin ewes or over conditioned ewes, along with ewes carrying multiple foetuses are more likely to develop pregnancy toxaemia (Fthenakis *et al.*, 2012; Olfati *et al.*, 2013).

Fthenakis *et al.*, (2012) describe the physiology of pregnancy toxaemia, caused by incomplete glucose synthesis and mobilisation, as well as fatty acid accumulation in the liver. This hampers the normal function of the liver which results in increased oxidation of fatty acids and increased ketone bodies. The risk factors are summarised by Olfati *et al.*, (2013), which include multiple foetuses, poor quality ingested energy, decreased dietary energy level, genetic factors, obesity, lack of body condition, high parasitic load and lack of exercise.

The symptoms of pregnancy toxaemia include depression, anorexia, weakness, staggering gait, blindness, recumbence, coma and death (Olfati *et al.*, 2013). Diagnosis of pregnancy toxaemia is from blood levels of beta hydroxybutrate (BOHB) which is now recognised as a sensitive tool to determine the energy status of the ewe (Olfati *et al.*, 2013). They described normal healthy sheep have BOHB levels below 0.8 mmol/litre and sheep

suffering from pregnancy toxaemia showing levels of more than 3.0 mmol/litre. An immediate and accurate diagnosis usually increases the possibility of successful treatment.

Cal-Pereyra *et al.*, (2015) evaluated three therapeutic alternatives for the early treatment of pregnancy toxaemia, these were combination of glucose and insulin or glycerol with propylene glycol or fed pasture with two intakes of cracked maize. The results showed that all treatments improved blood glucose and BOHB levels in the blood. The reduction in BOHB was fastest and most effective in ewes offered the glycerol and propylene glycol treatment. This treatment was also recommended by Olfati *et al.*, (2013), unless the ewes are confirmed to be more than 135 days pregnant when induction of parturition and subsequent treatment with intravenous dextrose was recommended (also by Fthenakis *et al.*, 2012).

### **3.3.7 Use of Metabolic Profiles and Their Interpretation**

Metabolic profiles are routinely utilised in dairy cows to monitor nutritional status and this approach is increasingly being used in ewes to assess the adequacy of nutrition (energy and protein) in late pregnancy.

#### **Energy**

The most common markers used are BOHB, which is produced when fat reserves are being mobilised and non-esterified fatty acids (NEFA), produced in response to an energy deficit (against an increasing foetal demand for glucose) and the liver is overwhelmed by the rate fat is being metabolised (Emery *et al.*, 1992). The resultant ketones (BOHB) are a direct indication of this.

Russell (1984) describes the use of blood metabolites such as plasma BOHB concentrations between days 90 and 147 of gestation as a practical and consistently satisfactory method of assessing nutritional adequacy in both individual ewes and groups. (The levels recommended are those that have subsequently been broadly adopted by clinicians (1.1 and 0.8 mmol/litre BOHB for individuals and flocks respectively).

Monitoring the level of BOHB 3 to 4 weeks pre-lambing is a means of checking that the ewe is not in serious energy deficit. Sargison (2008) outlines baseline levels for BOHB with a general recommendation the level should not exceed 1 mmol/litre in late pregnancy.

Cal-Pereyra *et al.*, (2015) have looked at levels in restricted ewes from day 130 of gestation most recently and conclude that the identification of a potentially harmful metabolic imbalance could lead to the improvement of treatment success. Their results suggest that concentrations of glucose, BOHB and cortisol in plasma may provide a precocious diagnosis of subclinical pregnancy

toxaemia. They conclude values of 1.59 (SD 0.24) mmol/litre for glucose, 2.26 (SD 1.03) mmol/litre for BOHB and 15.09 (SD 7.75) mmol/litre for cortisol respectively. The identification of a potentially harmful metabolic imbalance could lead to the improvement of treatment success.

NEFA can also be used as an indicator of energy balance, especially useful in the late dry period in dairy cows. These are precursors to ketone production and therefore may be an early warning of energy deficit but their role in pregnant ewes remains unclear.

### **Protein**

O' Doherty and Crosby (1998) investigated BOHB effects but also the use of serum albumin as an indicator of protein sufficiency, using a variety of diets and protein levels. They reported that urea was not a consistent indicator, with no difference between the non-supplemented and control ewes despite higher CP intakes. In contrast they conclude that serum albumin was sensitive. Normal levels are described as 24-30g/litre for pregnant ewes. Not supplementing the silage diet with protein resulted in a significant decrease in serum albumin compared to supplemented ewes; while the effect was not significant nor consistent for urea.

In general, laboratory guidance (SAC; NuVet information) is that urea can be a useful indicator of RDP deficiency in the short term and as such is viewed along with the serum albumin when data are interpreted.

### **3.3.8 Hypocalcaemia in Late Pregnancy**

Symptomatically hypocalcaemia resembles pregnancy toxaemia, being most likely to occur in older twin bearing ewes exposed to a change in or shortage of food with or without stress (Suttle, 2010). Hypocalcaemia, a deficiency in calcium can occur in late pregnancy, especially in ewes carrying multiple lambs. It is caused by the sudden increase in demand for calcium by the ewe to make colostrum and milk (Treacher and Caja, 2002). Suttle (2010) describes hypocalcaemia as the inability to release calcium from the bones, possibly due to excess dietary calcium but also due to antagonistic effects of phosphorus or magnesium. Excess phosphorus in the diet relative to calcium, reduced bone resorption and is a predisposing factor. Robinson (1990) discusses the mobilisation of calcium from bone due to a fall in circulating blood calcium, which goes against feeding more calcium in the diet. Also illustrated, older ewes are more susceptible to calcium deficiency due to the loss of receptors for calcium in both the intestines and bones. Suttle (2010) confirmed that hypocalcaemia is unlikely to be found in ewes in their first pregnancy.

Treacher and Caja (2002) described the symptoms of hypocalcaemia as uncoordinated movements, tremors and rapid breathing progressing to paralysis, coma and death if not treated rapidly. In the early stages of the

disease, treatment by intravenous injection of calcium borogluconate is generally effective and ewes will stand and eat in about one hour from treatment. Often diagnosis is the response to treatment, but if time allows blood results will show low calcium levels and this will determine whether the ewe has hypocalcaemia or pregnancy toxaemia (Suttle, 2010).

In late pregnancy ewes should be offered diets with calcium levels close to or slightly below requirements as increased intakes of calcium reduce the ability of the ewe to maintain the calcium level in the blood by mobilising bone calcium (Treacher and Caja, 2002). To prevent hypocalcaemia, sudden changes in diet and stress such as movement and transport must be avoided and diets should not contain excess calcium or phosphorus and magnesium (Suttle, 2010).

### **3.3.9 Methods of Feeding Pregnant Ewes**

Traditionally, concentrate feeding in late pregnancy has increased as the demand for nutrients rise in line with the pattern of foetal growth. This is known as 'step rate feeding'. Robinson (1990) reviews flat rate feeding, ewes are offered the same level of feed over the last six to seven weeks of pregnancy. The total amount of food offered is the same, but with flat rate feeding the amount is divided equally by the number of estimated days to lambing. Flat rate feeding is found to work well for prolific ewes carrying multiple lambs when feed quantities are very high in the last couple of weeks of pregnancy. It is found to reduce the risk of loss of appetite, pregnancy toxaemia and hypocalcaemia which can be caused by high concentrate intakes leading to a fall in rumen pH and poor fibre digestion.

Feeding concentrates once or twice a day either as a flat rate or step feeding can lead to swings in rumen pH, with a sudden drop after feeding. Feeding twice a day seeks to reduce the drop and maintain a more stable rumen pH. Reduction in rumen pH can lead to reduced dry matter intake as described in section 2. TMR feeding allows the ewes to spread the concentrate intake throughout the day which stabilises the rumen pH and maximises dry matter intake.

The use of TMR feeding to pregnant ewes was researched by ADAS at Bridget's Experimental Husbandry Farm (EHF) in the 1970's (ADAS Results of Experiments Reports 27 Part 7 1979 GA03256). In the first experiment dry matter intake was measured in twin bearing Mule ewes (body weight 76kg at start) for seven weeks fed either a conventional diet of hay and concentrates or a TMR, see Table 25.



Table 25. Ewe intakes fed hay and concentrates or a TMR (ADAS, 1979)

| Diet                       | Total DM Intake (kg) | Average DM Intake (kg/day) | Total ME Intake (MJ) |
|----------------------------|----------------------|----------------------------|----------------------|
| Hay + concs (conventional) | 73.8                 | 1.32                       | 682.6                |
| TMR (hay based)            | 91.35                | 1.63                       | 887.6                |

The results showed that ewes had higher dry matter and ME intakes when they were fed the TMR diet compared to the conventional diet. In a second experiment on a commercial farm undertaken by ADAS, twin bearing Mule ewes were offered hay and concentrates or either a hay or straw based TMR, see Table 26.

Table 26. Ewe intakes fed hay and concentrates or a hay or straw based TMR (ADAS, 1979)

| Diet                       | DM Intake (kg/day) | ME Intake (MJ/day) | Digestible Crude Protein Intake (g/day) |
|----------------------------|--------------------|--------------------|---|
| Hay + concs (conventional) | 1.34               | 14.7               | 112                                     |
| Hay TMR                    | 1.50               | 16.6               | 130                                     |
| Straw TMR                  | 1.60               | 15.0               | 152                                     |

Ewes offered TMR diets of either hay or straw base, had increased dry matter, ME and digestible crude protein intakes compared to ewes fed the conventional hay and concentrate diet. In both studies the ewes had lambing percentages of 180-190%.

In practice TMR offer the ewe a consistent diet with forage and concentrates digested simultaneously and evenly throughout the day, avoiding large shifts in rumen pH associated with conventional meal feeding of concentrates. Anecdotally TMR diets have additional benefits of reduced incidence of prolapse, reduced competition at the feed trough and reduced stress and physical injury (Stubbings, Phillips and Povey, personal communication).

Chestnutt and Wylie (1995) offered pregnant ewes increasing levels of concentrates fed either as one, two or three feeds a day with silage or

concentrates mixed with good quality silage. Silage intake increased with concentrate feeding frequency and was greatest with the mixed diet at an average of 1.38 x that of the single daily concentrate meal. The results were consistent with enhanced supply or more efficient capture of dietary energy and protein when concentrate feed offered over several hours rather than in a single feed.

A more recent trial (Herlander *et al.*, 2014) showed that mixing concentrates with forage resulted in a higher proportion of large particles in faeces effectively showing less dietary selection than on conventional diets but dry matter intakes were not consistently higher on the complete diet in pregnancy. A trial funded by Eblex and run by ADAS (AHDB, 2014b) showed good performance of Mule ewes on complete diets based on good quality grass silage and fed one of four protein sources with barley in complete diets. There were no significant differences between treatments (beans, soya, rape or wheat distillers) and intakes of forage were high at 1.5 to 1.8 kg DMI per day. The incidence of prolapse was much reduced on previous years. Further work is needed to confirm the benefits of complete diet feeding with high quality forages under commercial conditions.

A recently developed system for feeding sheep to spread concentrate feeding throughout the day are '3 in 1 Feeders'. The aim of these feeders is to allow concentrates to be fed little and often and therefore reduce swings in rumen pH and increase forage digestibility. The ewes have constant access to the concentrate (cereal grains or small pellets) but intake is restricted by the ability of the ewe to produce saliva and lick the feed out of the feeder. It is predicted that ewes return to the feeders every hour through the day. Anecdotal reports from the field suggest variable results and further research and details of managing the system are required.

Different forage feeders for ewes were evaluated by ADAS Pwllpeiran EHF comparing the conventional rack to big bale feeders of different designs (1982 ADAS R & D Reports – Reference Book 229). Silage was offered to groups of 31 Welsh Mountain ewes per feeder. The silage was 45% dry matter and 64% digestibility and was offered to the ewes from circular or rectangular feeders, shown in Table 27. Ewes offered silage in the conventional racks had the highest dry matter intakes along with ewe fed from rectangular feeders with non-movable sides. Good management is required when offering ewes forage in feeders to ensure they have good access and can reach the forage at all times.

Successful ewe feeding in late pregnancy is essential to ensure the ewe achieves maximum intakes. Therefore, concentrates and forage need to be easy access for the ewes, of good quality which are refreshed regularly and provided in a regular routine that the ewes are used to.

Table 27. Comparison of ewe intakes of silage fed in different feeders (ADAS 1982).

| Feeder Type   | DM Intake (kg/day) |
|---|--------------------|
| Conventional rack (control)                             | 0.83               |
| Circular feeder with movable rods (went in as they ate) | 0.73               |
| Circular feeder – basket type – non movable             | 0.67               |
| Rectangular feeder – 2 sides movable                    | 0.74               |
| Rectangular feeder – non movable sides                  | 0.88               |

### 3.3.10 Winter Shearing and Forage Intake

Winter shearing is generally considered to increase forage dry matter intake and increase lamb birth weight and survival. Between 1976 and 1984 ADAS carried out a range of experiments on their EHF's and shorn ewes were shown to eat 12 to 15% more forage than unshorn ewes and lambs were between 0.4 and 0.6 kg heavier.

The effect of winter shearing on food intake and performance of housed ewes was also studied by Vipond *et al.*, (1987) and showed a proportional increase in DMI in ewes of 0.16 and 0.43 on two silage based diets, of 0.09 on a swede based diet and of only 0.02 on a hay based diet. Shearing increased average lamb birthweight by about 600g (4.65 vs 4.06kg), apparently as an effect of shearing per se rather than as a result of the increased energy intake. An increased gestation length of 1.8 days accounted for one fifth of this increased birth weight.

Likewise, in a study by Corner *et al.*, (2010b) lambs born to shorn ewes were heavier and had a longer crown rump, forelimb and hind-limb lengths than lambs born to non-shorn stressed or cortisol injected ewes. It was concluded that the mechanism by which mid-pregnancy shearing increases lamb birth weight is unlikely to be repeated stressors. Keady and Hanrahan (2009) also showed that shearing ewes at housing (day 63 of pregnancy) increased silage intake (by 0.125kg DM) and lamb birth weight and this was probably associated

with cold stress immediately post shearing and reduced heat stress in late pregnancy. Shearing ewes also tended to increase lamb weaning weight. Kenyon *et al.*, (2003) showed no good evidence for interactions between level of feeding and the effect of shearing but one study suggested that there was no increase in lamb birthweight in shorn, undernourished ewes.

As well as the effects on lamb birthweight and food intake shearing allows more ewes to be housed at once which can be beneficial on farms with limited housing. It is critical that ewes are not shorn too close to lambing since bare skinned ewes are more susceptible to cold once turned out after lambing and the risk of mastitis increases. In the UK it is recommended to shear no closer than 8 weeks pre-lambing to allow sufficient regrowth of wool before turnout.

### 3.3.11 Housing Requirements

A ewe housing review by Slade and Stubbings (1994) outlines the requirements for housed sheep. The standards quoted for space allowances are still generally accepted across the industry and the current Welfare Code (Defra 2003) has adopted these as industry standards.

Tables 28 and 29 show recommended lying area and trough space allowances respectively.

*Table 28. Recommended Lying area allowances (m<sup>2</sup>/ewe) (Defra, 2003)*

| Type of Sheep  | Area on Straw (m <sup>2</sup> ) |
|--|---------------------------------|
| Large ewe 60-90 kg in lamb   | 1.2 - 1.4                       |
| Large ewe 60-90 kg in early lactation                                  | 1.4 - 1.8                       |
| Large ewe 60-90 kg – with lambs to 6 weeks of age (Defra welfare code) | 2.0 - 2.2                       |
| Small ewe 45-60 kg in lamb   | 1.0 - 1.3                       |
| Small ewe 45-60 kg in lactation  | 1.3 – 1.7                       |
| Small ewe 45-60 kg - with lambs to 6 weeks of age (Defra welfare code) | 1.8 - 2.0                       |

Winter shorn ewes can have a 10% reduction in lying area which is also accepted in the welfare codes. However, there should be no corresponding reduction in trough space allowed.

