Agri-Food and Biosciences Institute ®

# Pace-Setter Project Lamb

## Research to develop a more sustainable lamb supply chain

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# RESEARCH TO DEVELOP A MORE SUSTAINABLE LAMB SUPPLY CHAIN

A REPORT PREPARED BY:

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## EXECUTIVE SUMMARY

Over the past 10 years there have been growing concerns over the sustainability of UK lamb production, with producers rapidly exiting the industry and production declining year on year. To help address this issue, a study was commissioned by Marks and Spencer PLC, with assistance from Linden Foods, to investigate the merits of using Highlander and Primera genetics in UK sheep flocks as a means to develop a more sustainable lamb supply chain and to maximize value within the supply chain through increasing lamb output, improving welfare, reducing production and processing costs and delivering environmental benefits in terms of carbon emissions, while ensuring lambs remain within retail specification and deliver a consistently high quality eating experience.

The study was undertaken jointly by the Agri-Food and Biosciences Institute (AFBI) and the College of Agriculture, Food and Rural Enterprise (CAFRE), both based in Northern Ireland. The work was undertaken on two upland flocks belonging to the Buccleuch Group, based in southern Scotland and currently a multiplier for Rissington Breedline Ltd (now Focus Genetics). A 'typical' UK production system was represented by Mule and Texel X Mule ewes, which were evaluated alongside Highlander and Highlander X Blackface ewes to represent different replacement breeding strategies for upland/lowland flocks. These ewes were crossed with Texel rams, representing a typical UK terminal sire breed, as well as UK-bred Primera and New Zealand-bred Primera rams, the latter being selected from the top 10% performance-recorded rams in the Primera Nucleus flock. Performance of these breeds was evaluated throughout the production and processing cycle, finishing with an evaluation of meat eating quality using consumer taste panels.

The key findings from this study are as follows:

### LAMB OUTPUT AND PRODUCTION EFFICIENCY

1. Highlander and Highlander X Blackface ewes were around 8 kg lighter than Mules, which equates to a reduction in feed requirements of approximately 17%. Highlander X Blackface ewes also maintained their body condition score better than Mules.

2. Fertility performance overall was excellent with ewes rearing 1.69 lambs per ewe put to the ram. Within the trial flock, Highlander ewes reared an extra 0.19 lambs compared with Mules. Highlander X Blackface ewes tended to rear fewer lambs than Mule ewes but their level of efficiency, in terms of lamb output per kilogram of ewe body weight, was similar.

3. Higher growth rates in Primera-sired lambs were evident from as early as 6 weeks old and ultimately reduced age at slaughter by up to 18 days compared with Texel-sired lambs.

4. Compared with a typical indoor lambing flock (Mule ewes crossed with Texel rams), there was evidence of higher growth performance and lower labour inputs when the Focus Genetics

Production Model (Highlander-cross ewes with Primera rams) was utilized for outdoor lambing.

## Welfare

5. Highlander X Blackface ewes required the lowest level of lambing intervention (6.8%), followed by Texel X Mule (9.5%), Highlander (13.9%) and Mule (16.8%). Overall, the levels of intervention recorded were below average for a flock of this type (typically 20-40% ewes assisted). Requirements for lambing assistance were similar for Primera and Texel rams.

6. There were no differences in lamb mortality between any of the breeds studied. Mortality rates were also similar when the Focus Genetics Production Model (Highlander-cross ewes with Primera rams) lambing outdoors was compared with a typical indoor lambing flock (Mule ewes crossed with Texel rams).

7. A high proportion of Highlander X Blackface ewes presented problems with flightiness and limited colostrum availability, which could be an indicator of increased stress within indoor lambing systems. However there was no evidence that this had a detrimental effect on their subsequent performance.

## Carcass quality and consistency of specification

8. When finished at the same carcass weight, there was no difference in the carcass conformation (assessed on the EUROP scale) or carcass value of lambs coming from Mule, Highlander or Highlander X Blackface ewes. Inclusion of terminal sire genes in the Texel X Mule ewes led to superior carcass conformation in their offspring, which was worth an extra 10 p/kg compared with the other dam breeds.

9. Lambs born to Highlander X Blackface dams matured earlier than those from Highlander dams, reaching fat class 3L at approximately 19 kg carcass weight (compared with just over 20 kg for Highlander dams). Rearing these lambs to heavier carcass weights will result in a high proportion of over-fat lambs, leading to greater price penalties.

10. Carcasses from Primera-sired lambs had slightly poorer conformation (assessed on the EUROP scale) and were marginally fatter than Texel-sired lambs at the same carcass weight, equating to a 6 p/kg price penalty at the abattoir. At the same fat class (3L), 1.4% Texel-sired lambs achieved O conformation grades compared with 9.1% Primera-sired lambs.

11. Apart from carcass conformation (assessed on the EUROP scale), which tended to be better for UK-bred Primera versus NZ-bred Primera lambs, there was no difference in performance between these two groups.

## ON-FARM PRODUCTION COSTS

12. The lower labour requirements with Highlander X Blackface at lambing amounted to a 7% reduction in annual labour inputs compared with Mules, although labour costs per kilogram of carcass were the same

13. Switching from Mule to Highlander ewes reduced production costs of lamb (including labour) by 55 p/kg, due mainly to their superior lamb output. Switching to Highlander X Blackface or Texel X Mules increased production costs by 19 and 64 p/kg respectively.

14. Switching from Texel to Primera rams had minimal impact on production costs (- 1 p/kg carcass weight).

## CARBON EMISSIONS ON-FARM

15. Using Highlander X Blackface ewes reduced greenhouse gas emissions from the 1350 ewe flock by more than 47 t $CO_2$-e/year compared with Mule ewes. However, only Highlander ewes were successful in reducing emissions intensity (-1.57 kg $CO_2$-e/kg carcass) relative to Mules due to their superior lamb output. When compared with Texel rams, UK-bred and NZ-bred Primera rams reduced GHG emissions by 0.22 and 0.26 kg $CO_2$-e/kg carcass respectively.

## PROCESSING EFFICIENCY

16. At the same carcass weight, carcasses from Primera-sired lambs yielded marginally higher proportions of the higher price cuts (rack and loin) compared with Texel-sired lambs, but lower proportions of shoulder and leg. This had the potential to increase the wholesale value of carcasses by almost 1% (£1.20 or 6 p/kg)

17. The main disadvantage with Primera-sired lambs was that just over 40% did not meet M&S retail specifications for conformation (E, U and R grades) and fat (fat class 2 and 3L) when slaughtered at 19 kg carcass weight, compared with less than 20% Texel-sired lambs. Thus the actual average wholesale value of Primera carcasses was up to 4% (£5.37 or 28 p/kg) lower than those of Texel carcasses. The primary reason for lambs falling outside M&S spec was because they were marginally overfat (14% Texel lambs and 24% Primera lambs were fat class 3H).

18. Dam breed also had a small but significant effect on meat distribution within the carcass. At the same weight, carcasses from Texel X Mule dams yielded a higher proportion of leg meat but a lower proportion of saddle compared with the other ewe breeds. While this tended to put pressure on wholesale value, over 90% lambs from Texel X Mule ewes reached target specification compared with around 80% for the other dam breed, making carcasses from Texel X Mule ewes worth £2.82 (15 p/kg) more than those from Mule ewes. In general,

carcasses from Highlander-type ewes yielded heavier rack and loin weights compared with Mule types, increasing wholesale value by up to £1.75 (9 p/kg).

## Meat eating quality

19. Inclusion of Texel genes, either in the dam (Texel X Mule) or sire, resulted in a greater eye muscle area in the loin chops, potentially making them more attractive to the consumer.

20. Instrumental meat quality analysis indicated that UK-bred Primera sires produced the most tender meat, followed by Texel and NZ-bred Primeras. There were also small but significant differences between dam breeds in terms of ultimate pH, lightness and hue (colour). However all of the values observed were within the range considered acceptable to consumers.

21. When assessed by taste panels, the only noticeable difference reported for eating quality was a lower juiciness score, and subsequently lower overall liking score, for NZ-bred Primera-sired lambs compared with the other sire breeds. However all of the breeds scored well in terms of customer satisfaction, with scores tending towards a rating of better than everyday quality.

## Supply chain sustainability

Overall, increasing lamb output and production efficiency by switching from Mule to Highlander ewes offers the best opportunity to develop a more sustainable lamb supply chain through reducing on-farm production costs and greenhouse gas emissions, while maintaining product quality, processing efficiency and meat eating quality. Replacing Texel rams with Primera has minimal impact at farm or retailer level. However, for processors, Primera-sired lambs are potentially less efficient than Texel-sired lambs due to their higher fat cover and, to a lesser extent, poorer conformation if assessed using the EUROP scale.

# 1. BACKGROUND TO THE SUSTAINABLE LAMB PROJECT

*Steve McLean, Head of Agriculture & Fisheries Sourcing, Marks & Spencer PLC*

For a number of years, due to the commercial volatility of UK lamb production, the industry has seen increasing numbers of producers leave the industry. Over the last 7 years, M&S, Focus Genetics (formally Rissington Breedline (RBL)) and a number of individual farmers have been involved in a project to replicate RBL's successful New Zealand lamb production system in the UK. Initial feedback from UK producers recognised that the RBL model, , while delivering clear cost of production savings to many producers, identified a number of issues that could make wider roll out in the UK unattractive and, in some instances, could be making lamb production less commercially sustainable than standard UK systems. The main issue highlighted by producers and processors with the existing programme is a perceived reduction in carcase conformation (too many 'O' grade lambs which fall outside of UK retail procurement specification) which is claimed to have resulted in a drop in farm-gate returns, in many instances by a greater amount than the cost of production savings.