Table 29. Trough space allowances (mm/ewe) (Defra, 2003)

| Ewe                   | Concentrate | Restricted Forage | Forage Ad Libitum and TMR* |
|-----------------------|-------------|-------------------|----------------------------|
| Large ewes (70-90 kg) | 500         | 250               | 150                        |
| Small ewes (50-70 kg) | 450         | 200               | 150                        |

\*Total Mixed ration (TMR) used the same allowance as ad lib forage.

Since this review, the major change in housed feeding systems is a move to replace troughs for concentrates to floor feeding. This replaces the ‘Norwegian box’ type feeders which were both labour intensive and tended to cause a lot of competition for trough space among the animals.

The advantages of this are to slow down consumption, reduce competition and hence allow more even uptake across a group of ewes. This process has been mechanised in some flocks using a feeder that throws nuts over the top of the ewes, giving an even spread on to the bedding.

### 3.3.12 Water Requirements

Water intakes vary according to the stage of the production cycle and the water content of the diet. Slade and Stubbings (1994) refer to ewes in late pregnancy taking 4.5litre/day on a hay based diet increasing to 9litres in lactation; in contrast on a lower DM silage based diet 2litres / ewe was recorded in late pregnancy. AHDB Manual 12 (2016f) contains a guide to water allowances at various stages. When designing a system, the general advice is to allow for a capacity of 10litre/ewe/day if they will be housed during lactation; 5litre/day if only up to lambing.

Corbett and Ball (2002) outline the positive correlation between water intake (drunk and in feed) and dry matter intake. For dry sheep (non-pregnant or lactating) at various temperatures the litres/kg DM intake are: 2litres at a temperature of 15C; 2.5litres at a temperature of 20C; 3.5litres at a temperature of 25C; 5litres at a temperature of 30C and 7litres at a temperature of 35C. These data can however, be used to help validate our estimations above of water allowance for housed sheep.

In addition, the welfare codes demand that water supplies must be clean and available at all times. It is not acceptable to rely on ‘wet’ feeds such as roots to supply the animals.

### 3.3.13 Peri Parturient Relaxation in Immunity and Faecal Egg Counts

The peri-parturient period (just before and just after lambing) has long been considered a time when the host (ewes) immune system is put under pressure. As a consequence, the ewe becomes a significant source of contamination for co-grazing lambs because she is unable to control her worm burden and her egg counts (FEC) rises significantly. This is known as the Peri-Parturient Relaxation in Immunity (PPRI) and the net result is that sheep farmers have for many years been advised to de-worm ewes at or around lambing to reduce this effect. Sargison (2008) states this period lasts for around 6 weeks after parturition, but in practice this is extremely variable for the reasons discussed below.

With increasing concern regarding the prevalence of anthelmintic resistance (AR) the necessity of this as a 'blanket flock' practice is now under question (SCOPS 2012). Any reduction in the frequency anthelmintics are used in sheep flocks constitutes a reduction in selection pressure on the worm population. The question is whether or not we can reduce the impact of the PPRI through the nutrition of the ewe in this period.

In the review of sheep immunity and gastro-intestinal parasites (McClure, 2000), the basis of the host immune response in adult ruminants is explained. This supports the hypothesis put forward by others (e.g. Houdijk, 2008) that the PPRI has a nutritional basis. Donaldson (1998) reported that host/parasite interactions in the ewe were more influenced by protein supply than energy and this has been further supported by subsequent work (Coop and Kyriazakis, 1999; Coop and Sykes, 2002; Houdijk *et al.*, 2003; Sykes and Kyriazakis, 2007). It has been suggested that 20 to 30% increases in the level of MP supply, above AFRC recommendations are required to achieve maximum milk yield and maintain the immune response. Sykes (2010) concludes that the immune system is given a lower priority when protein supplies are allocated than milk production. Feeding regimes that enhance both ewe body condition at parturition (Kahn *et al.*, 2003) or protein reserves (Houdijk *et al.*, 2003; 2009) and adequate dietary protein supply (MP) have been shown to reduce the worm egg output of ewes in the peri-parturient period.

A recent paper (Houdijk *et al.*, 2016) suggest that additional MP supply from xylose-treated soybean meal rather than faba bean is more effective at reducing egg output, suggesting that protein source (amino acid composition) may be important.

There may also be some genetic influence involved in the PPRI. For example Zaralis *et al.*, 2009 found that Mule ewes had a much higher FEC count in the peri-parturient period than Blackface ewes despite there being no effect on the degree of anorexia due to *T.circumcincta* infection. They conclude that the lower degree of PPRI in the Blackface ewes during lactation compared to the

Mule ewes, given a similar degree of MP scarcity cannot be explained by associated differences in nutrient demand only.

Houdijk *et al.*, (2005) also report a difference according to worm species. They suggest that increased MP supply, is more effective against abomasal worms (such as *T. circumcincta*) than small intestine worms (such as *T. colubriformis*). It is clear that ewe nutrition has a vital role to play in the ability to maintain her immune response in the peri-parturient period. The evidence supports the need for ewes to maintain good levels of body condition up to lambing and that ensuring an adequate protein (MP) supply is critical. In single bearing ewes this does not present a problem in most systems; conversely the triplet bearing ewe is under more pressure. For ewes rearing twins, however, we must consider the implications for feeding levels and constituents.

It has been suggested that the standards should be increased by up to 30% over the AFRC (1993) recommendations. However, we must also consider the economic, practical and alternatives to simply adopting this approach. At the workshop held in April 2016, as a preliminary to this review, industry experts discussed this and from a practical perspective concluded that:

1. Protein (MP) supply below the AFRC (1993) standard will impair the ewe's ability to maintain her immune response to internal parasites in the peri-parturient period.
2. A significant majority of sheep flocks in the UK currently do not meet current AFRC standards with respect to levels of MP actually fed, so the scope for improvement is significant.
3. Work to better understand dry matter intakes and rumen turnover rates to establish actual MP supplies would improve our ability to assess adequacy in the field.
4. Ewe body condition at lambing is also a significant factor both in terms of milk supply but the prioritisation of protein to the immune response.

The consensus of the meeting was that the current MP standards should be viewed as a minimum in practical rationing for sheep farmers.

### **3.3.14 Alternative Feeds and Their Relative Costs**

Supplements are not only fed as dry concentrates or moist bulky straights (e.g. brewers grains) but are also fed as liquid feeds (usually molasses or pot ale syrup based) or compressed feed blocks. Ben Salem and Nefzaoui (2003) reviewed the use of feed blocks for feeding sheep and goats across the world.

Early work on the use of feed blocks (Ducker *et al.*, 1981) showed that their use in the upland/hill situations did not ensure a uniform intake of nutrients. They concluded that 19% of the 2931 ewes sampled had not eaten from the feed blocks on offer. This was due to the effect of grazing area per ewe and the age of the ewes. Kendall *et al.*, (1983) also showed a large variation in feed intake

from ewes offered feed blocks outdoors, estimates of ME intakes varied between 5 and 22 MJ per day. Lawrence and Wood-Gush (1988) found that age had a strong effect on the time spent eating, with older ewes (over 4 years) eating more than young animals. They predicted that 82% of ewe lambs did not eat from feed block as at all and this was due to the competitive behavior of older ewes.

In the UK feed blocks have been used extensively on hill sheep farms over many decades and have improved the welfare and performance of hill sheep in harsh environmental conditions through providing additional energy and protein but also essential trace nutrients. The convenience of providing additional feed without the daily need to carry dry feed out to sheep has saved labour costs on many farms and increased flock performance. Many blocks include urea which has been well proven to improve the digestibility of poor quality forages.

Davies and Griffiths (2000) demonstrated how the strategic use of feed blocks can be used to manage semi-natural rough grazing, helping to avoid over-or under-grazing of specific areas. In more recent years many lowland farmers have chosen to buy feed blocks instead of conventional concentrates to reduce labour costs. An added benefit of blocks is that ewes can visit the block frequently in a day which removes competition for feed and provides nutrients 'little and often' helping to maintain more stable rumen conditions. On a cost/kg DM, per MJ or unit of protein these products are expensive but when set against the saving in labour can work out cost effective on many farms. Product ranges vary by manufacturer but most are designed to limit sheep intake to certain levels. The products are available on an *ad libitum* basis and therefore intakes can be variable between animals.

McLean *et al.*, (2002) highlight the use of feed blocks in organic hill systems where the use of bought in feedstuffs is restricted. The trial looked at supplementing twin bearing hill ewes post lambing with either feed blocks and half the ration of a concentrate mix or full ration of a concentrate mix. Lambs reared by ewes receiving the feed block/supplement had greater live weight gains compared to lambs from ewes fed the concentrate mix only. Intakes and the cost of feeding were lower in the groups of ewes offered feed blocks, showing a place for their feeding in extensive systems.

### **3.3.15 Feed Additives**

Many 'feed additives' are marketed in the UK to enhance animal performance and not all of these can be covered in this review. Evidence is sometimes scarce and only promoted by commercial companies with few peer reviewed papers available.

#### **Long Chain Fatty Acids**

Studies in humans and animals have investigated the potential of using long-chain n-3 fatty acids to improve neonatal vigour and vitality. Long-chain n-3 fatty acids, particularly docosahexaenoic acid (DHA) (22:6 n-3), are required for



many specific structural and metabolic functions in the body and are found in high concentrations in the brain. It is thought that between 10 and 6 weeks before birth the ovine foetal brain is rapidly growing and that supplementing the ewe with long-chain fatty acids at this point might have beneficial effects on lamb survival. However dietary fish oil has been shown to benefit lamb vigour at birth but has negative effects on colostrum output and fat concentration (Capper *et al.*, 2006) which can adversely affect lamb survival. Annett *et al.*, (2009) supplemented ewes with 0, 20 or 40 g/d of herring or salmon oil for the final 6 weeks of pregnancy. Lambs born to control ewes had higher serum IgG concentrations than those fed herring oil. Colostrum output at 10 hours post lambing and total yield were lower for fish oil supplemented ewes. The results indicated that low levels of crude fish oil supplementation (up to 20g/day) during late pregnancy improved lamb survival and output at weaning but these benefits disappeared at higher inclusion rates.

Mahboub *et al.*, (2013) compared feeding ewes 40g of sardine oil in the concentrate part of the ration for the last 6 weeks pre-lambing with two injections of selenium-vitamin E (5ml of 2mg sodium selenite and 100mg vitamin E) at 20 and 10 days pre-lambing, with control unsupplemented ewes. The work concluded that supplementing pregnant ewes with fish oil or selenium-vitamin E increased lamb birth weight, decreased the latency to stand and suckle and improved pre-suckling body temperature and immunocompetence of neonatal lambs with better lamb performance and survival.

Pickard *et al.*, (2008) offered Mule ewes one of four dietary treatments: DHA supplement (as algal biomass) from 9 to 6 weeks pre-lambing, DHA from 9 to 3 weeks, DHA for 9 weeks or no DHA (control). Ewes were fed grass silage and commercial concentrates. At birth concentrations of eicosapentanoic acid (EPA) and DHA in ewe and lamb plasma and colostrum were elevated in line with the increased periods of DHA supplementation. Lambs from the 6 and 9 week groups stood significantly sooner after birth than lambs from the control group ( $P < 0.05$ ). It was concluded that neonatal vigour can be improved by supplementation of maternal diets with DHA-rich algal biomass and its beneficial effect depends on the timing and duration of DHA allocation.

Benefits have also been shown in lactation ewes. Ferreira *et al.*, (2014) added fish oil in combination with soya bean oil to lactating ewe diets and found that the addition of 7.5 g/kg DM of fish oil mixed with 32.5 g/kg DM of soybean oil increased the concentration of EPA, DHA and C18:1 trans-11 in the milk, as well as increasing the milk yield of ewes and pre-weaning daily gain in lambs. Reynolds *et al.*, (2006) fed 60:40 forage concentrate rations based on alfalfa or corn silage from lambing. At 22 days post lambing 3 pens of ewes on each forage (alfalfa or corn silage) were supplemented with a 2:1 mix of soybean oil and marine algal biomass oil (30g/kg of ration dry matter) in place of corn meal. DMI was lower ( $P < 0.02$ ) for ewes offered the diets containing corn silage and

for oil but milk yield was not affected by treatment. Milk fat tended to be higher for oil, and milk protein was higher for alfalfa based diets. Total CLA increased with corn silage and oil and the response to oil was greater on alfalfa haylage than on alfalfa pellets.

Prenatally stressed offspring exhibit increased susceptibility to inflammatory disorders due to in utero programming. Research into the effects of n-3 PUFAs shows promising results for the treatment and prevention of such disorders.

### **Mannan-oligosaccharides**

Oligosaccharides – fructooligosaccharides (FOS), galactooligosaccharides (GAL) and especially mannanoligosaccharides (MOS), which act as prebiotics, have recently been studied as alternatives to antibiotics in livestock diets. These substances have the effect of improving the immunological system of animals by stimulating a beneficial microbial population in the gastro-intestinal tract, preventing or fighting infections caused by pathogenic bacteria, or diminishing the effects of toxins produced by some bacteria. Mannanoligosaccharides are among the most efficient immunomodulators. They can be obtained from the cell wall of the yeast *Saccharomyces cerevisiae*.

### **3.4 Nutritional Management of the Ewe in Lactation**

In the first six weeks after lambing, lamb growth rates are largely dependent on milk supply. Milk yield in the ewe peaks at about four weeks post lambing and then declines, reaching low levels by around 12 weeks (see Table 30). Protein and fat levels follow a similar pattern. They are higher at the start but also at the end of lactation when yields are lower.

*Table 30. Estimates of milk yield (kg/day) by month of lactation (AFRC, 1993)*

| <b>Litter Size</b> | <b>Type of Ewe</b> | <b>Month of Lactation</b> |          |          |
|--------------------|--------------------|---------------------------|----------|----------|
|                    |                    | <b>1</b>                  | <b>2</b> | <b>3</b> |
| One lamb           | Hill               | 1.25                      | 1.05     | 0.70     |
|                    | Lowland            | 2.10                      | 1.70     | 1.05     |
| Two Lambs          | Hill               | 1.90                      | 1.60     | 1.10     |
|                    | Lowland            | 3.00                      | 2.25     | 1.50     |

### 3.4.1 Energy and Protein Requirements of Lactating Ewes

The protein and energy requirements of the ewe effectively double between the end of pregnancy and lactation to meet the demands of producing milk (Robinson, 1990). For example, an 80kg ewe rearing twins (with 50g/day weight loss), will increase her daily energy and protein requirements by 12 MJ and by 166 g respectively.

Based on the current information, it is suggested that the energy and protein requirements published in AFRC (1993) for lactating ewes continue to be used, as a minimum requirement. This view was confirmed by industry consultants at a workshop on 06 April 2016 for this project who agreed there was insufficient evidence to support the cost effectiveness of any increases. The consensus was that the current ME and MP requirements for sheep worked satisfactorily on UK farms with 'practical adjustment'. However, when rationing ewes, it is essential to consider their live weight and body condition, and the number of lambs reared, their environment, quality of forage and dry matter availability.

The calculated energy and protein requirements for housed lactating ewes are shown in Table 31.

*Table 31. Energy (MJ/day) and MP (g/day) requirements of housed lactating ewes offered a diet M/D of 11.5MJ/kg DM. (AFRC 1993)*

|  | Milk Yield   |            |              |            |              |            |
|--|--------------|------------|--------------|------------|--------------|------------|
|  | 1.0 (kg/day) |            | 2.0 (kg/day) |            | 3.0 (kg/day) |            |
|  | ME (MJ/day)  | MP (g/day) | ME (MJ/day)  | MP (g/day) | ME (MJ/day)  | MP (g/day) |
| Ewe Weight Loss (g/day)  |              |            |              |            |              |            |
| Housed 60kg Ewe (lowland ewes outdoors add 0.3 MJ/day, ewes on hills add 1.1 MJ/day) |              |            |              |            |              |            |
| 0  | 15.6         | 146        | 23.7         | 222        | 32.2         | 297        |
| -50  | 13.8         | 140        | 22.0         | 216        | 30.3         | 291        |
| -100   | 12.1         | 134        | 20.2         | 209        | 28.5         | 285        |
| Housed 80kg Ewe (lowland ewes outdoors add 0.4 MJ/day, ewes on hills add 1.5 MJ/day) |              |            |              |            |              |            |
| 0  | 17.5         | 158        | 25.6         | 234        | 33.9         | 309        |
| -50  | 15.8         | 152        | 23.8         | 228        | 32.0         | 303        |
| -100   | 14.0         | 146        | 22.0         | 221        | 30.2         | 297        |

There is a slow increase in voluntary intake in early lactation, when nutrient requirements are at their peak, but ewes are generally in negative energy balance for the first few weeks after lambing (Geenty and Sykes, 1986). If the ewe's nutrient demands are not met by good grazing and/or supplementary feeding, this results in loss of milk yield unless the ewe has sufficient body reserves (Treacher and Caja, 2002).

There are huge changes within the mammary cells to enable fast production of colostrum and milk post lambing. The functional genetic development of the ovine mammary gland was reviewed by Paten *et al.*, (2015). A coordinated regulation of a large number of genes is required to switch between mammary tissue establishment during late pregnancy and activation and maintenance of milk production during lactation. They demonstrated that 27% of the ewe's genes changed between pregnancy and lactation, with expression of genes involved in fatty acid and amino acid biosynthesis and transport, lipogenesis and protein processing were upregulated during early lactation. Hormones and growth factors, signalling pathways and epigenetic regulation were highlighted as having potential roles in mediation of the changes undertaken by the mammary gland to support lactation (Paten *et al.*, 2015).

A large number of hormones are involved in the initiation of lactation, including oestradiol and progesterone, when progesterone levels fall at lambing, full milk secretion begins (Treacher and Caja, 2002; Yart *et al.*, 2014). Yart *et al.*, (2014) reviewed mammary gland development from when the ewe is a foetus through her growth and future pregnancies and lactations. They confirmed that the ovarian steroids, oestradiol and progesterone are the key regulators of the different stages of mammary development and mammary function throughout the life of the ewe. They describe how the mammary gland undergoes involution and regression at the end of lactation and how the ducts elongate and develop during pregnancy for milk production from lambing.

### **3.4.2 Animal Factors Affecting Milk Production**

The quality and yield of milk is affected by a number of factors, including genetics, ewe age and parity, stage of lactation, live weight and number of lambs being suckled (Bencini and Pulina, 1997).

Milk yield between and within breeds is very variable. In breeds selected for meat production, peak yield varies from 2 and 4 kg/day, with total yields over three months of lactation of 50 to 200kg (twins rearing) and 90 to 160kg (single rearing) ewes (Treacher and Caja, 2002). Milk yield and milk composition are negatively correlated (Bencini and Pulina, 1997) and this is thought to be due to a link to lactose secretion. As milk yield increases, fat and protein synthesis cannot keep up with lactose production, reducing the solid content overall.

The protein and fat content of milk varies with sheep breed, as shown in Table 32.

Table 32. Milk quality by sheep breed (Bencini and Pulina, 1997)

| Ewe Breed      | Protein (%) | Fat (%) |
|----------------|-------------|---------|
| Clun Forest    | 5.90        | 5.80    |
| Dorset         | 6.50        | 6.10    |
| Merino         | 4.85        | 8.48    |
| Romney (NZ)    | 5.50        | 5.30    |
| Suffolk        | 5.80        | 6.60    |
| Welsh Mountain | 5.40        | 6.20    |

Age and parity also influences milk yield, with maximum yields generally achieved at the third and fourth lactation of the ewe. Heavier ewes also produce more milk (Bencini and Pulina, 1997).

Ewes suckling twins produce 30 to 50% more milk than ewes with a single lamb, given the same level of nutrition. Ewes rearing twins, also have a higher peak yield and it is reached more quickly (2 to 3 weeks post lambing) compared to 3 to 5 weeks for singles, but yield then declines more rapidly in twin and triplet rearing ewes and by week 12 of lactation, the difference between single, twin or triplet bearing ewes is negligible. The increased milk production in ewes suckling twins or triplets is due to the number of lambs suckled and the higher frequency and duration of the lambs suckling. It is not affected by the number of foetuses carried (Treacher and Caja, 2002).

Any damage to the udder, through mastitis or injury will detrimentally affect milk yield. In a trial reported by Jordan and Mayer (1989), ewes with only one functional teat had significantly ( $P < 0.05$ ) reduced daily milk yield, lamb growth rate and lamb weight at four to six weeks of age compared to ewes with two functional teats.

### 3.4.3 Nutritional Factors Affecting Milk Production

The nutrient supply to the ewe throughout pregnancy affects milk production. Effects of nutrition early in pregnancy are mediated via placental size and secretion of placental lactogen (Treacher and Caja, 2002). Severe undernutrition in the last six weeks of pregnancy results in a small udder, little colostrum and a delay of several hours in the start of full lactation. This has a major effect on lamb survival, especially as the lambs are likely to be small and lacking in body reserves at birth. Treacher and Caja (2002) reported that when underfeeding was severe in pregnancy, leading to a reduction of 17 to 32 % in twin birth weight, they found reductions of 7 to 35% in milk yield over the whole

lactation. In an experiment reported by Geenty and Sykes (1986), they found that sheep undernourished in pregnancy had an overall energy requirement in lactation that was 10 to 20% greater than ewes that were well fed during late pregnancy.

Undernutrition in early lactation impairs milk secretion and the growth rate of the lambs (Bencini and Pulina, 1997), but the extent of this depends on the body condition of the ewe (Robinson, 1990; Treacher and Caja, 2002). An early trial reported by Jordan and Mayer (1989) showed that ewes offered diets at 110, 90 and 70% of maintenance level significantly affected ewe and lamb performance in lactation. Estimated daily milk yields, lamb survival, ewe live weight at weaning and lamb growth rates were significantly ( $P < 0.05$ ) higher for ewes fed on 110 and 90% of their requirements compared to those fed at 70% of requirements.

In a trial reported by Geenty and Sykes (1986), ewes were offered restricted diets in early lactation. Ewes can recover from short periods of restriction. Treacher and Caja (2002) reported that restricted periods of nutrition of 7 to 14 days in early lactation had little sustained effect on milk yield, levels returned to normal within a few days of feeding being restored. However, if the lower plane was continued for 28 days, there is at best a slow or worst no response to increased feeding levels after 2 weeks.

Treacher and Caja (2002) describe a model first proposed by Robinson (1990), which considers responses in milk production by the ewe to intake of energy and protein. They concluded:

- For a particular level of energy intake there is a critical protein intake, below which milk yield will decrease.
- The minimum ratio of crude protein to energy increases with increasing level of milk yield.
- An increase in MP intake without a change in energy intake will result in an increase in milk production and mobilisation of body reserves, if the ewe has not reached her potential yield.

The model demonstrates that in early lactation, when energy requirements are high and voluntary intake has not reached its maximum, protein intake has a critical effect on milk production. The extent of the response to protein intake depends on the level of body reserves.

A recent experiment reported by Corner-Thomas *et al.*, (2015) looked at the effects of BCS and nutrition in lactation on twin bearing ewe and lamb performance. On day 141 of pregnancy, 297 twin bearing ewes with a BCS of 2.0, 2.5 or 3.0 were allocated to low, medium or high feeding treatments to day 79 of lactation. The feed treatments were achieved by managing herbage supply from pasture at different levels (800 to 1000kg DM/ha, 1200 to 1400kg DM/ha and 1500 to 1700kg DM/ha for low, medium and high respectively). The

feeding treatments had no effect on lamb birth weight, metabolic rate or colostrum intake. At weaning lambs born to the high treatment ewes were significantly heavier ( $P<0.05$ ) than lambs from medium and low fed dams. Lambs reared by BCS 2.0 ewes were significantly ( $P<0.05$ ) lighter than those born to BCS 2.5 and 3.0 ewes. However, in this trial lambs reared by ewes in BCS 2.0 had significantly ( $P<0.05$ ) greater metabolic rates and survival to weaning than those reared by ewes of condition score 3.0. Corner-Thomas *et al.*, (2015) concluded that low condition should be avoided in late pregnancy and lactation (ewes should be at least condition 2.5 or 3.0), although there was no interaction between BCS and feeding rates in this trial.

Robinson (1990) showed responses in milk yield when increasing amounts of soya bean meal and fish meal were added to low protein basal diets while maintaining a constant intake of energy. At each energy level, the additional protein increased milk production to a maximum response level after which no further increase in milk yield was seen. Responses to dietary protein are best in early lactation when voluntary intake is still relatively low and the ewe is in negative energy balance. Treacher and Caja (2002) concluded that the response depended on the degradability of the protein, with low RDP sources such as soya bean meal leading to greater milk responses compared to ewes offered urea and ground nut protein sources. They also reported greater milk yield responses in ewes offered protected protein sources, such as formaldehyde treated soya bean meal.

However, an experiment reported by Wilkinson *et al.*, (2000) found that supplements differing in DUP had no effect on the yield of milk from ewes at pasture. They concluded that the rumen degradability of grazed grass is very variable and may result in a RDP and fermentable energy ratio below the optimum for rumen function. In this situation the ewes responded to additional RDP supply resulting in increased milk lactose and protein levels and milk yields.

Liamadis and Milis (2007) showed that soya bean meal was a superior source of protein compared to corn gluten due to its higher lysine content. Ewes offered diets with the same energy and protein levels, had higher milk yields and milk protein levels in lactation when the protein was supplied by soya bean meal rather than corn gluten.

The role of protected lipids in the diets of lactating ewes has been reviewed by Robinson (1990), Bencini and Pulina (2000) and Treacher and Caja (2002). The ewe's body fat plays a significant role in sustaining milk yield, therefore feeding a source of rumen protected fat in the diets of lactating ewes has been considered. Feeding protected fat to ewes in lactation had no effect on milk yield, but increased milk fat levels and led to inconsistent increases in lamb growth rate. Research also showed that the milk fat response was independent of protein intake and also that addition of protected fat did not interfere with fibre

digestion and rumen function. It was concluded that the increase in milk fat levels associated with addition of protected fats to the diet would be more beneficial in ewes milked for human consumption.

#### **3.4.4 Ewe Body Condition and Milk Yield**

In early lactation there is often a gap between energy needs and dietary supply, in part caused by a slow increase in voluntary intake following lambing. As a result, ewes utilise their body reserves in the first weeks of lactation even if they are offered food *ad libitum* or when grazing at high herbage allowances (Treacher and Caja, 2002). It is therefore important that ewes are carrying sufficient body reserves at lambing. The loss in condition of the ewe is almost all fat.

Robinson (1990) concluded that the extent to which reserves are lost in early lactation is affected by the nutrient intake of the ewe but also by the level of her body reserves. Thin ewes with poor reserves, mobilise less energy and produce less milk than fatter ewes subjected to the same level of undernutrition. When ewes of different condition scores are fed at requirements (30 MJ/day for a 70kg ewe), milk yield is maintained at about 3.5 kg/day and the minimal weight loss (about 20g/day) is the same irrespective of ewe body fatness/condition. As energy intake drops below requirement, thin ewes produce less milk and lose less body fat compared to ewes in good condition. Ewes in good condition will maintain milk yield but lose more body fat compared to thin ewes. Therefore, to maintain milk yields in early lactation to maximise lamb survival, ewes need to have good body reserves at lambing.

There have been numerous studies looking at the effect of BCS on lamb birthweight, colostrum production and subsequent lamb growth rate. Mathias-Davis *et al.*, (2013) highlight various studies that have been undertaken to examine the relationship between ewe BCS and lamb growth rate. They conclude that while some studies report a positive relationship between lamb growth rate and ewe BCS, others do not.

In the experiment reported by Mathias-Davies *et al.*, (2013) they looked at single, twin and triplet bearing ewes at various condition scores (range 1 - 5) and measured condition score change from pre-lambing to weaning. They found that where ewes were in good condition score (above 3) at lambing, lamb growth was significantly (positive) correlated to a loss in condition score to weaning; conversely when they were in lower BCS (below 3) this was significantly (positively) correlated to a positive gain in BCS. In contrast triplets only demonstrated the relationship when condition score was high and then lost in lactation. Kenyon *et al.*, (2007) postulate that this effect is due to placental insufficiency in many triplet lambs and their inability to avoid negative energy balance in late pregnancy due to a ceiling on dry matter intakes resulting from high foetal load.



It would therefore seem that the effect of BCS is variable depending on the starting condition score and subsequent availability of nutrients in early lactation. Preliminary data from the KPI project (AHDB, 2015), using lamb 8-week weight as the indicator of ewe performance (milk yield) suggests, as we would expect, that there is a positive correlation between BCS at lambing and subsequent lamb growth rates, though it is not consistent. This may be explained by the significant effect of BCS much earlier in the production cycle, as far back as the condition score of the ewe at scanning and even the previous weaning. This has far reaching implications for ewe management and the use of BCS targets in the future. This significant longitudinal effect may also explain why other reports have been inconsistent and suggests that the final KPI results need to be analysed in a similar way to Mathias-Davis *et al.*, (2013) regarding lambing ewe BCS.

### **3.4.5 Ewe Feed Intake in Lactation**

For a full review of factors affecting voluntary feed intake see Section 2.

Voluntary intake of feed normally rises rapidly at the start of lactation and continues to rise for several weeks (Treacher and Caja, 2002). Intake in the first week of lactation is only 10% higher than the intake at about two weeks pre lambing. Intake rises rapidly in weeks two and three of lactation and then continues to rise at a slower rate to a maximum in week eight, approximately four weeks after the peak of lactation. At peak intake, twin rearing ewes have higher intakes than single rearing ewes, which for a twin rearing ewe is 85% above their intakes in week one of lactation. After week eight intakes decline slowly until weaning. Kenyon (2013) simply confirms that in lactation when nutritional requirements are at peak, feed supply must be unrestricted.

Pulina *et al.*, (2103) show the pattern of herbage intake with different yields of milk with intake increasing by approximately 100gDM for each increase in 0.5kg per day of milk yield.

The large increases in intake in response to the huge increase in nutrient demand for milk production is associated with major effects on the ewe's digestive system (Treacher and Caja, 2002). The weight, size, nitrogen content and gut enzyme activity increase over the first four to seven weeks of lactation in the rumen and intestines. This enables the lactating ewe to maintain the same diet digestibility in spite of the large increases in intake. If feed intake is restricted in early lactation, these changes to the digestive tract are reduced which affects longer term intake and milk yield. Forage type and supplementation will also affect voluntary intake in lactation. The forage type offered and supplementation of the forage will affect voluntary intake of the ewe in lactation.

### 3.4.6 Forage Intake and Supplementary Feeding

Speedy and Bazely (1986); Treacher (1990) and Freer (2002) review the role of grass as the major feed source for lactating ewes. Further details in Section 2.5 including other forages such as clover. To achieve maximum milk production, grass (or forage) quality must be high and available in sufficient quantities to enable *ad libitum* intakes. Dove (2010) concludes that quantifying what and how grazing sheep eat represents the major constraint of this balance and he warns that because ewe behaviour is different when grazing compared to feeding indoors, extrapolation of results from indoor fed ewes to the grazing situation should be treated with care.