UK Lamb production continues to fall year on year and there is a growing and real need to identify and commercialise a more sustainable production model in order to safeguard the continuity of M&S supply. Many of the elements of the RBL model are recognised by UK producers as being industry leading and to have the potential, through fine tuning and further genetic selection, to address carcase conformation issues, to deliver a sustainable model that reduces farm inputs, is more resource efficient whilst producing a product that hits UK retail carcass specification, and is more consistent in terms of quality than product produced through standard UK production systems.

The M&S 'Sustainable Lamb Production' Project was funded by M&S to provide baseline information on the effectiveness of the Rissington Breedline model in the UK to quantify the benefits and allow producers to make an informed choice on their production model. M&S recognise that there are many different systems for lamb production in the UK and with many different breeds and cross-breeds resulting from the UK's stratified sheep industry. This project was established to validate marketing claims made and to assess whether the RBL model was capable of delivering a sustainable production system that would benefit UK producers.

This project was established to work with commercial sheep producers, who are recognised by the UK industry as being inspirational and who operate a range of different farm types in different geographical locations, and Focus Genetics NZ, our chosen breeding company partner to supply Primera genetics suitable for the UK market. The Agri-Food & Biosciences Institute (AFBI) and College of Agriculture, Food & Rural Enterprise (CAFRE), both based in Northern Ireland, were appointed to manage, monitor and independently evaluate the project work-streams and to provide an independent assessment on the options for full commercialisation should the trial prove successful.

## 2. AIMS AND OBJECTIVES

The Sustainable Lamb Project had eight specific objectives:

1. To import improved conformation Primera rams from New Zealand to be used on participating farms in a controlled manner alongside the existing stock of Primera Rams and other UK terminal sires.

2. To independently assess carcass grade and yield of lambs born from Primera sires (taking into account the different dam lines of Highlander and Mule) taking into account both farm-gate and processor returns and the fact that M&S retail carcass specification is for grades E, U & R at fat class 2 & 3L.

3. To identify cost of production of Primera and Highlander genetics and to establish baseline performance and financial data to monitor business efficiency and carbon benefits of systems currently in place.

4. To establish the environmental and carbon efficiency benefits as marketed by Rissington Breedline to UK producers.

5. To identify the eating quality benefits (tenderness, succulence & flavour) of lambs produced from improved-conformation Primera rams mated to Highlander ewes in comparison to lambs sired by the standard Primera and other UK sire breeds.

6. To identify the consistency of specification achieved from improved-conformation Primera, standard Primera and other UK sires on Highlander ewes.

7. To identify the welfare benefits/issues of the easier-care system that Rissington Breedline promotes.

8. To share the findings identified with the wider sheep farming community to enable producers make informed decisions on future production models.

## 3. Background to the farms involved in the Sustainable Lamb Project

The study was carried out in Scotland on two estate farms belonging to the Duke of Buccleuch.

### 3.1 Queensberry

The Queensberry Estate is situated along the valley of the River Nith just outside the village of Thornhill, Dumfriesshire. Its focal point is the sandstone-clad Drumlanrig Castle which was built by Sir James Douglas of Drumlanrig between 1679-1691. The estate extends to a total of 34,500 ha, rising from 50 m to 800 m above sea level on a range of soil types from alluvial loams to heavy clays. Around 3,400 ha are managed directly by the Estate.

The farm at Queensberry supports three main enterprises: beef finishing, hill and lowland sheep and arable crops. The beef finishing enterprise consists of 400 spring-born store cattle (Aberdeen Angus, Charolais, Shorthorn and Galloway) bred on the Bowhill Estate at Selkirk. After their second grazing season the cattle are finished indoors on rations based predominantly on home-produced feedstuffs, including grass silage, cereals and spring beans. The beef enterprise is run by one full time stock person plus one tractor driver who is responsible for TMR feeding and bedding. All other work (slurry spreading, silage harvesting, etc) is undertaken by a local contractor.

The lowland sheep flock consists of 3000 Texel, Mule and Highlander-cross ewes, most of which are mated to Texel and Suffolk rams to produce quality lambs for slaughter. The main flock commences lambing in mid-March with ewes and lambs being turned out to grass as soon as possible after lambing. In recent years, an easy-care flock of Highlander ewes mated to Primera rams has been established for outdoor lambing in mid-April. All lambs are finished off grass with kale being grown for fattening lambs at the end of the season. The Estate's 3,000 Scottish Blackface ewes are managed in two hill flocks. The ewes are bred mainly to Scottish Blackface rams although some Texel rams are also used. Ewes come off the hills onto in-bye land for lambing outdoors in mid-April, but return to the hills when the lambs are stronger. The lambs remain on the higher ground until autumn, when they are moved to lower ground for finishing on grass and kale. The three sheep flocks are managed by three full time shepherds, with veterinary students recruited during March and April to provide extra help at lambing. When the lowland flock is housed, total mixed ration (TMR) feeding and bedding of the ewes is undertaken by beef unit staff.

Approximately 400 ha of the better quality arable land is used for growing cereals, predominantly barley, wheat, oilseed rape and spring beans. The barley and wheat are harvested mainly for use in the beef enterprise, although a proportion of the wheat crop is ensiled for finishing cattle. The barley straw is used entirely for feeding and bedding. The oilseed rape and some of the beans are sold, while the remainder of the bean crop is used for feed. This enterprise currently employs one full time tractor driver who also helps with the feeding. Combining, spraying and sowing operations are undertaken by contractors.

In July 2011, a decision was taken by Buccleuch Group to cease its in-hand farming operations at the Queensberry Estate and lease the land.

## 3.2 Bowhill

The Bowhill Estate spans the valleys of the Ettrick and Yarrow rivers in the Scottish Borders. The focal point of the Estate is Bowhill Country House, 2 miles outside the town of Selkirk, home to the Duke of Buccleuch and housing a large proportion of the renowned Buccleuch art collection. The present house dates mainly from 1812 with little now remaining of the original house built in 1708. The Estate itself extends to approximately 25,500 ha in total, with 4217 ha managed directly by the Estate.

The farm at Bowhill comprises a number of enterprises including a pedigree herd of Aberdeen Angus cattle, a commercial suckler cow enterprise, hill and lowland sheep flocks, a free-range egg business and a small arable enterprise. The 150 strong “Eildon” herd is one of Scotland’s leading Aberdeen Angus herds. All progeny from the herd are performance recorded through Breedplan, with the top-performing bulls exhibited at local and national agricultural shows and breed society sales. Alongside the pedigree herd, the Estate also runs a commercial suckler cow herd comprising 370 Aberdeen Angus and Beef Shorthorn cows. The best performing cows are criss-crossed with

Aberdeen Angus and Beef Shorthorn bulls to produce easy-managed replacement heifers, while the remainder are crossed with Aberdeen Angus and Charolais bulls to produce prime beef cattle. After weaning, all non-breeding stock are moved to the Queensberry Estate for finishing. The suckler enterprise is managed by three full time stock persons plus two tractor drivers who are responsible for TMR feeding and bedding. Slurry spreading and silage harvesting is undertaken jointly by farm staff and a local contractor.

The lowland sheep flock consists of 1277 Texel, Mule and Highlander-cross ewes, which are mated to Texel and Primera rams. The flock is also a Highlander multiplier flock, producing around 100 purebred Highlander rams each year for use on flocks around Scotland as well as the Estate itself. The ewes are lambed indoors from early March, with ewes and lambs turned out to grass as soon as possible after lambing. All lambs are finished off grass and sold to Marks and Spencer through Scotbeef in Stirling. Bowhill's 2890 Scottish Blackface ewes are used to manage extensive areas of grouse moorland on the Estate. The ewes are mainly bred to Scottish Blackface rams and come off the hills for lambing in early April. Surplus Blackface lambs are moved onto lowland areas after weaning for finishing on grass and kale. The sheep flocks are managed by three full time shepherds, with casual staff being recruited to provide extra help at lambing and marking. TMR feeding and bedding of the ewes is undertaken by staff from the suckler cow enterprise.

The Freedom Foods-accredited free range egg business houses 32,000 free range hens and is managed by two full time members of staff. Approximately 40 ha of spring barley are grown each year to supply cereals and straw for the suckler cow and sheep enterprises and a further 45 ha of kale is grown for fattening lambs and outwintering the suckler cows.

*(Photos courtesy of Buccleuch Group)*

# 4. MATERIALS AND METHODS

## 4.1 ANIMALS

The study was undertaken using a total of 1350 ewes - 900 at Queensberry and 450 at Bowhill - all of known age and breed. The ewes were a mixture of 18-month old and adult sheep, predominantly Blue-faced Leicester X Scottish Blackface (more commonly called the 'Mule', **M**) and Highlander X Scottish Blackface (**HB**), with some Texel X Mule (**TM**) and purebred Highlander (**H**) ewes in the Queensberry and Bowhill flocks respectively. Details of the breed and age structure of the two trial flocks are presented in Table 1.

Two ram breeds were investigated in the study: Texel (**T**), the most common terminal sire breed within the UK sheep industry, and Primera (**P**), a composite terminal sire breed developed in New Zealand by Rissington Breedline Ltd (now Focus Genetics). The Texel rams used in the trial were bred within the pedigree Texel flocks at Queensberry and Bowhill. All of the Texel rams were sired by performance recorded rams with above average Estimated Breeding Values (**EBVs**) for growth and muscling, but the rams themselves were not performance recorded. Two contrasting strains of Primera rams were investigated. UK-bred Primera (**$P_{UK}$**) were produced from Focus Genetics Nucleus and Multiplier flocks in the UK. Their dams were either embryos imported from the New Zealand Nucleus, or the daughters of these ewes. Their sires were UK born rams that had been selected based on the EBVs of their parents within the NZ nucleus, but were not themselves performance recorded. The NZ-bred Primera (**$P_{NZ}$**) were selected from the top 10% rams within the Primera Nucleus flock in New Zealand, where selection was based on EBVs, growth performance, muscle scanning and progeny testing. Assessment of visual conformation was also undertaken when selecting rams for use in the trial In total, 9 rams of each breed were evaluated across the two flocks - 6 per breed at Queensberry (N=18) and 3 per breed at Bowhill (N=9), giving a total of 27 rams used in the trial.

## 4.2 EXPERIMENTAL DESIGN

On 11th and 12th October 2010 (approximately two weeks prior to mating), ewes were allocated to six experimental groups on each farm, in a 3 x 3 (ram breed x ewe breed) factorial design experiment, balanced for age, live weight (**LW**) and body condition score (**BCS**) of the ewes. Within each experimental group, ewes were further divided into mating groups of 50 ewes, each group also balanced for age, LW and BCS.

Ewes were joined with the rams in single sire mating groups of 50 ewes per ram, enabling the parentage of all lambs to be established. Unfortunately one of the UKP rams at Bowhill developed locomotion problems within a few days of joining his mating group, and there were concerns over the semen quality from another UKP ram at Queensberry. These ewes were subsequently divided at random between the remaining UKP rams on each farm. Mating commenced in both flocks on 26th October 2010 with the aim of commencing lambing around 22nd March 2011. After 2 mating cycles (35 days), single sire mating groups were randomly amalgamated into mob groups of 150 ewes plus a 3 ram team, all of the same breed, as a safeguard against ram fertility issues and for ease of grazing management.

## 4.3 Flock management

### 4.3.1 Nutrition

Ewes were grazed on permanent pasture from mating until housing. Heavy snowfall in the east of Scotland resulted in difficult grazing conditions at Bowhill during December 2010 and January 2011 so these ewes were supplemented with hay plus molasses-based licks prior to housing. Ewes were scanned on 6th and 13th January. After scanning, the twin and triplet-bearing ewes at Queensberry were housed in a 'lean-to' shed in groups of 30-40 ewes per pen and remained there until after lambing. The single-bearing ewes remained outdoors on kale, with grass silage provided in feeding trailers, until the start of lambing. At Bowhill, twin and triplet-bearing ewes were housed in polytunnels immediately after scanning, in groups of 20-30 ewes per pen.

At both sites, ewes were bedded with barley straw and received a total mixed ration (TMR) once daily. From 6 weeks pre-lambing until lambing, the twin and triplet-bearing ewes at Queensberry were fed a basal TMR supplying 2.0 kg grass silage, 1.0 kg wholecrop silage, 0.35 kg barley, 0.05 kg field beans and 0.03 kg minerals per head per day. The balance of their nutrient requirements were met by feeding purchased concentrates (18% crude protein) as a 'top-up' to the TMR. Twins initially received 0.1 kg/ewe/day concentrates from 5-6 weeks pre-lambing, increasing to 0.2 kg/ewe/day from 3-4 weeks pre-lambing and 0.4 kg/ewe/day thereafter. Corresponding feeding levels for the triplet-bearing ewes were 0.2, 0.4 and 0.7 kg/ewe/day respectively. For the final 2 weeks of pregnancy, the quantity of barley and field beans offered through the TMR were also increased to 0.40 and 0.08 kg/ewe/day respectively.

At Bowhill, single-bearing ewes were fed grass silage only while the twin and triplet-bearing ewes were fed a basal TMR supplying 3.5 kg grass silage plus 1.05 kg concentrates per head. Triplet-bearing ewes received an additional top-up of concentrates, beginning at 0.2 kg/ewe/day at 6 weeks pre-lambing, and increasing weekly by 0.1 kg/day to a maximum of 0.7 kg/ewe/day. The concentrates comprised a mixture of barley (335 kg/t), oats (335 kg/t), soya bean meal (115 kg/t), sugar beet pulp (115 kg/t), molasses (75 kg/t) and minerals (25 kg/t). The level of concentrate feeding at Bowhill was higher than in previous years due to difficult silage-making conditions in 2010 which impacted on silage quality. Details of the nutritive value of the grass and wholecrop

*Sheep accommodation at the Queensberry Estate*

silages fed to the ewes are outlined in Table 2. On both farms the feeding and bedding operations were undertaken using a diet feeder and straw chopper shared with the cattle enterprises.

Individual lambing pens were set-up in the sheep pens during the lambing period. Shortly after lambing, ewes were moved to the lambing pen for 24-48 hours to aid bonding, before being turned out to pasture. The policy at Bowhill was to turn out no more than two lambs with each ewe, hence triplets and quads were either fostered to ewes suckling a single lamb or reared artificially when no foster ewes were available. While the aim was to cease feeding concentrates to the ewes after being turned out to pasture, a small quantity of turnips plus concentrates were fed to the Bowhill ewes immediately after turnout due to a grass shortage. Minerals were supplied at pasture using free-access licks.

Lambs received a selenium and cobalt drench at weaning and thereafter were finished predominantly on grazed grass without additional concentrate supplements being fed. At Bowhill, the lambs were moved onto kale w/c 24$^{th}$ October 2011 for further finishing as grass supplies had become scarce. Following a decision by Buccleuch Estates to cease its in-hand farming operations at Queensberry, all remaining lambs were moved to Bowhill on 15$^{th}$ November 2011 and finished off kale also. Concentrates were offered via ad lib feeders from 20$^{th}$ January 2012 onwards, although just 260 lambs remained at this stage.

#### 4.3.2 Health

Prior to mating, all ewes were treated for liver fluke (Fasinex 5%, Novartis Animal Health, Basel, Switzerland) and worm infections (Panacur Sheep SC 2.5%, Intervet UK Ltd, Milton Keynes, UK) due to the presence of high faecal egg counts. Gimmer ewes were also vaccinated to help prevent enzootic abortion (Enzovax, Intervet UK Ltd) and toxoplasmosis (Toxovax, Intervet UK Ltd). At around 4 weeks before lambing, ewes were treated again for liver fluke (Flukiver, Janssen Animal

*Sheep housing at Bowhill*

Health, Wycombe, UK), worms and sheep scab (Cydectin LA, Pfizer Animal Health, Tadworth, UK), and were vaccinated to help prevent early lamb losses by clostridial infection (Covexin 8, Intervet UK Ltd). To help reduce the need for dosing, ewes were moved onto silage fields immediately after turnout, and then to summer pastures which had been grazed by cattle the previous year.

Lambs were vaccinated against clostridial diseases (Ovivac-P Plus, Intervet UK Ltd) and orf (Scabivax, Intervet UK Ltd) at 6 weeks old, and were given an oral drench to treat *Nematodirus* infection (Panacur Sheep SC 2.5, Intervet UK Ltd) before moving onto summer pastures. No further worm treatments were given until weaning in August when lambs were drenched with a broad spectrum wormer (Zolvix, Novartis Animal Health) before moving onto silage aftermaths.

#### 4.3.3 Outdoor lambing

As an addendum to the main trial flock at Queensberry, 67 adult 1$^{st}$-cross Highlander X Blackface ewes and 123 2$^{nd}$-cross Highlander X Blackface gimmers were lambed outdoors from mid-April to assess the performance of these breeds within an easier-care sheep system. All of the ewes were scanned with single and twin foetuses, having been mated to $P_{UK}$ rams the previous November. After scanning, the ewes were moved onto kale along with the single-bearing ewes from the main trial flock, and remained there until approximately 10 days before lambing when they were moved to the lambing paddocks. During the lambing period, ewes were checked three times daily with assistance being given only if necessary. Lamb mortality and growth performance data were monitored through to weaning.

### 4.5 Production and Carcass Measurements

Ewe LW (to the nearest 0.5 kg) and BCS were recorded at mating, 6 weeks pre-lambing, 6 weeks post-lambing and at weaning. Body condition was assessed from the level of fat cover on the spinous and transverse processes of the lumbar vertebrae and was scored on a five point scale (1 = thin, 5 = fat) using the method described by Russel et al. (1969).

After lambing, flightiness of the ewe while moving to the lambing pens was scored on a 3-point scale with a score of 1 indicating that the ewe followed her lambs closely, score 2 where the ewe followed at a distance, and score 3 where the ewe ran away from her lambs. Milk supply from the ewe was also scored on a 3-point scale with a score of 1 indicating that the supply of colostrum was adequate, score 2 where the colostrum supply was limited and supplementation was required, and score 3 when no colostrum was produced.

Lambs were individually identified with a small plastic tag (Bubblegum, Allflex) within 24 h of birth and their date of birth, dam tag number, sex, birth weight (to the nearest 0.5 kg), lambing difficulty score (**LDS**) and viability score (**VS**) were recorded. Lambing difficulty was scored on a 4-point scale (1 = unassisted, 2 = minor assistance, 3 = major assistance, 4 = veterinary intervention) while lamb viability was scored on a 3-point scale (1 = up and suckled, 2 = slow to suckle, 3 = helped to suckle). If a lamb was assisted at birth, the primary reason for giving assistance was also recorded (management, oversized or malpresented).