The intake pattern described for lactating ewes applies when herbage quality and quantity are both high. Treacher and Caja (2002) suggest that on low quality pasture, intake rises very slowly and may not peak before weaning. In these situations, the gap between supply and requirement of the ewe has to be met by supplementary feeding.

Pulina *et al.*, (2013) gives a recent review of intake models for grazing sheep, with factors affecting intake at grass:

- Sheep on herbaceous pasture tend to graze only within a layer of green leaves and are reluctant to penetrate below this layer where there is a prevalence of dead material. The higher the mass of green leaves the higher the intake achieved.
- When herbage mass is low, ewes will change their behaviour and increase their bite rate and move more, but there will be a reluctance to move too far from other animals in the flock.
- Forage composition and digestibility affect intake, but to a certain extent this can be overcome as sheep are selective. They prefer some plants to others and have been shown to select diets richer in digestible organic matter and protein if this is available.
- Intake is most sensitive to neutral detergent fibre content in both continuous and rotational grazing management conditions.
- Un-supplemented ewes increase their intakes linearly as pasture height increases from 2 to 8cm, although peak intake is thought to be 6 to 9cm in herbage height.

Rutter (2010) details the grazing preferences of sheep which are affected by time of day and physiological state and suggests the highest intakes can be achieved when ewes have the ability to choose their herbage consumed.

Fresh spring grass of good quality and at the right sward height and stocking rates (AHDB, 2016d Planning Grazing Strategies for Better Returns, BRP Manual 8) may provide the nutrient requirements of the lactating ewe without supplementation with concentrate feed. Ewes should have continuous access

to forage and when concentrates are offered should act as a true supplement thereby enhancing total intake (Robinson, 1990). In practice it is very difficult to prove this as measuring true intake in a grazing situation is very difficult to achieve with any accuracy (Pulina *et al.*, 2013).

Dove (2002); Freer (2002) and Pulina *et al.*, (2013) concluded that supplementation almost always causes substitution effects which are related to pasture height and herbage mass. There is also the time taken away from grazing when a supplement is fed and the effect the supplement has on rumen pH and stability.

The optimum sward height for lactating ewes is 4.5 to 8cm to obtain near maximal intakes (Treacher, 1990; Treacher and Caja, 2002 and AHDB Manual 8, AHDB 2016d). Supplementation of ewes is recommended when pasture sward height is below 4cm with extra forage required as well, if sward height is below 3cm (Maxwell and Treacher, 1986; Treacher, 1990).

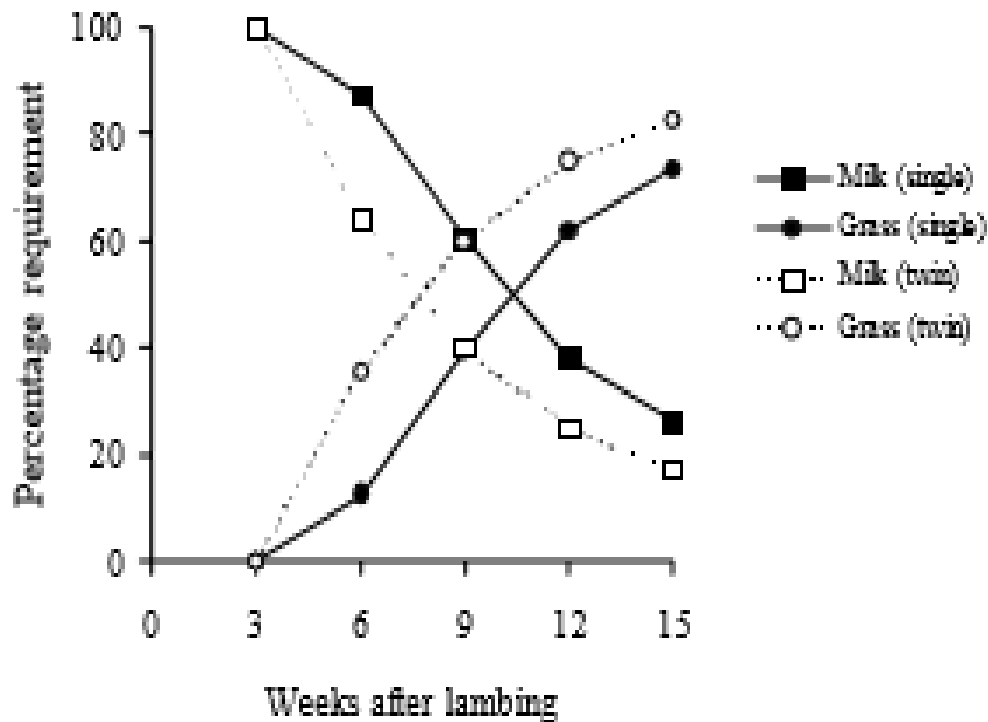
### **3.4.7 Contribution of Ewe to the Lambs Feed Requirements**

Lamb growth rate and health is dependent on adequate milk supply from the ewe). Figure 6 shows how the lamb's diet changes between 3 and 12 weeks of age.

Although ewes rearing twins produce 30 to 50% more milk than those rearing singles, this extra milk is shared between two lambs which means they have to make up for the gap by eating pasture at an earlier age and at higher quantities than single reared lambs. Beef and Lamb New Zealand (2010) show that the intake of pasture (kg/day) overtakes intake of milk when lambs are about four weeks of age (see diagram). By six weeks of age the twin lamb has an energy requirement of about 10MJ and only gets about 6.5MJ ME from milk leaving a gap of 3.5 MJ ME to be derived from pasture and/or creep. The interaction between pasture supplies becomes particularly important when pasture growth is poor. As the age of the lambs increase, a decision has to be made as to whether to continue supplementing the ewe to feed the lambs or wean and directly supplement the growing lambs (Beef and Lamb New Zealand, 2010).

Geenty and Dyson (1986) reviewed the relationship between lamb growth rate and ewe milk yield, including ewe breed, lamb rearing status, herbage allowance and lambing date and season. They concluded that when sheep grazed high quality spring pasture the relationship is very variable and lamb birth weight is a poor indicator of ewe milk production. They found that lambs suckling ewes with low milk production compensate by utilising milk more efficiently for growth and consuming more pasture.

Figure 6. The percentage of total ME requirement met by ewe's milk (averaged across all breeds) for both single and twin lambs, and by difference, the theoretical residual energy requirement to be met by grazing (Muir *et al.*, 2000).



### 3.4.8 Age of Lambs at Weaning

Lambs rely on ewe's milk almost entirely until about 4 weeks of age although they start grazing by about 2 to 3 weeks after birth. By 8 weeks their reliance on the ewe declines and 75% of their diet comes from forage or other feeds (e.g. creep). Muir *et al.*, (2000) undertook a study to evaluate the relative importance of milk and pasture to lamb growth during lactation under a high performance lamb production system. Assuming that lambs consume all the milk produced and under optimum grazing, twin lambs needed to acquire over a third of their energy requirements from pasture by the time they were 6 weeks of age. At this age, lambs were unlikely to have a fully developed rumen and the opportunity for the lamb to select high quality, highly digestible pasture components would be critical for maximum growth. Therefore, in a situation where feed is limiting, competition between ewes and lambs for highly quality feed is likely to restrict lamb growth rate indicates that weaning should be considered early when grass supplies are limiting.

Evidence from a variety of sources suggests that optimum weaning age is around 12 weeks in grass based systems. Preliminary data for the AHDB KPI project supports Beef and Lamb New Zealand (2010) who recommend lambs should be left with their mothers until they are 25kg-30kg or more. The KPI

project has used an adjusted 90day weight of 30Kgs as a target, which equates to a weaning age of 12-13 weeks.

Once lambs and ewes start competing for grass then weaning should take place giving lambs priority. However, if ewe condition is low then this must be factored in to the weaning date to allow the ewe adequate time to gain condition in time for mating.

#### **3.4.9 Mastitis in Lactating Ewes**

Mastitis in ewes is the major cause of milk yield drop and hence reduction in lamb growth rate and survival. In recent AHDB funded studies on mastitis in ewes (AHDB, 2012 and 2015e) undertaken at Warwick University, it is estimated that about 5% of ewes get acute mastitis with up to 50% of ewes dying and 90% losing the affected quarter. A further 20 to 30% of ewes in a flock get sub-clinical mastitis during lactation. Bencini and Pulina (1997) showed that mastitis also causes qualitative changes in milk composition.

Huntley *et al.*, (2012) reported an association between udder conformation, milk somatic cell count and lamb weight in lactating ewes. They concluded that poor udder and teat conformation are associated with high levels of intra-mammary infection and this was linked to lamb growth. They also reported age of ewe and BCS as significantly correlated to the incidence of mastitis with a greater risk of high somatic cell counts. Subclinical mastitis was associated with suboptimal weight gain in lambs over the first eight weeks of life and teat lesions (a possible indicator of undernutrition), poor udder conformation and ewe ageing were also factors in lower lamb performance (AHDB, 2012).

In the second phase of the AHDB funded research the impact of nutrition was specifically identified (AHDB, 2015e). They concluded that 24% of the cases of acute mastitis were attributable to ewe's underfed protein in pregnancy and 25% of the cases were associated with underfeeding energy in lactation. Bencini and Pulina (1997) also showed that improving the quality of the diet reduced somatic cell counts in milk especially towards the end of lactation. They linked this to the rumen function and its effect on general health of the ewe.

#### **3.4.10 Hypomagnesaemia in Lactation**

Sudden changes in diet, including abrupt turnout onto lush grass should be avoided to avoid hypomagnesaemia (Suttle, 2010). Hypomagnesaemia (also known as grass staggers or grass tetany) is caused by a magnesium deficiency during early lactation (in the first four to six weeks after lambing) when demand for the mineral is high. Most cases occur when ewes are turned out onto lush spring grass especially if nitrogen or potash fertilisers have been applied to the

pasture. Hypomagnesaemia generally is caused by a rise in potassium in the diet from a sudden change to grass or warm weather which reduces the absorption and utilisation of magnesium to the animal (Suttle, 2010). It is more prevalent in older ewes and those rearing twin lambs in which nutrient demand and stress is higher (Treacher and Caja, 2002). Onset of hypomagnesaemia is generally very rapid and will result in death unless treated in time. Before tetany occurs, ewes appear nervous with trembling. Treacher and Caja (2002) confirmed symptoms are generally caused by low dietary magnesium, a sudden change in diet, exercise and transportation.

Treatment of hypomagnesaemia is an intravenous injection including magnesium hypophosphite along with calcium borogluconate (Suttle, 2010). Methods of preventing hypomagnesaemia are given by Treacher and Caja (2002) and Suttle (2010):

- Reduce use of potassium based fertilisers on pasture used for early lactation.
- Avoid sudden changes in diet type, i.e. forage type or concentrate type or system of feeding.
- Once turned out, ewes should be offered concentrates or block feeds with additional magnesium.
- Minimise distance walked by ewes to seek water.
- Avoid stress of transportation in early lactation.

#### 4. Nutrition of Replacement Ewes

A report on 'Breeding from Ewe Lambs' produced by the AHDB (2016i) concluded that ewes bred as ewe lambs have a higher potential lifetime productivity compared with ewes bred as shearlings (lambing at two years old). A review by Keady and McNamara (2012) and a study reported by Keady and Hanrahan (2016) concurs. Keady and Hanrahan (2016) found that mating replacements at seven months of age had no negative effect on ewe performance the subsequent year, compared to those lambing at two years of age (mated at 19 months) for the first time. The birth weight of the lambs at the second lambing from ewes first mated at seven months were significantly heavier ( $P < 0.001$ ) than lambs from ewes lambing for the first time at 2 years. This was the only significant difference. Litter size, lambs reared, lamb weaning weights, lamb growth rates and conception rates at the 30 months mating were the same.

To ensure the potential of the ewe lamb is realised, her nutrition has to encompass all phases of her development. This includes the nutrition of the growing foetus and neonate as well as her growth up to puberty and mating and then through pregnancy and lactation up to her second mating.

The fertility and prolificacy rates of ewe lambs are lower than those of adults. Corner-Thomas *et al.*, (2015b) report fertility rates of ewe lambs to be between 47 and 82% compared with 85 and 97% in mature multiparous ewes. Fertility rate is limited by a number of factors such as failure to attain puberty prior to the breeding season, oestrus without ovulation, shorter and less intense oestrus, impaired breeding behaviour and fertilisation failure. The nutrition and subsequent body weight and condition affect fertility rates. The threshold breeding live weight for ewe lambs to reach puberty is between 40 and 70% of their mature live weight.

##### 4.1 Foetal Growth

The production of a successful replacement ewe starts before their dam is pregnant. Nutrition of the ewe up to mating affects the viability of the embryos produced and the ability of the female lamb to breed because the development of the reproductive system and mammary gland starts at the foetal stage (Robinson *et al.*, 2005; Kenyon and Blair, 2014).

Asmad *et al.*, (2014) reported the effects of dam size and nutrition during pregnancy on the lifetime performance of female offspring over six years. Dams were selected for size and fed *ad libitum* or maintenance pasture based diets at mating and during pregnancy. The live weights and condition scores of their daughters were inconsistently affected by dam size and nutrition over time and no significant differences were found. When the breeding daughter's performance was assessed at 5.5 years of age, it was found that daughters

from dams fed *ad libitum* had higher survival rates, greater number of follicles, higher ovulation rates and produced more lambs than daughters from dams fed at maintenance levels. There was no interaction between the dam size and nutrition, but nutrition of the dam had an effect on the lifetime breeding performance of the daughter.

A review of mammary gland development (Yart *et al.*, 2014) confirm that mammogenesis also begins during the embryonic stage, with nutrition of the ewe around mating being critical because maternal undernutrition at this stage alters the hypothalamic, pituitary and adrenal gland development of the foetus. Underdevelopment of these glands has also been shown to alter lamb physiology, metabolism and behaviour, affecting her ability to be a successful breeding ewe (Hernandez *et al.*, 2010).

## 4.2 Pre Mating Nutrition

For successful reproduction, live weight targets based on reaching 60% of mature body weight at mating as a ewe lamb or 80% of mature weight as a shearling have proved successful (SAC, 2009a). However, ewe lambs mated at 60% of their body weight must then continue to grow over successive lambings, reaching 80% at their second mating and their full mature weight by their third mating at 3 years old (SAC, 2009a). AHDB (2016i) and Keady and McNamara (2012) concur with a mating weight of ewe lambs of 60% of mature weight, i.e. for a ewe of 75kg mature weight, her mating weight is 45Kg. Kenyon (2013) recommends that ewe lamb replacements should be a minimum of 60 to 70% of their mature weight for a lifetime's successful breeding.

Replacement ewe lambs must achieve the correct growth rate from weaning to mating. Their weight at mating is important, Gaskins *et al.*, (2005) found that ewe weight at breeding had a positive effect on fertility and prolificacy ( $P<0.001$ ), whereas total weight gain from weaning to breeding had a positive effect on fertility ( $P<0.05$ ). Also increasing weight at mating increased ( $P<0.01$ ) the probability of the ewe producing multiple lambs.