Lambs were weighed again at approximately 6 weeks of age and at weaning, and their average daily live weight gain (**LWG**) since birth was calculated. Lambs were weighed again at fortnightly intervals and drafted for slaughter with the aim of achieving an 18-21 kg carcass weight and fat class 3L. Slaughter weight of the lambs was recorded within 48 h of leaving the holding and was used to calculate the average daily lifetime LWG and kill-out percentage. All lambs were housed overnight before leaving the farm. Lambs were loaded onto an articulated lorry at Queensberry around 12.00 noon on the day before slaughter. The lorry then made a 2 hour 30 minutes journey to pick up the lambs at Bowhill before making a further 2 hour journey to the abattoir.

All lambs were slaughtered at Linden Foods Burradon, near Newcastle-upon-Tyne. The lambs were stunned, bled, skinned and eviscerated before the carcasses were weighed and graded by an inspector from Meat and Livestock Commission Services Ltd. Cold carcass weight was estimated by applying a 5% reduction to the hot carcass weight, determined immediately after slaughter. Carcass conformation was graded on a 5-point scale according to the EUROP classification system (E = excellent, P = poor) and fat cover was graded on a 7-point scale (1 = lean, 5 = fat) according to Commission Regulation (EC) Nos 2137/92 and 461/93. Conformation and fat class grades were subsequently converted to numerical values for statistical analysis, as described in Section 4.9. Following grading, the carcasses were chilled for 24 h in a cold room in which air chill temperature cycled between 0 and 2$^{o}$C every half hour for periods of five hours. The refrigeration unit defrost cycle was active for one hour in every six hours during which the air temperature in the chill rose to between 4 and 5$^{o}$C for no more than 30 minutes during these defrost on-off cycles (Appendix 3).

*Weighing lambs at Bowhill Estate*

Carcasses from 756 lambs (n = 28 per ram), pre-selected at weaning to represent all ewe breed x ram breed combinations in direct proportion to the number of ewes in the trial and balanced for sex, age at weaning, weaning weight and lamb sire ID, were transported in refrigerated containers to Linden Foods Dungannon for dissection. At Dungannon, the carcasses were split into three primal joints and the weights of the untrimmed shoulder, barrel and legs were recorded (to the nearest 1 g). Length of the barrel was also recorded (to the nearest 0.5 cm). The barrel was then trimmed, having both flanks removed, before being split into the rack and loin. The weights of the trimmed rack and loin were also recorded (to the nearest 1 g).

Whole loins (*M. longissimus dorsi*) from a representative sample of 216 of these lambs (n = 8 per ram), were retained for meat quality assessment. Eye Muscle Area (EMA) was measured on the cross section from each pair of loin muscle (*M. longissimus dorsi*) racks obtained from the 216 carcasses selected for meat quality analysis. A digital camera mounted perpendicular to the meat surface was used to capture images of each eye muscle. The digital images were then individually calibrated and EMA determined using Image J software. EMA was obtained by tracing the contour of the eye muscle and counting the number of pixels, which were then electronically converted into area measurements corresponding to the image plane.

## 4.6 Lamb Processing and Meat Quality Measurements

Prior to the delivery of carcasses for meat quality assessment, loin pH/temperature declines and air chill temperatures were measured in the cold room at Linden Foods, Burradon, on $30^{th}$ June 2011. These measurements were also carried out on $4^{th}$ August and $24^{th}$ November 2011 on a minimum of 20 carcasses from batches of experimental lambs destined for Linden Foods Dungannon. Measurements of muscle pH and temperature were carried out at least once per hour in the *M. longissimus dorsi* between the $10^{th}$ and $11^{th}$ ribs, using a calibrated Ionode IJ44c glass electrode combined with a Jenway 370 temperature compensated pH meter. The pH and temperature probes were inserted into the loin from the dorsal surface so that readings were taken as close as possible to the centre of the muscle. Air chill temperatures were measured over a 24 h period using a calibrated Ebro datalogger, type EBI 20-TE, programmed to read every 10 minutes. The data was subsequently downloaded to a PC. Details of these assessments are presented in Appendix 3.

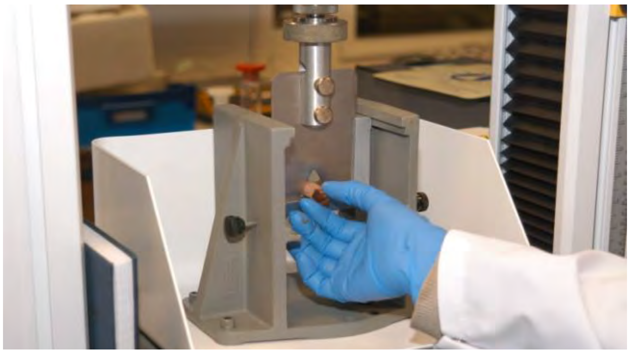
Whole loins (*M. longissimus dorsi*) from 216 lambs (n = 8 per ram), balanced for sire breed, sire ID, dam breed and sex were retained from the 756 carcasses sent to Linden Foods Dungannon. Following dissection, the loins were transported to AFBI Newforge and held at $2^{o}$C prior to assessment. Instrumental meat quality parameters (ultimate pH, sarcomere length, cooking loss, Warner Bratzler Shear Force, and colour parameters) were determined on the right loin of each carcass, while the left loin was used for consumer assessment of meat eating quality (aroma, tenderness, juiciness, flavor, overall liking, satisfaction)

Ultimate pH (pHu) was measured 6 days post-slaughter in the centre of the right *M. longissimus dorsi* of each short loin, using an Ionode IJ44c glass electrode combined with a Jenway 370 temperature compensated pH meter. Sarcomere length measurements were carried out on approximately 20 g of fresh tissue removed at 6 days post-slaughter from the centre of the right *M. longissimus dorsi* at the exterior end of each loin rack. Each subsample was vacuum-packed and immediately frozen. Sarcomere length was subsequently determined using a modification of the laser diffraction method of Cross et al. (1981). Approximately 4 g of tissue was cut from each frozen sample, placed in 15-20 ml of an aqueous 0.25 M sucrose/0.002 M KCl solution, and homogenized until fibre separation was noted. A drop of homogenate was then placed on a glass microscope slide and sarcomere length was measured using the diffraction patterns created by a He-Ne laser (JDS Uniphase, 0.5 mw linear). Ten measurements were made per sample. Calculations of sarcomere length, in micrometers, were performed according to the formula by Cross et al. (1981).

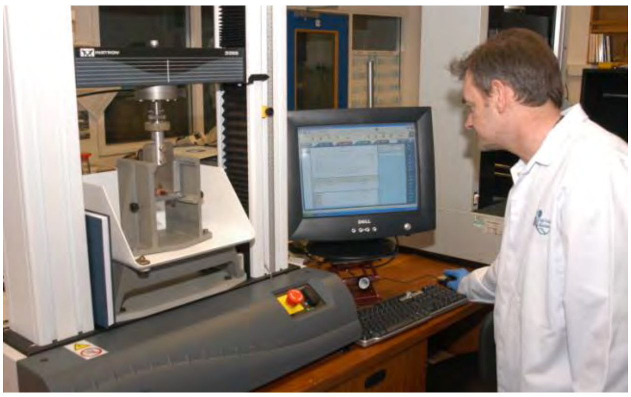
Meat colour was measured 6 days post slaughter on each *M. longissimus dorsi* located at the cut surface of the short loin section. Reflectance measurements were made by scanning from 380 nm to 780 nm at 1 nm intervals (Monolite System Controller 6800) using illumination geometry $0^{o}/45^{o}$. CIE (Commission Internationale de l'Eclairage) LAB colour parameters were calculated specified for illuminant D65.

Cooking loss and shear force were determined on five one inch thick samples of *M. longissimus dorsi* taken from the right loin of each carcass 6 days post slaughter. These were taken from deboned short loins, with surplus fat covering removed, that had been vacuum packed and aged for a further 8 days (14 days total aging post-slaughter) at $2^{o}$C. The left loin of each carcass was treated and stored in the same way before being frozen for subsequent sensory evaluation by consumer panel. Each sample was weighed, placed in individual polythene bags, and cooked in a water bath at 75$^{o}$C for 50 minutes.  Cooked loin steaks were then chilled in an ice bath before re-weighing.  Cooking loss was calculated as the percentage difference between pre- and post–cooked weight, and the mean of the five values for each carcass were recorded.  From each cooked steak, 2 round cores (1.27cm diameter) were removed parallel to the long axis of the muscle fibres using a handheld coring device to provide a total of 10 cores for analysis.  Each core was sheared once through the centre using a Warner-Bratzler shear attachment (V-notch blade) connected to an Instron Universal Testing Machine fitted with a 50 kg load cell and driven at a crosshead speed of 100 mm/min.  The mean shear force value from the five representative loin steaks of each carcass was then recorded.

The left loins from each of the 216 carcasses selected for meat quality assessment were used for sensory evaluation of eating quality by consumer panel.  These loins were at least ten inches long to provide 10 x one inch steaks per loin.  Following aging to 14 days post-slaughter in vacuum packs at 2$^{o}$C, as described earlier, the vacuum packed loins were stored frozen at -20$^{o}$C until required for sensory evaluation.  Twelve loins were subsequently selected at random for each of 18 consumer panel sessions to optimize the balance of experimental factors across the different panels.  Duplicate consumer panel sessions were run each night on nine separate occasions between 24 November 2011 and 1 March 2012.  Each of the 18 consumer panels comprised 20 untrained panelists, giving a total of 360 independent consumers for the sensory study.  Each panelist was presented with a starter sample followed by six test samples of roast lamb.  The test samples (10 from each animal) were balanced over the two groups on each evening, based on a Latin square design to ensure random presentation of roast lamb.  Thus loins from 24 animals were required for each of the nine duplicate sessions (6 servings x 40 panelists / 10 steaks per animal).  In total, 2160 lamb samples (plus an additional 360 starter samples) were assessed for the entire sensory evaluation study.



*Assessing Warner-Bratzler shear force (left, below left) and eye muscle area (below right)*



*Taste panels assessing the eating quality of lamb*

Loins were selected as specified in the statistical sampling plan for each consumer panel and defrosted for approximately 24 h at 2°C prior to preparation. Ten one inch steaks were cut from each loin. The steaks were arranged on metal trays according to the presentation design, so that each tray contained the 20 samples for each of the seven rounds of the sensory panel. Thus each panel of 20 people was served seven samples of roast lamb – one starter round followed by six test sample rounds. The trays were kept at room temperature for two hours prior to placing on the oven racks of a Rational oven at 170°C where they were cooked for 12 minutes (dry heat) to give a "just well done" degree of cooking. Consumers were asked to assess each sample by scoring on a 0 - 100 horizontal line scale for liking of aroma, tenderness, juiciness, and flavour, and for overall liking as appropriate for each attribute, where 0 is dislike extremely and 100 is like extremely. They were also asked to rate the sample on how satisfactory it was on a scale of 1 = unsatisfactory, 2 = satisfactory everyday quality, 3 = better than everyday quality, and 4 = premium quality. The questionnaires were scanned using Biosystemes FIZZ software prior to statistical analysis.

## 4.7 Cost of production analysis

On-farm production costs were determined using CAFRE's Beef & Sheep Benchmarking Tool, based on the actual costs and receipts attributed to the upland flock at Bowhill (see Appendix 4). Although the majority of the trial flock were located at Queensberry, financial data from the Queensberry flock was considered atypical due to the change in farming practice in 2011/12 and was not considered in the analysis. The Benchmarking Tool was used to calculate total income (lamb sales, wool sales, sundry receipts), total variable costs (forage, concentrates, veterinary and medicines, miscellaneous, replacements) and total fixed costs (common fixed costs, labour/finance/conacre) for the Bowhill flock, from which the gross margin (total receipts minus total variable costs), net margin (gross margin minus common fixed costs) and net profit (net margin minus labour/finance/conacre) were calculated.

Breed effects on production costs were estimated by applying an adjustment factor to the actual production costs outlined above. Adjustment factors were determined only where significant breed differences in relevant performance data were noted. For each significant parameter, the mean value for the trial flock was calculated and the percentage deviation about the mean was determined for each breed. Baseline values for the ewe and ram comparisons are presented for Mule ewes and Texel rams respectively.

Lamb sales receipts were estimated as the product of total carcass output per ewe and the average price per kilogram of carcass weight, determined using the dynamic models described in Section 4.9. Relative forage costs per ewe were estimated from the predicted methane output of ewes and their lambs (Section 4.8) after adjustment for differences in metabolic live weight (ewes), weaning rate (ewes) and age at slaughter (lambs). Where costs and receipts are expressed 'per hectare', the financial data was calculated by dividing all costs and receipts by the forage cost adjustment factor. Mean concentrate costs per ewe were determined from the total concentrate inputs to the ewes over a 6 week housing period pre-lambing, and were based on the relative proportions of single, twin and triplet-bearing ewes between breeds. Veterinary and medicine costs per ewe were assumed to be attributed mainly to the lambs (dosing, vaccines, tags, etc) so the costs were adjusted relative to the litter size of the ewes. Output of wool and ewe longevity were not assessed in the trial so the income from wool sales and the cost of replacement ewes were assumed to be equivalent across breeds. Miscellaneous costs, common fixed costs and labour/finance/conacre costs per ewe were assumed to be equivalent across breeds. However, in order to investigate labour savings from easier-lambing sheep breeds, total annual labour requirements (as full-time equivalents) were estimated for each breed after adjustment for labour inputs over a 6 week lambing period (on a linear scale), estimated from the differences in lambing intervention rates between breeds.

### 4.8 Carbon footprint assessment

Greenhouse gas (**GHG**) emissions from the Bowhill flock, as carbon dioxide equivalents (**$CO_2$-e**), were estimated from animal and farm inputs data using the methods recommended by the Intergovernmental Panel on Climate Change guidelines for reporting of national greenhouse gas inventories (IPCC, 2006). Outputs of the primary greenhouse gases (methane, $CH_4$; nitrous oxide, $N_2O$ and carbon dioxide, $CO_2$) arising from enteric methane production, manure management, soil management, crop residues, burning of residues, fuel use and waste incineration were estimated using IPCC (2006) Tier 1 emission factors, unless otherwise stated. Outputs of methane and nitrous oxide were then converted to carbon dioxide equivalents using a multiplication factor equivalent to their 100 year global warming potential (GWP) (25 and 298 for methane and nitrous oxide respectively)

Estimates of enteric methane production were based on the IPCC (2006) Tier 1 emission factor for sheep (8 kg/head/year) with an adjustment factor applied to take account of variation in body size of the ewes (based on the percentage variation in metabolic body weight). IPCC (2006) do not report a separate emission factor for growing lambs. For the purposes of this report, it was assumed that daily methane emissions from young sheep (< 1 year-old) increased linearly from 1 month old, prior to which the intake of forage and hence enteric methane production is almost negligible (Meat and Livestock Commission, 1981), until 12 months old.

Diesel fuel usage in field operations (silage harvesting, spraying, etc) was estimated using data reported by Downs and Hansen (1998) plus AFBI data produced by Frost and Binnie (unpublished). The emission factor used to calculate GHG emissions during the manufacture of chemical fertilizers was 6.28 kg $CO_2$-e/kg N applied (Edward-Jones et al., 2009), while the equivalent emission factor for concentrate manufacture was 0.232 kg $CO_2$-e/kg fed (Lovett et al., 2006). Carbon sequestration from grassland was assumed to be 1.16 t $CO_2$-e/ha, as reported in the Natural England Carbon Baseline Survey (Natural England, 2008). Other changes in soil carbon stocks (e.g. carbon released during tillage operations) have not been considered.

## 4.9 Statistical analysis

Data from animals that died during the course of the study were included as missing values in the analysis, where appropriate. For statistical analysis, the conformation grade and fat class of lambs were converted to numerical values using a 5 point scoring system for conformation (E = 5, U = 4, R = 3, O = 2, P = 1) and a 7 point scoring system for fat (1=1, 2=2, 3L=3, 3H=3.5, 4L=4, 4H=4.5 and 5=5).

All data were analysed using GenStat (2009). Due to the unbalanced nature of the experimental design, Residual Maximum Likelihood (REML) Analysis was used to analyse linear mixed models for continuous variables. For the consumer panel assessments of eating quality, the data were first reduced to an animal basis by calculating the mean of all responses from the various panellists. Where overall effects were significant ($P<0.05$), pairs of means were compared using the Least Significant Difference (LSD). Lamb carcass data were analysed with mean values predicted for a range of end points (18, 19 and 20 kg cold carcass weight and fat score 3L) to represent the different criteria used commercially to select lambs for slaughter.

Binary data (conception rate and lambing assistance) were analysed with generalized linear mixed models, assuming a binomial distribution with a logit link function. Where overall effects were significant, Fisher's Protected Least Significant Difference test was used to test for significant differences between breeds. Lambing difficulty, following score, milk score, lamb viability score and carcass classification data were analysed with generalized linear mixed models, assuming a multinomial distribution with a logit-link function. Where effects were significant, the t-probabilities of all pairwise comparisons were used to test for significant differences between breeds.

Fitted fixed effects for ewe breed, ram breed and their interaction were included in all the models, while the effects of farm, age of ewe (adult or gimmer), age of lamb, lamb sex, birth rank, carcass weight and fat class were adjusted by covariate, where appropriate. Random effects were included in all of these analyses to account for within litter variance and within breed variance among individual rams/sires. Details of the models and analyses, with the fixed and random terms used, are described in Appendix 1.

To estimate breed effects on the distribution of carcass grades and to quantify the proportions of lambs meeting retail specification, a dynamic model was developed. This model used a linear mixed model to estimate carcass weight at a range of slaughter weights, and an ordinal logistic regression to estimate the proportion of lambs within each grade/price band. When grade was dichotomised (as in-spec/out-of-spec), a generalized linear mixed model was fitted using a binomial distribution with a logit link function. In all cases the fixed terms fitted were Slaughter weight + Sex X Birth Dam Breed X Sire breed, and the random terms were Farm/Sire ID/Birth Dam ID. The fixed effect parameters were saved from the analyses, transferred to Excel and through a combination of equations and an Excel macro function, the various prediction models were implemented.

# 5. Results and Discussion

Since the main objective of this study was to investigate the effects of ewe and ram breed on ewe and lamb performance, only breed effects are presented in this report. The effects of farm of origin and age of the ewe along with sex, birth rank and rearing status of the lambs, though included in the statistical models, are not presented. Where significant ewe breed X ram breed interactions exist, these are presented in separate tables. For clarity of presentation, the effects of ewe and ram breed on production, processing and eating quality of lamb meat will be considered separately.