Low pre-mating weight and/or a low weight gain of ewe lambs from mating to late pregnancy was found to be associated with increased foetal loss (Ridler *et al.*, 2015). Their work emphasises the importance of achieving target weights pre-mating and continued weight gain through pregnancy. Corner-Thomas *et al.*, (2015b) investigated the relationship of ewe lamb live weight and BCS immediately prior to mating on fertility and reproductive rates, with the aim of identifying specific targets. Over two years approximately 15,500 ewe lambs (NZ Romney cross) were monitored from mating to lambing. Fertility rates (ewe lambs pregnant per 100 mated) increased with live weight up to 47.4kg but did not increase above this. Reproductive rate (foetuses per 100 ewe lambs bred) peaked for ewes in the 47.5 to 52.4 kg live weight category at 138%. Ewe lamb



fertility peaked at a BCS of 3.5 (90%) while reproductive rates peaked at score 3.0 (130%). They concluded that this plateau indicated there is no benefit from increasing live weight or BCS above these levels. The mature live weight of Romney cross ewes are approximately 70 to 80kg, so their findings agree with the recommended 60% of mature weight (42 to 48 kg). Their final recommendation was that farmers should aim to have replacement ewe lambs at a minimum of BCS 3.0 or a minimum live weight target of 47.5kg.

AHDB (2016i) recommends an average growth rate of 250g per day from weaning until six weeks after mating in order to meet these targets. In practice this requires careful management from birth, with moderately restricted diets pre puberty and then controlled *ad libitum* feeding up to mating to achieve adequate live weight and BCS for mating. Lambs weaned at 30kg body weight will need to grow at a rate of at least 215 g/day to reach a minimum mating weight of 45kg in ten weeks.

A study to assess the effects of restricted feeding on the body growth and mammary development of ewe lambs was reported by Villeneuve *et al.*, (2010). Dorset ewe lambs were offered a restricted diet to achieve 70% of the average daily gain of unrestricted ewe lambs from weaning at eight weeks of age to eighteen weeks of age to cover the growth phase of mammary gland development. During the phase daily live weight gain of the lambs were 225 and 305 g/day for the restricted and unrestricted lambs respectively. At the end of the experimental phase, ewe lambs offered the restricted diets had more mammary development than those fed the *ad libitum* diets. The restricted ewe lambs achieved near full compensatory growth following the restriction period so that at mating and at lambing the ewe lamb live weight, loin eye depth and back fat depth was similar for all groups. They concluded that restricted feeding before puberty of ewe lambs improves mammary development without compromising growth performance.

Research has also established a negative relationship between pre-pubertal growth and lifetime milk production in sheep and cattle. Tolman and McKusick, (2001) showed that if pre-pubertal nutrition is restricted, there is inadequate growth of the mammary fat pad, which provides the energy for growth and development of the milk ducts (Tolman and McKusick, 2001). Mammary gland development begins at the onset of cyclic ovarian secretion activity at puberty (Yart *et al.*, 2014).

However, high levels of energy intake and growth rates of pre-pubertal lambs (one to five months of age) have also been shown to reduce mammary development and can result in 10 to 17% less milk production during the first three lactations (Tolman and McKusick, 2001). This is thought to be due to an inverse relationship between feeding level and growth hormone production. Growth hormone inhibits development of mammary epithelial tissue that later forms the milk producing alveolar cells, thus limiting lifetime milk yield. This has

important implications for management regimes because breeders may push ewe lambs to achieve mating weight targets. Therefore, there has to be a compromise between reaching the minimum 60% of mature weight target without detrimentally affecting mammary gland development. Tolman and McKusick (2001) suggest this can be achieved by restricting energy intake to 65 to 75% of their *ad libitum* intake, though the negative impact is greatest at four to six weeks of age and declines over the next few months as growth hormone levels reduce and are less influential. This points to very intensive rearing systems as the highest risk.

In conclusion, ewe lamb growth rates of 200 to 250 g/day from weaning to achieve at least a 60% of mature weight at mating is recommended. This can be achieved by good grassland management with supplementary feeding as required.

### **4.3 Nutrition of Pregnant and Lactating Replacements**

During early and mid-pregnancy, the ewe lamb has to continue to grow and it is generally accepted that they will require about 20% more feed than mature ewes of the same weight (AHDB, 2016i). However, there are negative impacts of planes of nutrition that are both excessive and restrictive around this guideline. In practice ewe lambs should be at least 75 to 80% of their mature weight at lambing (SAC, 2009a).

Robinson *et al.*, (2002) reviewed the age/weight of the ewe lamb and the interaction with plane of nutrition in pregnancy and the effects on placental and foetal growth. They compared two groups of adolescent sheep growing at 300g or 80g per day from day 50 to 104 of pregnancy. The ewe lambs with the higher growth rate had lower placental cotyledon weights, lower lamb birth weights and a five-fold increase in lamb mortality compared to the ewe lambs growing at the slower rate.

Mulvaney *et al.*, (2008) report an experiment to determine the performance effects on ewe lambs offered different feeding regimes through pregnancy. After mating, 240 lambs were randomly allocated to one of three nutritional regimes up to lambing:

- Low treatment group were fed pasture to maintain live weight during the first 100 days and thereafter feeding was increased to achieve a growth rate of 180g per day.
- Medium treatment group were managed to ensure a live weight gain of about 100g per day throughout pregnancy.
- High treatment group were offered *ad libitum* feed throughout pregnancy.

The results showed that the medium treatment ewe lambs had a significantly ( $P<0.05$ ) higher pregnancy rate at day 50 of pregnancy compared to lambs offered the low and high treatment diets which had higher foetal losses. Lambs born to low treatment group ewe lambs also had significantly ( $P<0.05$ ) lower birth weights, weights at day 53 and 87 post lambing and lower survival rates compared to lambs born to the medium and high treatment group ewes.

A similar experiment in New Zealand (Kenyon *et al.*, 2008) explored higher growth rates through pregnancy. They demonstrated some benefits of feeding at a high, but controlled level. After mating, 337 ewe lambs were randomly allocated to one of three nutritional regimes up to lambing:

- Medium treatment group were managed to gain 100g per day throughout pregnancy.
- Medium/High treatment group were managed to grow at 100g/day until day 36 of pregnancy and then 200g per day up to lambing.
- High treatment group managed to gain 200g per day throughout pregnancy.

The average daily live weight gains achieved were 134.3 and 223.7g for the medium and high group of ewe lambs and for the two periods of the medium/high group 103.3 and 237.2 g/day. Pregnancy scanning showed there was no difference in the ewe lambs pregnancy percentage (approximately 48%) or the number of ewe lambs which lambed (approximately 45%) when the three nutritional regimes were compared. There was also no difference in the birth weight of lambs born to the dams on the different feeding regimes in pregnancy. In late lactation lambs born to the dams on the high feeding regime were significantly ( $P<0.05$ ) heavier than those lambs born to dams on the medium feeding regime. Also the dams themselves were heavier after the high feeding compared to the medium regime. Kenyon *et al.*, (2008) concluded that high live weight gains of approximately 200 g/day in pregnancy may be beneficial to their offspring and long term breeding capacity of the ewe lambs.

The current AHDB (2016i) recommends a ewe lamb growth rate of 250 g/day from mating, for the first two months of pregnancy. Followed by growth rate of at least 150 g/day until six weeks pre lambing. These growth rates may be too high and difficult to manage and they suggest that ewe lambs need 20% more feed than mature ewes to sustain continuing body growth through this period. Kenyon (2013) recommends ewe lambs should gain around 130 g/day of weight throughout pregnancy, while Keady and McNamara (2012) suggest that live weight gain of ewe lambs from mating to lambing should be only 80 g/day.

In practice a ewe lamb with a mature weight of 75kg should be 57 to 60kg bodyweight at lambing (75 to 80% of mature weight). To achieve this from a mating weight of approximately 45kg (60% of mature weight) she needs to gain weight at a minimum of 100 g/day. However, growth of the ewe in the last six weeks of pregnancy will be reduced due to the competing foetal growth and

consequential reduced rumen capacity. Therefore, a growth rate of about 140 – 150 g/day in the first 15 weeks of pregnancy should be aimed for.

To achieve this energy is normally the first limiting component in the diet of pregnant ewe lambs (Keady and McNamara, 2012). When formulating a ration as a general rule a pregnant ewe lamb requires an extra 2.5 MJ/day of ME to account for growth compared to a mature ewe of the same stage of pregnancy.

The key messages of achieving at least the 60% of mature weight at mating and controlled growth through pregnancy are therefore critical to avoid the need to feed ewe lambs for 'catch up' growth because this increases the risk of producing lambs of low birth weight, lack of vigour, limited brown fat reserves and poor survival (SAC, 2009a).

During late pregnancy and lactation, ewe lambs need to be managed in a separate group to the mature ewes of the flock. In the last six weeks of pregnancy, AHDB (2016i) recommends that ewe lambs are offered diets for maintenance and foetal growth, in line with mature ewes of the same weight. A flat rate feeding system is also suggested for these immature ewes.

In lactation, AHDB (2016i) recommends allowing ewe lambs 20% more feed than mature ewes of similar weight in order to supply sufficient nutrients for their body growth and milk production. Lambs should be creep fed and weaned at eight to nine weeks of age so that the ewe lambs do not lose too much weight and condition. Ideally a ewe lamb should produce and rear one lamb. Keady and McNamara (2012) suggest that ewe lambs with twins should be treated as mature ewes with triplets, in a separate flock with access to feed and creep feed for the lambs.

## References

Addah, W., Karikari, P. K and Baah, J. 2012. Under nutrition in the ewe: Foeto-placental adaption and modulation of lamb birth weight: A review. Livestock Research for Rural Development. 24:9.

ADAS/MAFF. 1986. Feeding straw to housed ewes – Technical note P3016.

ADAS. 1987. On farm treatment and feeding of straw – Technical note P618.

AFRC. 1991. TCORN, Report No. 6. A reappraisal of the calcium and phosphorus requirements of sheep and cattle. Nutr. Abs and Rev., Series B 61. CAB International, Wallingford, UK.

AFRC. 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on responses to Nutrients. CAB International, Wallingford, UK.

AHDB. 2012. Understanding mastitis in ewes.  
[http://beefandlamb.ahdb.org.uk/wp/wpcontent/uploads/2013/04/understanding\\_mastitisinewes\\_-\\_final\\_report\\_jan\\_2012.pdf](http://beefandlamb.ahdb.org.uk/wp/wpcontent/uploads/2013/04/understanding_mastitisinewes_-_final_report_jan_2012.pdf)

AHDB. 2013a. How to condition score.  
[http://beefandlamb.ahdb.org.uk/wp/wpcontent/uploads/2015/10/brp\\_l\\_Sheep\\_BCS\\_190713.pdf](http://beefandlamb.ahdb.org.uk/wp/wpcontent/uploads/2015/10/brp_l_Sheep_BCS_190713.pdf)

AHDB. 2013b. The mini feeds directory.  
[http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2013/10/brp\\_b\\_mini-feeds-directory-141013.pdf](http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2013/10/brp_b_mini-feeds-directory-141013.pdf)

AHDB. 2013c. All grass wintering of sheep.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2013/04/All-Grass-Wintering-Final-Report-150713.pdf>

AHDB. 2013d. Genetics of trace element deficiencies in sheep. Project No. 73411. [www.beefandlamb.ahdb.org.uk/research](http://www.beefandlamb.ahdb.org.uk/research) and development/genetic selection/genetic selection-sheep

AHDB. 2014a. The Home-Grown Forages Directory.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2014/12/BRP-Home-grown-forages-directory-181214.pdf>

AHDB. 2014b. Sustainable protein for pregnant ewes. Report for AHDB Beef and Lamb.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2014/04/73206-Protein-Sources-and-TMR-Feeding-Final-Report-050114.pdf>

AHDB. 2014c. Sheep KPI Validation Project.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2014/03/74210-KPI-Sheep-Validation.pdf>

- AHDB. 2014d. To refine and confirm the level of selenium and iodine supplementation for breeding ewes.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2014/03/Selenium-and-iodine-for-breeding-ewes-Final-Report-190214.pdf>
- AHDB. 2015a. Sheep BRP Manual 4 – Managing ewes for Better Returns.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2015/12/BRP-Managing-ewes-for-better-returns-111215.pdf>
- AHDB. 2015b. Beef and Sheep BRP Manual 5 – Making grass silage for Better Returns.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2015/10/BRP-Making-grass-silage-for-better-returns-manual-5-160915.pdf>
- AHDB. 2015c. Maximising forage and grassland utilisation through, out wintering in-lamb ewes on swedes.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2014/02/73205-In-lambs-Ewes-on-Swedes-Final-Report-180515.pdf>
- AHDB. 2015d. All grass wintering of sheep – Phase 111.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2014/03/73209-All-grass-Wintering-Final-report-210115.pdf>
- AHDB. 2015e. Mastitis in ewes: Phase II.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2014/03/73104-Mastitis-in-Ewes-Phase-II-Final-Report-180915.pdf>
- AHDB. 2015f. Stocktake Report 2015.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2015/11/Stocktake-report-2015-101115.pdf>
- AHDB. 2016a. Beef and Sheep BRP Manual 1 - Improving Pasture for Better Returns.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/01/BRP-improving-pasture-manual-1-180116.pdf>
- AHDB. 2016b. Beef and Sheep BRP Manual 4 – Managing clover for Better Returns.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/07/BRP-Managing-clover-manual-4-150716.pdf>
- AHDB. 2016c. Beef and Sheep BRP Manual 6. Using brassicas for better returns.  
<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/07/BRP-Using-brassicas-for-better-returns-manual-6.pdf>
- AHDB. 2016d. Beef and Sheep BRP Manual 8 - Planning grazing strategies for Better Returns.

<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/07/BRP-Planning-grazing-strategies-manual-8-150716.pdf>

AHDB. 2016e. Beef and Sheep BRP Manual 10 – Growing and feeding maize silage for Better Returns.

<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/01/BRP-Growing-and-feeding-maize-silage-Manual-10-180116.pdf>

AHDB. 2016f. Sheep BRP Manual 12 - Improving ewe nutrition for Better Returns.

<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/04/BRP-Improving-ewe-nutrition-manual-12-050416.pdf>

AHDB. 2016g. Trace element supplementation of beef cattle and sheep – BRP Plus.

<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/03/BRP-plus-Trace-element-supplementation-of-beef-cattle-and-sheep.pdf>

AHDB. 2016h. Using chicory and plantain in beef and sheep systems.

<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/03/BRP-plus-Using-chicory-and-plantain-in-beef-and-sheep-systems-080316.pdf>

AHDB. 2016i. Breeding from Ewe Lambs. BRP Plus.

<http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2016/03/BRP-plus-Breeding-Ewe-Lambs-080316.pdf>

Al-Sabbagh, T.A., Swanson, L.V and Thompson, J.M. 1995. The effect of ewe body condition at lambing on colostral immunoglobulin G concentration and lamb performance. *J. Anim. Sci.* 73: 2860-2864.

Amanlou, H., Karimi, A., Mahjoubi, E and Milis, C. 2011. Effects of supplementation with digestible undegradable protein in late pregnancy on ewe colostrums production and lamb output to weaning. *Journal of Animal Physiology and Animal Nutrition* 95: 616-622.

Annett, R.W and Carson, A.F. 2006. Effects of plane of nutrition during the first month of pregnancy on conception rate, foetal development and lamb output of mature and adolescent ewes. *Animal Science* 82: 947-954.

Annett, R.W., Carson, A.F. and Dawson, L.E.R. 2008. Effects of digestible undegradable protein (DUP) supply and fish oil supplementation of ewes during late pregnancy on colostrum production and lamb output. *Animal Feed Science and Technology*, 146, pp. 270-288.

Annett, R. W., Dawson, L. E. R., Edgar, H. and Carson, A.F. 2009. Effects of source and level of fish oil supplementation in late pregnancy on feed intake, colostrum production and lamb output of ewes. *Animal Feed Science and Technology* 154: 169-182.