## 5.1 Breed effects on lamb production on-farm

### 5.1.1 Ewe live weight and live weight change

The body weight of ewes has implications for the growth performance, feed requirements and greenhouse gas (GHG) emissions of a sheep flock. On the one hand, the mature weight of an animal is highly correlated with its growth rate (Black, 1983) so the use of heavy mature weight breeds within sheep breeding strategies is likely to improve lamb growth rates. On the other hand, increasing mature weight of ewes increases their daily nutrient requirements for maintenance. According to the UK feeding standards for sheep (Agricultural and Food Research Council, 1993), a 10 kg increase in live weight of ewes, from 55 to 65 kg, is predicted to increase daily metabolizable energy (ME) requirements by 0.95 MJ/d, which is equivalent to a 13% increase. To meet this extra demand, ewes would need to consume an extra 0.5 kg/d grass just to maintain their body composition. With feed intake a key driver of methane emissions from sheep, reducing the body weight of ewes without impacting on lamb output is one strategy that can be used to help reduce total GHG emissions from sheep systems (Section 7).

With a mean LW at mating of 68.3 kg, TM ewes were consistently heavier (P<0.001) than any of the other ewe breeds evaluated. When compared with M ewes, TM were on average 7.0, 5.5, 5.9 and 5.7 kg heavier (P<0.001) at mating, pre-lambing, post-lambing and at weaning respectively (Table 3). In comparison, the H and HB ewes were 7.3 and 8.1 kg lighter (P<0.001) than M ewes at mating, and this weight differential remained reasonably constant throughout the study. On this basis, switching from Mule to Highlander X Blackface ewes would be expected to reduce maintenance energy requirements by more than 17%. This could provide the opportunity to reduce feed inputs (rented land, fertilizer inputs, purchased concentrates, etc) or alternatively, the theoretical maximum stocking rate could be increased by up to 20% while maintaining total feed inputs. Within the Highlander-type ewes, H ewes were on average 3.3 kg heavier than HB at 6 weeks pre-lambing (P<0.001) and 6 weeks post-lambing (P<0.001) although, at mating and at weaning, the live weights of these breeds were not significantly different.

Over the course of the study, the various ewe breeds studied did not vary in terms of their total live weight change but there were significant breed effects on the weight change profile, as shown in Table 4. All ewes gained body weight during early and mid-pregnancy but the magnitude of this gain was much higher (P<0.001) for M and H ewes (+6.8 kg) compared with TM and HB (+4.0 kg), reflecting their larger litter sizes. During the final 6 weeks of pregnancy and first 6 weeks of lactation, HB and H ewes gained 1.5 kg live weight whereas M and TM lost 0.5 kg live weight (P<0.001). Considering that the total birth weight of Mule-type ewes was around 1.5 kg heavier than Highlander-type ewes (Section 5.1.6), this difference in body weight change over the lambing period can be attributed to the lambing process and loss of uterine fluids, rather than the mobilization of body tissue. During mid and late lactation, all ewes lost body weight but the magnitude of this loss was much greater (P<0.01) for H ewes (-4.4. kg) compared with the other breeds (-2.1 kg).

### 5.1.2 Condition score of ewes and changes in body condition

Conditioning scoring is used to indicate the level of fat reserves that can be utilized by ewes during periods of nutritional stress, such as late pregnancy and early lactation. The level of body condition at key stages in pregnancy can therefore have significant effects on reproductive performance. For example, fertility levels in hill breed types, in terms of the number of lambs born per ewe lambed, has been shown to fall when ewes are in poor condition (BCS<2.0) around mating (Carson et al., 2001). Also, ewes lambing down in poor body condition can struggle to produce enough milk to suckle two lambs, resulting in reduced lamb growth rates. Tailoring feeding regimes to ensure ewes achieve their target levels of body condition is therefore important to maximize flock productivity and economic performance.

H ewes began the trial with 0.21-0.32 units lower (P<0.001) BCS than the other ewe breeds, as shown in (Table 3), and they continued to have a lower mean BCS throughout the study, although the magnitude of this differential ranged from 0.22-0.33 units through the year. However, with a mean BCS of 3.48, H ewes were in good condition at mating and their reproductive performance is unlikely to have been disadvantaged as a result. Despite their lower initial BCS, H ewes gained a small amount of body condition in early and mid-pregnancy (+0.05 units) whereas the other ewe breeds tended to maintain or lose some condition (-0.05 units, P<0.05) (Table 4). This response is likely to represent the change in nutritional status of ewes from pre- to post-mating, rather than a breed effect *per se*. In fact, when ewes are in good condition at mating (3.5 or above), modest loss of body condition (up to 0.5 units BCS) during mid-pregnancy (40-100 d) can aid development of the placenta, producing heavier (Faichney and White, 1987) and more active/viable lambs at birth (Munoz et al. 2008).

At mating and 6 weeks pre-lambing, M and TM ewes were in marginally better body condition compared with HB (+0.07-0.12 units, P<0.001), but by 6 weeks post-lambing and weaning, the HB and M ewes had similar condition scores. Overall, feeding levels during late pregnancy were more than adequate to meet the nutritional requirements of ewes, resulting in a small increase in BCS during the late pregnancy and early lactation periods. Consistent with their smaller litter sizes and consequently lower energy demands, TM and HB ewes gained more (P<0.001) body condition than M ewes over this period, with TM maintaining a higher (P<0.001) level of body condition than the other breeds throughout lactation.

By weaning, all ewes ended the breeding year having lost some body condition relative to mating. Overall, M ewes lost 0.10 units BCS more (P<0.01) than HB ewes, even though their lamb output per kilogram of body weight was similar. Though not conclusive, this response would indicate that HB may be more capable of maintaining body reserves on grass-based systems which could have an impact on their subsequent longevity and lifetime productivity.

### 5.1.3 Conception and lambing rates

With ewes in good but not excessive body condition at mating, it is not surprising that fertility of the ewes was excellent overall. Just 18 non-pregnant ewes (1.3%) were recorded at scanning, and with a further 15 ewes (1.1%) having died between mating and scanning, this resulted in an overall conception rate of 97.6%. When this data was corrected for farm, age of ewe and ewe breed effects, the mean conception rate across breeds was 97.9%.

Of the ewes that were scanned in-lamb, 30 ewes (2.2% total flock) died prior to lambing and a further 19 ewes (1.4% total flock) had no lambing details recorded, which resulted in an overall lambing rate of 93.9%. When corrected for farm, age of ewe and breed effects, the mean lambing rate across ewe breeds was 92.8%. There were no significant differences in either conception rate or lambing rate between the different ewe breeds studied, as shown in Table 5.

Following an examination of semen quality before mating, there were some concerns that the stresses of transporting rams from New Zealand, combined with the fact that the sheep breeding season in NZ had been completed four months previously, could have an adverse impact on semen quality and fertility with the new $P_{NZ}$ rams, which had arrived in the UK just one month before breeding. However conception rates were high across all of the mating groups and there was no evidence that the breed of ram used had any effects on either conception rate or lambing rate (Table 5).

### 5.1.4 Fertility and fecundity

The fertility (number of lambs born per ewe mated) and fecundity (number of lambs born per ewe lambed, or litter size) are key factors affecting the biological efficiency and economic performance of sheep flocks. Fertility is a function of conception rate and litter size, and is a good indicator of reproductive performance overall. The ovulation rate of ewes is the main determinant of litter size and is under genetic control. Hence ewe breed selection is one of the main management tools that a sheep producer can use to increase their lamb output.

Mule ewes are the most popular ewe type found on lowland flocks in the UK, and the prolificacy of M ewes recorded here are consistent with levels reported in the scientific literature (Carson et al., 1999 and 2004). However, with a mean litter size of 2.21 lambs per ewe, H ewes were the most prolific ($P<0.001$) of the four breeds studied, followed by M (2.03), HB (1.88) and TM (1.83), although statistically there was no significant difference in litter size between TM and HB. This amounts to a 21% difference in litter size between the highest and least fecund ewe breeds. However it is worth noting that the larger litter size in H ewes was mainly driven by an increased proportion of triplet births (33% vs. 14-18% with the other breed types) which may not be ideal for some flocks, depending on management system and labour availability. Despite the pure Highlander ewes being the most prolific breed studied, as a crossing sire for Scottish Blackface ewes, the offspring of Blue-faced Leicester rams had superior fertility compared with those of Highlander rams, albeit fertility was high in both breed types.

With ewe breed having no effect on lambing rate, it is not surprising that the differences in ewe fertility overall (in terms of lambs born per ewe mated) were very similar to those observed for litter size, with H and M ewes achieving higher ($P<0.01$) levels of fertility compared with TM. Likewise, ewe breed effects on the number of lambs reared to 6 weeks and weaning closely resembled the differences observed at birth, as shown in Table 6.

At the Bowhill Estate, the policy around lambing was to turn out ewes with no more than two lambs at foot. Thus in the case of triplet births, the third lamb was either fostered onto a single-bearing ewe or was reared artificially pending a foster mother becoming available, irrespective of the birth dam's ability to rear three lambs. As a result the incidence of fostering and artificial rearing was artificially high. For this reason, lamb output of ewes up to weaning was determined at two different levels, firstly, assuming all lambs were reared by their birth dam, and secondly, based on the number of lambs actually reared by the ewe. For the majority of ewes these two parameters were the same.