Annison, E.F., Lindsay, D.B. and Nolan, J.V. 2002. Digestion and metabolism. In: Sheep Nutrition (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 95-118. ARC. 1980. The Nutrient Requirements of Ruminants. Commonwealth Agricultural Bureaux, Farnham Royal, Slough, UK.

Asmed, K., Kenyon, P.R., Pain, S.J., Parkinson, T J., Peterson, S.W., Lopez-Villalobos, N and Blair, H.T. 2014. Effects of dam size and nutrition during pregnancy on lifetime performance of female offspring. Small Ruminant Research. 121: 325-335.

Aubry, A. and Yan, T. 2016. Literature review on the effects of animal and dietary factors on maintenance energy requirements and energetic efficiencies in growing lambs and breeding sheep. AFBI review for DARDNI and AHDB.

Banchero, G.E., Milton, J.T.B., Lindsay, D.R., Martin, G.B and Quintans, G. 2015. Colostrum production in ewes: a review of regulation mechanisms and of energy supply. Animal. 9:5 831-837.

Beef and Lamb New Zealand. 2010. 400 plus - a guide to improved lamb growth.

<http://www.beeflambnz.com/Documents/Farm/400%20plus%20-%20a%20guide%20to%20improved%20lamb%20growth.pdf>

Bencini, R and Pulina, G. 1997. The quality of sheep milk: a review. Australian Journal of Experimental Agriculture. 37: 485-504.

Ben Salem, H. and Nefzaouii, A. 2003. Feed blocks as alternative supplements for sheep and goats. Small Ruminant Research 49: 275-288.

Boland, T.M., Keane, N., Nowakowski, P., Brophy, P.O. and Crosby, T.F. 2005. High mineral and vitamin E intake by pregnant ewes lowers colostral immunoglobulin G absorption by the lamb. J. Anim. Sci. 83:4 871-878.

Cal-Pereyra, L., Gonzalez-Montana, J.R., Benech, A., Acosta-Dibarrat, J., Martin, M.J., Perini, S., Abreu, M.C., Da Dilva, S. and Rodriguez, P. 2015. Evaluation of three therapeutic alternatives for the early treatment of ovine pregnancy toxemia. Irish Vet. J. 68:25.

Campion, F.P., McGovern, F.M., Lott, S., Fahey, A.G., Creighton, P. and Boland, T.M. 2016. Comparison of energy rationing systems for late gestation ewes: impacts on ewe and lamb performance. J. Anim. Sci. pre-publication.

Cannas, A., Tedeschi, L.O., Fox, D.G., Pell, A.N and Van Soest, P.J. 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. J. Anim. Sci. 82: 149-169.

Capper, J. L., Wilkinson, R. G., Mackenzie, A. M and Sinclair L. A. 2006. Polyunsaturated fatty acid supplementation during pregnancy alters neonatal behaviour in sheep. Journal of Nutrition 136: 397-403.



Chestnutt, D.M.B. 1989. The effect of contrasting silages offered in mid and late pregnancy on the performance of breeding ewes. *Animal Production* 49: 435-440

Chestnutt, D. M. B. and Wylie, A. R. G. 1995. The effects of frequency of feeding of supplementary concentrates on performance and metabolite and IGF-1 status of ewes given silage in late pregnancy. *Animal Science* 61: 269-276.

Clarke, L., Heasman, L., Juniper, D.T and Symonds, M.E. 1998. Maternal nutrition in early-mid gestation and placental size in sheep. *British Journal of Nutrition*. 79: 359-364.

Coleman, S.W. and Henry, D.A. 2002. Nutritive value of herbage. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 1-26.

Coop R.L. and Kyriazakis I. 1999. Nutrition–parasite interactions. *Veterinary Parasitology*. 84: 18.

Coop, R.L. and Sykes, A.R. 2002. Interactions between gastrointestinal parasites and nutrients. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 313-332.

Corbett, J.L. and Ball, A.J. 2002. Nutrition for maintenance. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 143-163.

Corner, R.A., Kenyon, P.R., Stafford, K.J., West, D.M., Morris, S.T. and Oliver, M.H. 2010a. The effects of pasture availability for twin and triplet bearing ewes in mid and late pregnancy on ewe and lamb behaviour 12 and 24 hours after birth. *Animal*. 4:1 108-115.

Corner, R.A., Kenyon, P. R., Stafford, K. J., West, D. M. and Oliver, M. H. 2010b. The effect of different types of stressors during mid- and late pregnancy on lamb weight and body size at birth. *Animal* 4:12 2065-2070.

Corner-Thomas, R.A., Hickson, R.E., Morris, S.T., Black, P.J., Ridler, A.L., Stafford, K.J and Kenyon, P.R. 2015a. Effects of body condition score and nutrition in lactation on twin bearing ewe and lamb performance to weaning. *New Zealand Journal of Agricultural Research*. 58:2 156-169.

Corner-Thomas, R.A., Ridler, A.L., Morris, S.T and Kenyon, P.R. 2015b. Ewe lamb live weight and body condition scores affect reproductive rates in commercial flocks. *New Zealand Journal of Agricultural Research*. 58:1 26-34.

Cottrill, B., Dawson, C., Yan. T. and Bai, X. 2009. A review of the energy, protein and phosphorus requirements of beef cattle and sheep. <http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15958>

Cranston, L.M., Kenyon, P.R., Morris, S.T., Lopez-Villalobos, N and Kemp, P.D. 2016. Morphological and physiological responses of plantain (*Plantago lanceolata*) and chicory (*Cichorium intybus*) to water stress and defoliation frequency. *J. Agro. Crop Sci.* 202: 13-24.

Davis, H.D. 2004. Major genes affecting ovulation rate in sheep. In *Genet. Sel. Evol.* 37 (Suppl. 1).

Davies, O. D. and Griffiths, J. B. 2000. The strategic use of feed blocks to manage sheep grazing in the uplands. *Proceedings of the British Grassland Society Conference, Harrogate. March 2000.* 67-72.

Dawson, L.E.R., Carson, A.F. and Kilpatrick, D.J. 1999. The effect of digestible undegradable protein concentration of concentrates and protein source offered to ewes in late pregnancy on colostrum production and lamb performance. *Animal Feed Science and Technology.* 82: 21-36.

Defra. 2003. Code of Recommendations for the Welfare of Livestock: Sheep. [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/69365/pb5162-sheep-041028.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69365/pb5162-sheep-041028.pdf)

Demmers, K.J., Smaill, B., Davis, G.H., Dodds, K.G. and Juengel, J.L. 2011. Heterozygous Inverdale ewes show increased ovulation rate sensitivity to pre-mating nutrition. *Reprod. Fertil. Dev.* 2011;23(7):866-75. doi: 10.1071/RD10344.

Donaldson J., van Houtert M. F. J., Sykes A. R. 1998. The effect of nutrition on the periparturient parasite status of mature ewes. *Animal Science.* 67:523

Donnem, I., Randby, A.T., Hektoen, L., Avdem, F., Meling, S., Vage, A.O., Adnoy, T., Steinheim, G and Waage, S. 2015. Effect of vitamin E supplementation to ewes in late pregnancy on the rate of stillborn lambs. *Small Ruminant Research.* 125: 154-162.

Dove, H. 2002. Principles of supplementary feeding in sheep grazing systems. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 119-142.

Dove, H. 2010. Balancing nutrient supply and nutrient requirements in grazing sheep. *Small Ruminant Research.* 92: 36-40.

Ducker, M.J., Kendall, P.T., Hemingway, R.G and McClelland, T H. 1981. An evaluation of feedblocks as a means of providing supplementary nutrients to ewes grazing upland/hill pastures. *Animal Production.* 33: 51-57.

Dwyer, C.M. 2014. Maternal behaviour and lamb survival: from neuroendocrinology to practical application. *Animal* 8:1 102-112.

Dwyer, C.M., Conington, J., Corbiere, F., Holmoy, I H., Muri, K., Nowak, R., Rooke, J., Vipond, J. and Gautier, J.M. 2016. Invited review: Improving

neonatal survival in small ruminants: science into practice. *Animal*. 10:3 449-459.

Earle, E., McHugh, N., Boland, T. and Creighton, P. 2016. Effect of stocking rate and prolificacy potential on lamb performance and carcass output from a grass based production system. *Advances in Animal Biosciences*. 7: 076.

Emery, DL, McClure, SJ, Wagland, BM and Jones, WO. 1992. Studies of stage-specific immunity against *Trichostrongylus colubriformis* in sheep: Immunization with adult parasites. *Int. J. Parasitol.* 22: 215–225.

Ewing, W.N. 1997. *The Feeds Directory: Commodity Products*. ISBN:978-1899043019.

FIM. 2004. *Feed into Milk – A new applied feeding system for dairy cows - An Advisory Manual*.

<http://bsas.org.uk/sites/default/files/files/FiM-Book.pdf>

Ferreira, E.M., Pires, A.V., Susin, I., Gentil, R.S., Gilaverte, S., Parente, M.O.M., Biehl, M.V. and Ribeiro, C.V.D.M. 2014. Lamb performance, milk production and composition from ewes supplemented with soybean oil partially replaced by fish oil. *Livestock Science*. 163: 51-61.

Fisher, G.E. 1991. Effect of cobalt deficiency in the pregnant ewe on reproductive performance and lamb viability. *Res. Vet. Sci.* 50:3 319-327.

Forbes, J.M. and Mayes, R.W. 2002. Food choice. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 51-69.

Frater, P., Genever, L., Vipond, J and Jones, R. 2014. Maximising winter grass utilisation on sheep farms: all grass wintering. *Advances in Animal Biosciences*. 5: 013.

Freer, M. 2002. The nutritional management of grazing sheep. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 357-376.

Fthenakis, G.C., Arsenos, G., Brozos, C., Fragkou, I.A., Giadinis, N.D., Giannenas, I., Marvrogiani, V.S., Papadopoulos, E. and Valasi, I. 2012. Health Management of ewes during pregnancy. *Animal Reproduction Science*. 130: 198-212.

Gaskins, C.T., Snowder, G.D., Westman, M.K. and Evans, M. 2005. Influence of body weight, age and weight gain on fertility and prolificacy in four breeds of ewe lambs. *J. Anim. Sci.* 83: 1680-1689.

Geenty, K.G. and Dyson, B. 1986. The effects of various factors on the relationship between lamb growth rate and ewe milk production. *Proceedings of the New Zealand Society of Animal Production*. 46: 265-269.

Geenty, K.G. and Sykes, A.R. 1986. Effect of herbage allowance during pregnancy and lactation on feed intake, milk production, body composition and

energy utilisation of ewes at pasture. *Journal of Agricultural Science*. 106:02 351-367.

Grazul-Bilska, A.T., Borowczyk, E., Arndt, W., Evoniuk, J., O'Neil, M., Bilski, J.J., Weigl, R.M., Kirsch, J.D., Kraft, K.C., Vonnahme, K.A., Redmer, L.P., Reynolds, L.P. and Caton, J.S. 2012. Effects of overnutrition and undernutrition on in vitro fertilisation (IVF) and early embryonic development in sheep. *Domest. Anim. Endocrinol.* 43:4 289-298.

Gunn, R.G., Smith, W.F., Senior, A.J. 1991. Pre-mating herbage intake and the reproductive performance of North Country Cheviot ewes in different levels of body condition. *Animal Production*, 52: 149–156.

Hammer, C.J., Thorson, J.F., Meyer, A.M., Redmer, D.A., Luther, J.S., Neville, T.L., Reed, J.J., Reynolds, L.P., Caton, J.S. and Vonnahme, K.A. 2011. Effects of maternal selenium and plane of nutrition during gestation on passive immunity and health in neonate lambs. *J. Anim. Sci.* 89: 3690-3698.

Hazzledine, M. 2008. Premier Atlas Ingredients Matrix. Rugeley, Premier Nutrition Products Ltd.

Herlander, C., Norgard, P., Reza Jalali, A. and Nadeau, E. 2014. Effect of chopping grass silage and mixing silage with concentrate on feed intake, dietary selection, chewing activity and faecal particle size of ewes in late pregnancy and early lactation. *Livestock Science* 163: 69-79.

Hernandez, C.E., Matthews, L.R., Oliver, M.H., Bloomfield, F.H. and Harding, J.E. 2010. Effects of sex, litter size and periconceptual ewe nutrition on offspring behavioural and physiological response to isolation. *Physiology and Behaviour*. 101: 588-594.

Hickson, R.E., Kenyon, P.R., Blair, H.T., Harding, J.E., Oliver, M.H., Jaquierey, A.L., Nicoll, G.B. and Burt, K.G. 2012. The effect of liveweight and liveweight gain of ewe immediately post-weaning on the liveweight and survival of subsequent lambs. *Animal Production Science*. 52:6/7 491-496.

Hosie, B.D., Low, J.C., Bradley, H.K. and Robb, J. 1991. Nutritional factors associated with vaginal prolapse in ewes. *Vet. Rec.* 128:9 204-208.

Houdijk, J.G.M 2008. The influence of periparturient nutritional demand on resistance to parasites in livestock. *Parasite Immunology* 30: 113-121.

Houdijk, J.G.M, Jessop, N.S. and Kyriazakis, I. 2001. Nutrient partitioning between reproductive and immune function in animals. *Proc. of the Nutrition Society*. 60: 515-525.

Houdijk, J.G.M. 2014. Benefits of by-pass protein supplementation on periparturient ewe performance. *Advances in Animal Biosciences*. 5: 030.

Houdijk, J.G.M., Jackson, F., Coop, R.C and Kyriazakis, I. 2006. Rapid Improvement of immunity to *Teladorsagia circumcincta* is achieved through a reduction in the demand for protein in lactating ewes. *International Journal for Parasitology*. 36: 219-227.

Houdijk, J.G.M., Jackson, F. and Kyriazakis, I. 2009. Nutritional sensitivity of resistance to *Trichostrongylus Colubriformis* in lactating ewes. *Veterinary Parasitology*. 160: 258-266.

Houdijk, J.G.M., Kyriazakis, I., Jackson, F., Huntley, J.F. and Coop, R.L. 2000. Can an increased intake of metabolisable protein affect the periparturient relaxation in immunity against *Teladorsagia circumcincta* in sheep? *Veterinary Parasitology*. 91: 43-62.

Houdijk, J.G.M., Kyriazakis, I., Jackson, F., Huntley, J.F. and Coop, R.L. 2003. Is the allocation of metabolisable protein prioritised to milk production rather than to immune functions in *Teladorsagia circumcincta* infected lactation ewes? *International Journal of Parasitology*. 33: 327-338.

Houdijk, J.G.M., Kyriazakis, I., Jackson, F., Huntley, J.F. and Coop, R.L. 2005. Effects of protein supply and reproductive status on local and systemic immune responses to *Teladorsagia circumcincta* in sheep. *Veterinary Parasitology*. 129: 105-117.

Houdijk, J.G.M., Smith, L.A. and Vipond, J.E. 2015. By-pass based protein supplementation and periparturient ewe performance. *Advances in Animal Biosciences*. 6: 162.

Houdijk, J.G.M., Van der Heiden, A., Trienes, Y. and Vipond, J.E. 2016. Interactive effects of by-pass protein supplementation and parasitism on ewe performance. *Advances in Animal Biosciences*. 7: 018.

Houdijk, J.G.M. and Vipond, J.E. 2014. Home-grown alternatives for by-pass soya bean meal. *Advances in Animal Biosciences*. 5: 017.

Huntley, S.J., Cooper, S., Bradley, A.J. and Green, L.E. 2012. A cohort study of the associations between udder conformation, milk somatic cell count and lamb weight in suckler ewes. *J. Dairy Sci*. 95: 5001-5010.