Litter size of ewes at birth was the main determinant of their lamb output, irrespective of breed. Assuming all lambs were reared by their birth dams, H ewes produced the largest average litter size at 6 weeks post-lambing (2.10) ($P<0.001$) and weaning (2.09) ($P<0.001$). The number of lambs reared by M ewes to 6 weeks post-lambing and weaning was numerically higher than HB ewes, reflecting their larger litter size at birth, but this result was not sufficiently large to be statistically significant. When the actual rearing performance of ewes was considered (i.e. including lambs fostered to the ewe but excluding those fostered away or reared as pets), the superiority of H ewes remained but was significantly reduced (+0.15-0.17 lambs/ewe at 6 weeks and weaning compared with HB or TM , P<0.05). These data help to highlight the importance of maximizing ewe fertility for efficient, high output sheep systems.

Consistent with the minimal impact on conception rate of ewes, choice of ram breed had no effects on the fertility or fecundity of ewes at birth or 6 weeks post-lambing. Unusually, when the actual rearing performance to 6 weeks was considered, ewes crossed with T rams reared 0.09-0.12 fewer lambs/ewe compared with those crossed to NZP or UKP rams. However these differences were no longer evident at weaning.

### 5.1.5 Lamb birth weight and pre-weaning performance

Birth weight is an important factor affecting the welfare of newborn lambs. Oversized lambs have a significantly increased risk of developing birth complications during the lambing process (Speijers et al., 2010), placing added stress on both the ewe and lamb. Excessive birth weights are also linked with a higher incidence of perinatal lamb mortality (Speijers et al., 2010). On the other hand, undersized lambs contain less brown fat, a vital energy resource for the newborn lamb (Mellor and Cockburn, 1986), and experience a higher rate of heat loss, which can be critical within extensive outdoor sheep systems with lower levels of human intervention. The aim is therefore to achieve a suitable balance to promote good viability and welfare. Birth weight is influenced by the genetics of the ewe and ram both directly, through their influence on mature body size, and indirectly, through dam effects on litter size. Nutritional status of the ewe is also important, especially during the final 6 weeks of pregnancy when 80% of foetal growth takes place (Robinson, 1983).

Lambs had an overall average birth weight of 4.5 kg, which is well within the optimum range for lamb viability (Speijers et al., 2010) and indicates that feeding levels in late pregnancy were adequate for the condition and litter size of the ewes. When corrected for litter size and age of ewe effects, lambs born to M and TM dams were up to 1.0 kg heavier (P<0.001) at birth compared with those born to H or HB dams, as shown in Table 7. Birth weight effects closely resembled the differences in body weight of the ewes at mating. The magnitude of this birth weight response was much greater than levels reported previously (0.3 kg, Carson et al., 2001; 0.4 kg, Annett et al., 2011) although this may be explained by the greater difference in mature body size of these ewes.

The differential in weight of lambs at birth increased to 2.1 kg when lambs were 6 weeks old, although, by this stage, only lambs born to H ewes were significantly lighter (P<0.01) than those from M and TM. By weaning, lambs from H dams remained numerically lighter in weight compared with those from the other dam breeds, although this weight difference was not statistically significant. Birth weight and growth rate are highly correlated in sheep and the use of heavy mature weight breeds can be expected to increase both the birth weight and growth rate of lambs (Black, 1983). Considering the heavier birth weights of lambs from M and TM ewes, one would expect to observe higher growth rates and heavier weaning weights also. The fact that both growth rate and weaning weights of the lambs were comparable could be an indicator of increased milk production from H and HB ewes compared with their contemporaries.

Lambs were weaned at an average age of 120 days and an average weight of 33.9 kg, which is equivalent to a mean growth rate of 246 g/d. While this level of growth performance is below the 260-280 g/d target for production systems based solely on grazed grass (Dawson and Carson, 2002a; Carson et al., 2004), pre-weaning growth rates overall were excellent considering the high weaning rate of the ewes.

During the first month of life, lambs are mainly dependent on the supply of milk from their dams to meet their nutrient requirements which could explain why lamb sire breed had no effects on growth performance during the first 6 weeks of life. Thereafter, milk yield of the ewe starts to decline and the intake of solid feed increases. From this point onwards the level of growth performance becomes increasingly influenced by the feed intake, foraging ability (within grass-based systems) and feed conversion efficiency of the lambs, all of which are influenced by lamb genotype. While there were no breed effects on lamb growth during the first six weeks after lambing, after correction for litter size effects the growth rates of $P_{UK}$- and $P_{NZ}$-sired lambs from birth to weaning were on average 11 and 13 g/d higher (P<0.001) than Texel-sired lambs respectively, producing 1.2 kg (+3.6%) and 1.5 kg (+4.5%) heavier (P<0.001) weaning weights respectively (Table 7). This improvement in growth performance represents a very positive development and has the potential to reduce both production costs and carbon footprint of UK lamb (see Sections 6 and 7 for further details).

### 5.1.6 LAMB OUTPUT AND EFFICIENCY OF EWES

Lamb output of ewes is primarily a function of litter size and the average weight of their lambs, as discussed previously. Whereas H ewes achieved the largest litter sizes of all the breeds studied, total lamb output at birth was 0.6-2.2 kg higher (P<0.001) for M ewes than the other breeds due to the heavier birth weights of their lambs (Table 9). Lamb output of HB ewes was lower (P<0.001) than all other ewe breeds at birth, and this differential was still evident at weaning. Assuming all lambs were reared by their birth dams, lamb output per ewe at 6 weeks post-lambing was 3.8-6.9 kg lower (P<0.001) from HB ewes compared with the other ewe breeds, due mainly to their smaller litter size. By weaning, the higher output of M ewes had increased to 4.1, 4.8 and 10.2 kg (P<0.001) compared with TM, H and HB respectively. When only the lambs actually reared by the ewe (both mothered and fostered on) were considered, lamb output per ewe at 6 weeks post-lambing and weaning were both significantly higher (P<0.001) for M and TM ewes compared with either H or HB.

Lamb output per kilogram of body weight is often cited as a measure of output efficiency from sheep systems (Al-Nakib et al., 1997; Annett et al., 2011). Some papers (Annett et al., 2011) also cite output efficiency in terms of lamb output per kilogram of metabolic body weight ($LW^{0.75}$) since the relationship between the body weight of ewes and their energy requirements is non-linear. Both of these efficiency measures are considered in this report.

Within the Focus Genetics selection programme for Highlander ewes, an efficiency target of 1.0 kg lamb weaned per kilogram ewe body weight has been established. While this target is rarely achieved in scientific studies, it is remarkable that three of the four ewe breeds examined in the current study were able to meet and even exceed this target. Despite achieving a higher weaned lamb output, the output efficiency of M ewes was similar to H and HB due to their heavier body weight at mating. While TM ewes had the heaviest body weights, their level of lamb output did not increase accordingly resulting in a lower (P<0.001) lamb output efficiency compared with the other ewe breeds.

Ram breed had no effect on total lamb output at birth or 6 weeks post-lambing, or on lamb output efficiency. When only lambs reared by the ewe are considered, weaned lamb output per ewe was on average 3.2 kg higher (P<0.001) for ewes crossed with $P_{UK}$ and $P_{NZ}$ rams compared with T rams, which is consistent with their higher growth rates discussed previously. However, if it is assumed that all lambs were reared by their birth dams, ram breed had no effect on weaned lamb output.

### 5.1.7 Ease of lambing

The ability of ewes to lamb down unaided is a key consideration for extensive or easier-care sheep systems and is important for maximizing labour efficiency and animal welfare standards in general. Studies undertaken on commercial lowland flocks in Northern Ireland have reported that between 20-40% ewes lambing down to terminal sire breed rams (Texel or Suffolk) require assistance at lambing (Dawson and Carson, 2002a; Carson et al., 2004) which adds considerably to the workload around lambing time. Looking to the future of the UK sheep industry in general, and the M&S lamb procurement chain in particular, identifying suitable breeding and management strategies to reduce labour inputs is a key priority.

Overall, 11.8% ewes and 7.6% lambs required some degree of assistance at lambing, which is well below the levels typically reported on-farm and could explain why no significant ram breed effects on incidence of lambing difficulties (dystocia) were observed. When corrected for age of ewe and litter size effects, the incidence of dystocia varied significantly (P<0.01) between all ewe breeds, as shown in Table 10. HB ewes were ranked highest in terms of lambing ease (6.8% ewes assisted at least once), followed by TM (9.5%), H (13.9%) and M (16.8%). The lower levels of lambing problems with the TM compared with M is surprising considering that retaining crossbred ewes sired by Texel rams often leads to increased lambing difficulties (Annett et al., 2011). Ewe breed effects on the proportion of lambs requiring assistance at birth were broadly similar to those observed for assistance given to ewes (Table 12). The proportion of lambs requiring minor or moderate/major levels of assistance were lowest (P<0.001) for lambs born to HB dams (1.7 and 2.5% respectively) and highest for lambs born to M dams (4.5 and 7.6%). The risk of ewes encountering lambing difficulties is related to the compatibility of the lamb with the ewe's pelvic canal. Not surprisingly, ewe breed effects on dystocia levels were similar to those observed for lamb birth weight, which is one of the main risk factors associated with dystocia in sheep (Speijers et al., 2010).

### 5.1.8 Mothering ability of ewes

Lambs are born with limited adipose tissue to utilize as an energy substrate, and have practically no immunity (Mellor and Cockburn, 1986). Achieving an adequate intake of colostrum in the first 4-6 hours after birth is critical to prevent starvation and hypothermia, especially within extensive outdoor lambing systems where prevailing weather conditions can greatly increase the risk of lamb mortality. Colostrum consumption is also vital to ensure the lamb acquires an adequate level of passive immunity to combat early post-natal infections.