Hussein, A.A., Mackenzie, A.M., Wilkinson, R.G. and Huntington, J.A. 2016. The effects of forage type and molybdenum and sulfur supplementation on copper status in growing lambs. *Advances in Animal Biosciences*. 7: 072.

Hutton, P.G., Kenyon, P.R., Bedi, M.K., Kemp, P.D., Stafford, K.J., West, D.M. and Morris, S.T. 2011. A herb and legume sward mix increased ewe milk production and ewe and lamb live weight gain to weaning compared to ryegrass dominant sward. *Animal Feed Science and Technology*. 164: 1-7.

Johnson, J. and Evans, B. 1987. Grass production for sheep. In: Efficient Sheep Production from Grass (Ed. G.E. Pollott). BGS Occasional Symposium No 21. 13-28.

Jones, D.R., Vipond, J.E., Frater, P. and Genever, E. 2014. All grass wintering of sheep. Sheep Veterinary Society Proceedings. Darlington. 84-86.

Jordan, D.J. and Mayer, D.G. 1989. Effects of udder damage and nutritional plane on milk yield, lamb survival and lamb growth of Merinos. Australian Journal of Experimental Agriculture. 29: 315-320.

Kahn, L. P., Knox, M.R., Walkden-Brown, S.W. and Lea, J.M. 2003. Regulation of the resistance to nematode parasites of single- and twin-rearing Merino ewes through nutrition and genetic selection. Vet Parasitol. 114: 15–3

Keady, T.W.J. and Hanrahan, J.P. 2008. The effects of grass silage harvest systems, concentrate feed level and maize silage maturity and soya bean supplementation on ewe and subsequent lamb performance. Proceedings of the British Society of Animal Science. 125.

Keady, T.W.J. and Hanrahan, J.P. 2009. Effects of shearing at housing, grass silage feed value and extended grazing herbage allowance on ewe and subsequent lamb performance. Animal. 3:1 143-151.

Keady, T.W.J. and Hanrahan, J.P. 2012. The effects of allowance and frequency of allocation of autumn-saved pasture, when offered to spring lambing ewes in mid pregnancy, on ewe and lamb performance and subsequent herbage yield. Livestock Science. 143: 15-23.

Keady, T.W.J. and Hanrahan, J.P. 2013. Lamb mortality in a prolific flock managed in an intensive grassland system: effect of ewe factors. Proceedings of the Research Forum. 86.

Keady, T.W.J. and Hanrahan, J.P. 2016. Effects of age at first joining and ewe genotype on performance of ewes lambing at two years of age. Advances in Animal Biosciences. 7: 075.

Keady, T.W.J., Hanrahan, J.P., Marley, C.L. and Scollan, N.D. 2013. Production and utilisation of ensiled forages by beef cattle, dairy cows, pregnant ewes and finishing lambs – A review. Agricultural and Food Science. 22: 70-92.

Keady, T.W.J. and McNamara, N. 2012. Breeding from ewe lambs – factors affecting performance.  
[https://teagasc.ie/media/website/publications/2012/Breeding\\_from\\_ewe\\_lamb\\_s-factors\\_affecting\\_perfor.pdf](https://teagasc.ie/media/website/publications/2012/Breeding_from_ewe_lamb_s-factors_affecting_perfor.pdf)

Kendall, P.T., Ducker, M.J. and Hemingway, R.G. 1983. Individual intake variation in ewes given feedblock or trough supplements indoors or at winter grazing. Animal Science. 36: 7-19.

Kenyon, P.R. 2013. The use of nutrition to increase sheep performance. *Rev. Client. Prod. Anim.* 15:1 63-76.

Kenyon, P.R. and Blair, H.T. 2014. Foetal programming in sheep – effects on production. *Small Ruminant Research.* 118: 16-30.

Kenyon, P.R., Morris, S.T., Burnham, D.L. and West, D.M. 2008. Effect of nutrition during pregnancy on hogget pregnancy outcome and birth weight and live weight of lambs. *New Zealand Journal of Agricultural Research.* 51: 77-83.

Kenyon, P.R., Morris, S.T, Hickson, R.E, Back, P.J., Ridler, A.L., Stafford, K.J. and West, D.M. 2013. The effects of body condition score and nutrition of triplet-bearing ewes in late pregnancy. *Small Ruminant Research.* 113: 154-161.

Kenyon, P. R., Morris, S.T., Revell, D.K. and McCutcheon, S.N. 2003. Shearing during pregnancy – review of a policy to increase birthweight and survival of lambs in New Zealand pastoral farming systems. *New Zealand Veterinary Journal.* 52: 145-149.

Kenyon, P.R., Stafford, K.J., Jenkinson, C.M.C., Morris, S.T. and West, D.M. 2007. The body composition and metabolic status of twin- and triplet- bearing ewes and their fetuses in late pregnancy. *Livestock Science.* 107: 103–112.

Kidane, A., Houdijk, J.G.M., Athanasiadou, S., Tolkamp, B. and Kyriazakis, I. 2010a. Nutritional sensitivity of periparturient resistance to nematode parasites in two breeds of sheep with different nutrient demands. *British Journal of Nutrition.* 104: 1477-1486.

Kidane, A., Houdijk, J.G.M., Athanasiadou, S., Tolkamp, B.J. and Kyriazakis, I. 2010b. Effects of maternal protein nutrition and subsequent grazing on chicory (*Cichorium intybus*) on parasitism and performance of lambs. *J. Anim. Sci.* 88: 1513-1521.

Kidane, A., Houdijk, J.G.M., Tolkamp, B.J., Athanasiadou, S. and Kyriazakis, I. 2009. Consequences of infection pressure and protein nutrition on periparturient resistance to *Teledorsagia circumcincta* and performance in ewes. *Veterinary Parasitology.* 165: 78-87.

Lawrence, A.B. and Wood-Gush, D.G.M. 1988. Influence of behaviour and utilisation of supplemental feedblocks in Scottish hill sheep. *Animal Production.* 46: 203-212.

Lee, J., Knowles, S.O. and Judson, G.J. 2002. Trace element and vitamin nutrition of grazing sheep. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 285-312.

Lewis, R.M. and Emmans, G.C. 2010. Feed intake of sheep as affected by body weight, breed, sex and feed composition. *J. Anim. Sci.* 88: 467-480.

Liamadis, D. and Milis, C.H. 2007. Significance of quality of truly digestible protein on performance of ewes at late pregnancy and early lactation. *Small Ruminant Research*. 71: 67-74.

Lifetime Wool – [www.lifetimewool.com.au](http://www.lifetimewool.com.au)

LINK. 2012. Estimation of ruminant energy and degradability values for maize silage using near infrared reflectance spectroscopy. Report Project No. LK06894.

Lou, C., Si, B., Deng, K., Ma, T., Jiang, C., Tu, Y., Zhang, N., Ji, S, Chen, D. and Diao, Q. 2015. Energy requirements of Dorper x thin tailed crossbred ewes during non-pregnancy and lactation. *Journal of Integrative Agriculture*. 14: 2605-2617.

Lozano, J.M., Lonergan, P., Boland, M.P. and O'Callaghan, D. 2003. Influence of nutrition on the effectiveness of superovulation programmes in ewes: effect of oocyte quality and post fertilisation development. *Reproduction*. 125: 543-553.

Mackie, R.I., McSweeney, C.S. and Klieve, A.V. 2002. Microbial ecology of the ovine rumen. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 71-94.

MacPherson, A., Fisher, G. and Paterson, J.E. 1988. Effect of cobalt deficiency on the immune function of ruminants. *Trace elements in man and animals*. 6: 397-398.

Mahboub, H.D.H., Ramadan S.G.A., Ragab, A., Darwish, R.A., Mohamed, A., Helal, M.A., Gafaar K.M. and Ashmawny, T.A.M. 2013. Fish oil supplementation and selenium-vitamin E injection of Egyptian ewes and their Finnish Landrace crossbred ewes during late pregnancy: 2. Lambs response. *Assiut Vet. Med. J*. 138: 60.

Marley, C.L., McCalman, H., Buckingham, S., Downes, D. and Abberton, M.T. 2011. A review of the effect of legumes on ewe and cow fertility. *IBERS Legumes and Fertility Review*.

Marquez, G.C., Haresign, W., Davies, M.H., Emmans, G.C., Roehe, R., Bunger, L., Simms, G. and Lewis, R.M. 2012. Index selection in terminal sires improves early lamb growth. *J. Anim. Sci*. 90:1 142-151.

Mathias-Davis, H.C., Shackell, G.H., Greer, G.J., Al Bryant, A.I. and Everett-Hincks, J.M. 2013. Ewe body condition score and the effect on lamb growth rate. *Proceedings of the New Zealand Society of Animal Production*. 73: 131-135.

Maxwell, T.J. and Treacher, T.T. 1987. Decision rules for grassland management. In: *Efficient Sheep Production from Grass* (Ed. G.E. Pollott). BGS Occasional Symposium No 21. 67-78.



McClure, S.J. and Emery, D.L. 2000. Host resistance to gastrointestinal nematodes in sheep. In Ruminant Physiology. CABI International 425-436

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A. and Wilkinson, R.G. 2011. Animal Nutrition. 7<sup>th</sup> Edition. ISBN 978-1-4082-0423-8.

McGovern, F.M., Campion, F P., Lott, S. and Boland, T M. 2015a. Altering ewe nutrition in late gestation: I. The impact on pre- and postpartum ewe performance. J. Anim. Sci. 93: 4860-4872.

McGovern, F.M., Campion, F P., Sweeney, T., Fair, S., Lott, S. and Boland, T M. 2015b. Altering ewe nutrition in late gestation: II. The impact on fetal development and offspring performance. J. Anim. Sci. 93: 4873-4882.

McLean, B.M.L., Frost, D. and Evans, D E. 2002. The use of feed blocks as supplementation for the upland hill flock: (2) Cost effective lamb production. From Powell *et al.*, UK Organic Research 2002: Proceeding of the COR Conference, 26-28 March 2002, Aberystwyth. 279-280.

McNeill, D.M., Slepatis, R., Ehrhardt, R.A., Smith, D.M. and Bell, A.W. 1997. Protein requirements of sheep in late pregnancy: partitioning of nitrogen between the gravid uterus and maternal tissues. J. Anim. Sci. 75: 809-816.

Merrell, B.G. 1998. The effects on lamb survival rate of supplementing ewes with vitamin E during late pregnancy. Proceedings of the Sheep Veterinary Society. Scarborough, Yorkshire. UK. 57-61.

Mitchell, L.M., Robinson, J.J., Watt, R.G., McEvoy, T.G., Ashworth, C.J., Rooke, J.A. and Dwyer, C.M. 2007. Effects of cobalt/ vitamin B<sub>12</sub> status in ewes on ovum development and lamb viability at birth. Reproduction, Fertility and Development. 19:4 553-562.

MLC. 1988. Sheep Improvement Services – Feeding the Ewe.

Mulvaney, F.J., Kenyon, P.R., Morris, S.T. and West, DM. 2008. Ewe lamb nutrition during pregnancy affects pregnancy outcome. Australian Journal of Experimental Agriculture. 48:8 1085-1089.

Muir, P. D., Smith, N. B. Wallace, C. J., Fugle, C. J. and Bown, M. D. 2000. Maximising lamb growth rates. Proceedings of the New Zealand Grassland Association. 62: 55-58.

Newton, J.E. and Davies, D.A. 1987. White clover and sheep production. In: Efficient Sheep Production from Grass (Ed. G.E. Pollott). BGS Occasional Symposium No 21. 79-87.

Nie, H.T., Wan, Y.J., You, J.H., Wang, Z.Y., Lan, S., Fan, Y.X. and Wang.F. 2015. Effect of age on energy requirement for maintenance and growth of Dorper and Hu crossbred F1 ewes weighing 20 to 50 kg. *Asian-Australas J. Anim. Sci.* 28:8 1140-1149.

Nowak, R. and Poindron, P. 2006. From birth to colostrum: early steps leading to lamb survival. *Reprod. Nutr. Dev.* 46: 431-446.

Ocak, N., Cam, M.A. and Kuran, M. 2005. The effect of high dietary protein levels during late gestation on colostrum yield and lamb survival rate in singleton-bearing ewes. *Small Ruminant Research.* 56: 89-94.

O'Doherty, J.V. and Crosby, T.F. 1997. The effect of diet in late pregnancy on colostrum production and immunoglobulin absorption in sheep. *Animal Science.* 64: 87-96.

O'Doherty, J.V. and Crosby, T.F. 1998. Blood metabolite concentrations in late pregnancy ewes in indicators of nutritional status. *Animal Science.* 66: 675-683.

Olfati, A., Moghaddam, G. and Bakhtiari, M. 2013. Diagnosis, treatment and prevention of pregnancy toxemia in ewes. *International Journal of Advanced Biological and Biomedical Research.* 1:11 1452-1456.

Orr, R.J. and Treacher, T.T. 1984. The effect of concentrate level on the intake of hays by ewes in late pregnancy. *Anim. Prod.* 39: 89-98.

Orr, R.J. and Treacher, T.T. 1989. The effect of concentrate level on the intake of grass silages by ewes in late pregnancy. *Anim. Prod.* 48: 109-120.

Orr, R.J. and Treacher, T.T. 1990a. The performance of ewes offered diets containing different proportions of perennial ryegrass and white clover silage in late pregnancy. *Anim. Prod.* 51: 143-153.

Orr, R.J. and Treacher, T.T. 1990b. Intakes of silages, hays and straws by ewes in mid pregnancy. *Anim. Prod.* 51: 301-310.

Orr, R.J., Treacher, T.T. and Mason, V.C. 1985. The effect of ammonia treatment on the intake of straw and hay when offered with rations of concentrates to ewes in late pregnancy. *Anim. Prod.* 40: 101-109.

Paten, A.M., Duncan, E.J., Pain, S.J., Peterson, S.W., Kenyon, P.R., Blair, H.T. and Dearden, P.K. 2015. Functional development of the adult ovine mammary gland – insights from gene expression profiling. *BMC Genomics.* 16: 748. DOI 10.1186/s12864-015-1947-9.

Pickard R. M., Beard, A. P., Seal, C. J. and Edwards, S. A. 2008. Neonatal lamb vigour is improved by feeding docosahexanoic acid in the form of algal biomass during late gestation. *Animal.* 2:8 1186–1192.

Pulina, G., Avondo, M., Molle, G., Francesconi, A.H.D., Atzori, A.S. and Cannas, A. 2013. Models for estimating feed intake in small ruminants. *R. Bras. Zootec.* 42:9 675-690.

Rae, M.T., Palassio, S., Kyle, C.E., Brooks, A.N., Lea, R.G., Miller, D.W. and Rhind, S.M. 2001. Effect of maternal undernutrition during pregnancy on early ovarian development and subsequent follicular development in sheep fetuses. *Reproduction.* 122:6 915-922.

Refshauge, G., Brien, F.D., Hinch, G.N. and van de Ven, R. 2015. Neonatal lamb mortality: factors associated with the death of Australian lambs. *Animal Production Science.* 56:4 726-735.

Reynolds, C. K., Cannon, V. L. and Loerch S. C. 2006. Effects of forage source and supplementation with soybean and marine algal oil on milk fatty acid composition of ewes. *Animal Feed Science and Technology.* 131: 333-357.

Ridler, A.L., Vallee, E., Corner, R.A., Kenyon, P.R. and Heuer, C. 2015. Factors associated with fetal losses in ewe lambs on a New Zealand sheep farm. *New Zealand Veterinary Journal.* 63:6 330-334.

Robinson J.J. 1983. Nutrition Requirements of the breeding ewe. In: *Sheep Production* (Ed. W. Haresign). 111-131. Butterworths, London.

Robinson J.J. 1987. Energy and protein requirements of the ewe. In: *Recent Advances in Animal Nutrition* (Ed. W. Haresign and D.J.A. Cole). 187-204. Butterworths, London.

Robinson J.J. 1990. Nutrition over the winter period – the breeding female. In: *New Developments in Sheep Production* (Ed. C.F.R. Slade and T.F.R. Lawrence), Occasional Publication No. 14 – British Society of Animal Production.55-69.

Robinson, J.J. 2002. Review of nutritional standards for sheep. Invited paper at the British Society of Animal Science Annual Conference, York.

Robinson, J.J., Ashworth, C.J., Rooke, J.A., Mitchell, L.M. and McEvoy, T.G. 2005. Nutrition and fertility in ruminant livestock. *Animal Feed Science and Technology.* 08:006.

Robinson, J.J., Rooke, R.A. and McEvoy, T.G. 2002. Nutrition for conception and pregnancy. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 189-211.

Rooke, J.A., Arnott, G., Dwyer, C.M. and Rutherford, K.M.D. 2015. The importance of the gestation period for welfare of lambs: maternal stressors and lamb vigour and well-being. *Journal of Agricultural Science.* 153:3 497-519.

Rooke, J.A., Matheson, S., Ison, S., Jack, M., Ashworth, C.J. and Dwyer, C.M. 2009. The effect of late pregnancy supplementation of ewes with vitamin E on lamb vigour. *Animal*. 3:11 1555-1561.

Rooke, J.A., Robinson, J.J. and Arthur, J.R. 2004. Effects of vitamin E and selenium on the performance and immune status of ewes and lambs. *Journal of Agricultural Science*. 142: 253-262.

Russell, A.J.F., 1984. Body Condition Scoring of sheep. In *Practice*, 6: 91-93.

Russel, A.J.F. 1984. Means of assessing the adequacy of nutrition of pregnant ewes. *Livestock Production Science*, 11, 429-436.

Rutter, A.M. 2010. Review: Grazing preferences in sheep and cattle: implications for production, the environment and animal welfare. *Can. J. Anim. Sci.* 90: 285-293.

SAC. 2009a. Year Round Feeding the Ewe for Lifetime Production. <http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2013/06/Booklet-Year-Round-Feeding-the-Ewe-for-Lifetime-Production.pdf>

SAC. 2009b. Livestock Information Note – Feedbyte rations for sheep.

Sargison, N. 2008. *Sheep Flock Health*. Blackwell. 1: 99-101.

Sakkas, P., Houdijk, J.G.M., Athanasiadou, S. and Kyriazakis, I. 2012. Sensitivity of peri-parturient breakdown of immunity to parasites to dietary protein source. *J. Anim. Sci.* 90: 3954-3962.

SCOPS. 2012. Sustainable worm control strategies for sheep – a technical manual for veterinary surgeons and advisers. <http://www.scops.org.uk/content/SCOPS-Technical-Manual-4th-Edition-updated-September-2013.pdf>

Sefdeen, S, Mackenzie, A.M. and Wilkinson, R.G. 2016. Effect of dietary iron with and without sulphur on copper metabolism in sheep. *Advances in Animal Biosciences*. 7: 073.

Sen, U., Sirin, E. and Kuran, M. 2013. The effect of maternal nutritional status during mid-gestation on placental characteristics in ewes. *Animal Reproduction Science*. 137: 31-36.

Slade, C.F.R. and Stubbings, L.A. 1994. Sheep Housing. In: *Livestock Housing*. CABI International.13: 359-378

Speedy, A.W. and Bazely, D. 1987. Grass as feed for sheep – its potential and limitations. In: *Efficient Sheep Production from Grass* (Ed. G.E. Pollott). BGS Occasional Symposium No 21. 29-48.

Speijers, M.H.M., Fraser, M.D., Haresign, W., Theobald, V.J. and Moorby, J.M. 2005. Effects of ensiled forage legumes on performance of twin-bearing ewes and their progeny. *Animal Science*. 81:2 271-282.

Stryker, J.A., Fisher, R., You, Q., Or-Rashid, M.M., Boermans H.J., Quinton, M., McBride, B.W. and Karrow, N.A. 2013. Effects of dietary fishmeal and soya bean meal on the ovine innate and acquired immune response during pregnancy and lactation. *Animal*. 7:1 151-159.

Stubbings, L.A. 2014. Ewe nutrition – what are the known ‘unknowns’. *Advances in Animal Biosciences*. 5: 012.

Stubbings, L.A. and Maund, B.A. 1988. Effects on fecundity of sheep of immunization against androstenedione. *Vet Rec*. 123: 489-92.

Suttle, N.F. 2010. *Mineral Nutrition of Livestock*, 4<sup>th</sup> Edition. ISBN 978-1-84593-472-9.

Sykes, A.R 2010. Host Immune responses to nematodes. *R. Bras Zootec*. 39: supplement.



Sykes, A. R. and Kyriazakis, I. 2007. Opportunities to control herbivore nematodes through manipulation of the grazing environment. In: *Herbivore nutrition for the development of efficient, safe and sustainable livestock production*. 329–353.

Tolman, B. and McKusick, B.C. 2001. The effect of growth rate on mammary gland development in ewe lambs: a review. *Proceedings of the 7<sup>th</sup> Great Lakes Dairy Sheep Symposium*.

[www.dsana.org/resources/proceedings/7proceedings2001.pdf](http://www.dsana.org/resources/proceedings/7proceedings2001.pdf)

Treacher, T.T. 1990. Grazing management and supplementation for the lowland sheep flock. In: *New Developments in Sheep Production* (Ed. C.F.R. Slade and T.F.R. Lawrence), Occasional Publication No. 14 – British Society of Animal Production. 45-54.

Treacher, T.T. and Caja, G. 2002. Nutrition during lactation. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 213-236.

Van Burgel, A.J., Oldham, C.M., Behrendt, R., Curnow, M., Gordon, D.J. and Thompson, A.N. 2011. The merit of condition score and fat score as alternatives to live weight for managing the nutrition ewes. *Animal Production Science*. 51: 834-841.

Van Emon, M.L., Schauer, C.S., Lekatz, L.A., Eckerman, S.R., Maddock-Carlin, K. and Vonnahme, K.A. 2014. Supplementing metabolisable protein to ewes during late gestation: 1. Effects on ewe performance and offspring performance from birth to weaning. *J. Anim. Sci*. 92: 339-348.

Villeneuve, L., Cinq-Mars, D. and Lacasse, P. 2010. Effects of restricted feeding of prepubertal ewe lambs on growth performance and mammary gland development. *Animal*. 4:6 944-950.

Vipond, J. E., King, M.E., Inglis, D. M. and Hunter, E. A. 1987. The effect of winter shearing of housed pregnant ewes on food intake and animal performance. *Animal Production*. 45: 211–221.

West, D.M., Pomroy, W.E. and Kenyon, P.R. 2009. Estimating the cost of subclinical parasitism in grazing ewes. *Small Ruminant Research*, 86: 84-86.

Weston, R.H. 2002. Constraints on feed intake by grazing sheep. In: *Sheep Nutrition* (Ed. M Freer and H Dove). ISBN 0-85199-595-0. 27-49.

Wilkinson, R.G., Gauld, C., Mackenzie, A.M., Pattinson, S.E. and Donaldson, J. 2015. Effect of level and source of protein supply on the performance of ewes during late pregnancy and early lactation. *Advances in Animal Biosciences*. 6: 158.

Wilkinson, R.G. and Houdijk, J.G.M. 2016. Should we feed more metabolisable protein to pregnant and lactating ewes? *Advances in Animal Biosciences*. 7: 164.

Wilkinson, R.G., Naylor, N., Mackenzie, A.M., Pattinson, S.E. and Donaldson, J. 2014. Effect of forage type and level and source of DUP supply on ewe and lamb performance. *Advances in Animal Biosciences*. 5: 018.

Wilkinson, R.G., Naylor, N., Mackenzie, A.M., Pattinson, S.E. and Donaldson, J. 2016. Effect of nutritional restriction in mid-pregnancy on the response of ewes to additional protein supply in late pregnancy and lactation. *Advances in Animal Biosciences*. 7: 017.

Wilkinson, R.G., Sinclair, L.A., Powles, J. and Minter, C.M. 2000. Response of lactating ewes grazing grass to variations in effective rumen degradable protein supply from concentrate supplements. *Animal Science*. 71: 369-379.

Wright, N., Sinclair, K., Kendall, N., Stubbings, L. and Genever, E. 2016. Ewe body condition scoring (BCS) as a key performance indicator on commercial sheep flocks: lamb performance to weaning. *Advances in Animal Biosciences*. 7: 016.

Yart, L., Lollivier, V., Marnet, P.G. and Dessauge, F. 2014. Role of ovarian secretions in mammary gland development and function in ruminants. *Animal*. 8:1 72-85.

Zaralis, K., Tolkamp, B.J., Houdijk, J.G.M., Wylie, A.R.G. and Kyriazakis, I. 2009. Consequences of protein supplementation for anorexia, expression of immunity and plasma leptin concentrations in parasitized ewes of two breeds. *British Journal of Nutrition*. 101: 499-509.

## Appendix 1. Feed Database – Proximate Composition (Ewing, 1997)

**NOTE:** All analyses are expressed on a dry matter basis. DM is g/kg, and ME and FME is MJ/kg DM. All other units are g/kg DM.

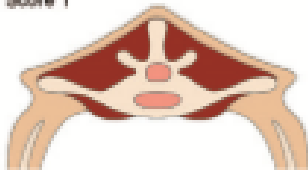
| Name                          | DM  | ME   | FME  | ERDP @<br>0.2 flow | DUP @<br>0.2 flow | ERDP @<br>0.5 flow | DUP @<br>0.5 flow | ERDP @<br>0.8 flow | DUP @<br>0.8 flow |
|-------------------------------|-----|------|------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| Grass Silage (clamp, chopped) | 300 | 11.0 | 8.0  | 100                | 5                 | 95                 | 10                | 90                 | 15                |
| Grass Silage (big bale)       | 350 | 10.5 | 8.0  | 75                 | 27                | 74                 | 30                | 72                 | 33                |
| Maize Silage                  | 300 | 11.5 | 10.1 | 70                 | 13                | 67                 | 16                | 65                 | 19                |
| Whole Crop Silage             | 400 | 10.5 | 8.5  | 60                 | 12                | 55                 | 15                | 52                 | 18                |
| Hay                           | 870 | 8.5  | 8.1  | 70                 | 20                | 56                 | 35                | 50                 | 50                |
| Straw                         | 870 | 6.5  | 6.0  | 16                 | 14                | 14                 | 17                | 13                 | 18                |
| Barley                        | 860 | 13.2 | 11.0 | 105                | 8                 | 96                 | 16                | 93                 | 18                |
| Wheat                         | 860 | 13.8 | 12.8 | 107                | 7                 | 103                | 11                | 99                 | 14                |
| Oats                          | 860 | 12.2 | 10.0 | 103                | 4                 | 99                 | 6                 | 97                 | 8                 |
| Maize                         | 890 | 14.5 | 12.8 | 80                 | 10                | 72                 | 17                | 70                 | 23                |
| Molassed Sugar Beet Pulp      | 900 | 12.5 | 12.3 | 64                 | 26                | 49                 | 38                | 45                 | 45                |
| Molasses                      | 750 | 12.7 | 12.2 | -                  | -                 | -                  | -                 | -                  | -                 |
| Beans                         | 860 | 14.0 | 12.7 | 250                | 15                | 235                | 30                | 225                | 39                |
| Soya Bean Meal                | 900 | 13.6 | 12.7 | 421                | 106               | 325                | 140               | 265                | 245               |
| Rape Seed Meal                | 880 | 12.1 | 10.5 | 301                | 41                | 262                | 69                | 235                | 89                |
| Distillers Dark Grain Wheat*  | 900 | 13.7 | 11.0 | 267                | 165               | 255                | 250               | 249                | 265               |
| Ewe Concentrate 18% protein   | 860 | 12.5 | 10.2 | 138                | 24                | 125                | 35                | 112                | 45                |
| Ewe Concentrate 20% protein   | 860 | 12.5 | 10.2 | 150                | 25                | 140                | 38                | 130                | 48                |

\*analysis very variable depending on product source

## Appendix 2. Body Condition Scoring (AHDB, 2013a)

### How to Condition Score

Score 1



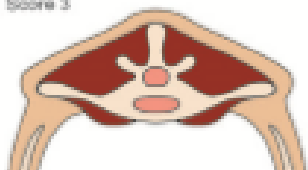
The vertical and horizontal processes are prominent and sharp. The fingers can be pushed easily below the transverse and each process can be felt. The loin is thin with no fat cover.

Score 2



The vertical processes are prominent but smooth; individual processes being felt only as corrugations. The horizontal processes are smooth and rounded, but it is still possible to press fingers under. The loin muscle is a moderate depth but with little fat cover.

Score 3



The vertical processes are smooth and rounded; the bone is only felt with pressure. The horizontal processes are also smooth and well covered; hard pressure is required with the fingers to find the ends. The loin muscle is full and with a moderate fat cover.

Score 4



The vertical processes are only detectable as a line. The ends of the horizontal processes cannot be felt. The loin muscles are full and rounded, and have a thick covering of fat.

Score 5



The vertical and transverse processes cannot be detected even with pressure; there is a dimple in the fat layers where the processes should be. The loin muscles are very full and covered with very thick fat.



**Appendix 3. Guide to Estimated Ewe Mature Live Weights by UK Breed (SAC, 2009b)**

| <b>Ewe Breed</b>      | <b>Live Weight Kg</b> | <b>Ewe Breed</b>          | <b>Live Weight kg</b> |
|-----------------------|-----------------------|---------------------------|-----------------------|
| Aberdale              | 60 – 80 *             | Mule North of England     | 75 – 80               |
| Aberfield             | 65 – 80*              | Mule Scotch               | 70                    |
| Beltex                | 65                    | Oxford Down               | 90                    |
| Berrichon du Cher     | 90                    | Romney Marsh              | 70 -75                |
| Beulah Speckled Face  | 55                    | Rouge de L'Ouest          | 75 – 100              |
| Bleu de Maine         | 45                    | Rough Fell                | 50                    |
| Bluefaced Leicester   | 80                    | Scottish Blackface Hill   | 50 – 60               |
| Border Leicester      | 80 -100               | Scottish Blackface Upland | 70                    |
| Cambridge             | 75                    | Scottish Halfbred         | 85 – 100              |
| Charollais            | 80 -100               | Scottish Greyface         | 60 – 90               |
| Cheviot South Country | 50 – 55               | Shropshire                | 80                    |
| Cheviot North Country | 75 – 90               | Southdown                 | 65 – 70               |
| Clun Forest           | 60                    | Suffolk                   | 85                    |
| Dalesbred             | 45 – 60               | Swaledale                 | 45 – 55               |
| Dartmoor              | 65                    | Texel                     | 85                    |
| Devon Closewool       | 55 – 60               | Vendeen                   | 65 – 80               |
| Dorset Down           | 80                    | Welsh Halfbred            | 55 – 60               |
| Dorset Poll and Horn  | 85                    | Welsh Mountain Hill       | 35 – 40               |
| Est a Laine Merino    | 90 -110               | Welsh Mountain Upland     | 45 – 50               |
| Friesland             | 50 – 55               | Wensleydale               | 115                   |
| Hampshire Down        | 80                    |                           |                       |
| Herdwick              | 35 – 45               | Meatlinc                  | 90 -100               |
| Jacob                 | 60 – 65               | Suffolk cross             | 80 – 85               |
| Leicester Longwool    | 95 – 100              | Continental cross         | 80 - 85               |
| Lleyn                 | 60 – 75               |                           |                       |
| Masham                | 75                    |                           |                       |

\*Depending on breed of dam.