For these reasons, colostrum production by the ewe was scored shortly after lambing, based on whether the supply of colostrum was sufficient to meet the needs of her lambs. Overall, more than 95% M, TM and H ewes were reported as having adequate colostrum supplies. While less than 1% ewes were recorded as lambing down without producing any colostrum, there was a small but significant (P<0.05) variation in this level between ewe breeds (Table 11). The proportion of ewes lambing down with either limited or no colostrum was highest (P<0.05) among HB ewes (8.0% & 1.1% respectively), followed by M (4.3% and 0.6%), TM (3.1% and 0.4%), and was lowest for H ewes (2.3% and 0.3%). It is worth noting that while lamb mortality rates at birth did not vary significantly between ewe breeds, there was a positive relationship between mortality at birth and the proportion of ewes with limited milk supplies, as might be expected. Ram breed had no effect on colostrum supply.

Within indoor lambing systems, ewes are typically housed in groups prior to lambing but are moved to individual lambing pens shortly after giving birth to prevent mis-mothering. The propensity of ewes to follow their lambs while moving between pens is therefore a management benefit. Behaviour of the ewes at this time varied significantly (P<0.001) between breeds. The proportion of HB ewes that followed their lambs closely (60.5%) was considerably lower than any of the other ewe breeds investigated (95.9-100%). While the majority of 'problem' ewes followed their lambs at a distance and did not present a major challenge, the incidence of ewes abandoning their lambs was also high (2.9%) among HB ewes but practically negligible among the other ewe breeds. The flightiness of HB ewes is surprising considering there were no such issues recorded for the purebred H ewes. M ewes (Blue-faced Leicester X Scottish Blackface) were ranked second in terms of flightiness, albeit to a much lesser degree than the HB, which would suggest that this trait could have been inherited from their Scottish Blackface dams, all of which are lambed outdoors with little or no human intervention. The apparent link between flightiness and colostrum supply in the HB ewes could both be related to stress. However the magnitude of this problem in HB ewes relative to the other breeds would imply that dam breed *per se* is not the causal factor. Management factors during the rearing phase, such as mishandling or limited human contact, could also play a role here but these are difficult to quantify. However it should be noted that the flightiness and milk supply issues highlighted in the HB ewes does not necessary indicate an inferior maternal ability, and there was no evidence of a longer term impact on lamb performance.

### 5.1.9 Lamb viability and mortality

Whereas colostrum production by the ewe is one of the most important factors influencing colostrum intake by the lamb, the ability of lambs to stand and suckle without the need for assistance is also a key contributing factor (Dwyer, 2003) and is essential for lamb survival within easier-care sheep systems. In this study, lamb viability was assessed on the basis of how quickly the lamb first stood to its feet and whether human intervention was needed to ensure successful suckling. Overall, lamb viability was not a major issue in this study with more than 97% lambs considered viable (Table 13). Whereas there have been some reports of sire and dam breed effects on lamb viability (Dwyer et al., 1996), neither sire breed nor dam breed had any effect on lamb viability in the current study.

High levels of lamb mortality represent a significant economic loss to the UK sheep industry. On-farm studies undertaken on lowland flocks in Northern Ireland indicate that between 6-12% lambs are born dead or die within 24 hours of birth, and a further 4-9% lambs die between birth and weaning (Dawson and Carson, 2002a; Carson et al., 2004). In the current study, 3.6% lambs were born dead or died before tagging (including aborted foetuses), which was excellent for the size of the flock. As a result of the different approaches to fostering lambs at Queensberry and Bowhill, lamb mortality rates up to weaning were determined at two levels – firstly with fostered and pet lambs included in the calculation to give an indication of actual on-farm mortality (8.6% lambs born), and secondly with these lambs excluded, assuming that they would have died had they not been adopted to another ewe or reared artificially (12.2% lambs born). In both cases, the mortality rates recorded here were comparable to or below levels reported in the scientific literature. There were no significant differences in lamb mortality rates between the various ewe and ram breeds studied.

### 5.1.10 Lifetime performance

A wide range of criteria can be used to select lambs for slaughter, depending on breed, sex and diet type. In the current study, lambs were drafted for slaughter when they were predicted by experienced shepherds to have reached fat class 2 or 3L and an 18-21 kg carcass weight. In order to investigate breed effects *per se* on lamb carcass characteristics, statistical models were used to adjust the data to a range of endpoints typical of those used commercially, namely a constant carcass weight (18, 19 and 20 kg) and a constant fat class (3L). This approach also enables the effects of physiological maturity to be investigated between breeds.

Reducing slaughter age by improving the lifetime growth performance of lambs provides an opportunity to reduce feed costs on-farm as well as cutting GHG emissions from sheep systems. Overall lambs achieved a mean lifetime growth rate of 207 g/d which, although comparable with levels reported for grass-only sheep systems by Dawson and Carson (2002b), was excellent considering the high weaning rate of the ewes. Breed effects on the lifetime performance were broadly similar to those reported earlier for pre-weaning growth performance. When slaughtered at a constant carcass weight, growth rate of $P_{UK}$- and $P_{NZ}$-sired lambs was 9 and 13 g/d higher ($P<0.001$) than T-sired lambs respectively (Table 15). As a result, slaughter age was reduced ($P<0.001$) by 15 and 18 days compared with Texel-sired lambs, although the benefits of using Primera rams for age at slaughter were smaller than expected from their growth performance due to their heavier ($P<0.01$) slaughter weight (+0.6-1.0 kg). When slaughtered at a constant fat class, average slaughter weight was similar for Texel- and Primera-sired lambs, reflecting the higher level of fat cover on the Primera-sired lambs, but the benefit in terms of age at slaughter increased to 25 and 26 days for $P_{UK}$- and $P_{NZ}$-sired lambs compared with Texel-sired lambs respectively ($P<0.001$). At a constant carcass weight endpoint, lambs from H dams achieved higher ($P<0.05$) growth rates and were slaughtered 13 days earlier ($P<0.01$) than lambs coming from HB dams, although there was no difference in slaughter weight between these dam breeds. When slaughtered at fat class 3L, dam breed effects on growth rate and slaughter age were no longer significant, but the mean slaughter weight of lambs from H dams was 1.7 kg heavier ($P<0.01$) than those from HB dams.

### 5.1.11 Lamb carcass characteristics

Within Europe, the farm-gate value of a lamb carcass is determined mainly by its weight, although bonuses (or penalties) are often applied depending on the conformation grade and level of fat cover achieved. Like most UK retailers, M&S require their lamb joints to be sourced from 18-21 kg carcasses that have been graded E, U or R for conformation (i.e. conformation score ≥3.0) and 2 or 3L in terms of fat class (i.e. fat score 2 or 3), so these lambs generally attract a price premium. It is therefore desirable to maximise the proportion of 'in-spec' lambs in order to maximize returns. In practice, there is a close relationship between these three parameters, with both conformation score and fat score becoming higher as lambs are slaughter later and at heavier carcass weights

(Dawson and Carson, 2002b). However, to make a fair comparison of breed effects on lamb carcass characteristics, it becomes necessary to fix at least one of these variables.

When lambs were compared at a constant fat class 3L, T-sired lambs produced 0.6-0.7 kg heavier (P<0.001) carcasses than $P_{UK}$- and $P_{NZ}$-sired lambs, due mainly to their 1.4-1.8% higher (P<0.001) killing-out percentage (Table 16). The mean carcass conformation score of T-sired lambs was also up to 0.72 units higher (P<0.001) than $P_{UK}$- or $P_{NZ}$-sired lambs at a fat class 3L endpoint, indicating a much superior carcass conformation with T-sired lambs, based on the EUROP scale. This was also reflected in the higher (P<0.001) proportions of E and U grade carcasses, and lower (P<0.001) proportion of O grade carcasses (out-of-spec) achieved by T-sired lambs, as shown in Table 18. The proportion of O grade carcass was marginally higher for $P_{NZ}$ (11.2%) versus $P_{UK}$-sired lambs (6.9%). Dam breed effects on lamb carcass characteristics were equally as large as the effects of sire breed, as shown in Table 16. When compared at fat class 3L, lambs from H dams produced 1.4 kg heavier (P<0.001) carcass weights than those from HB dams, but otherwise dam breed had no effect on carcass weight. Poor carcass conformation was not a major problem with the dam breeds investigated in this study, with fewer than 10% lambs failing to achieve the minimum R grade for conformation when slaughtered at fat class 3L (Table 17). There was no difference in carcass conformation of lambs born to M and HB dams; however the mean conformation score of lambs born to TM dams was up to 0.69 units higher (P<0.001) than either M or HB. This improvement in conformation is comparable with that noted earlier when Texel sires were used. Dam breed had no effects on the killing-out percentage of lambs.

When compared at a constant carcass weight, the superior killing out percentage (P<0.01) and conformation score (P<0.001) of T-sired lambs remained evident, although the benefits for both killing out percentage (+1.2%) and conformation score (+0.61) were marginally lower than those reported when lambs were compared at fat class 3L (Table 16). Likewise, the effects of dam breed on carcass conformation were also evident when carcasses were compared at the same weight. At carcass weights above 19 kg, there was no evidence of any major carcass conformation issues for any of the sire or dam breeds studied, with the majority of lambs (89%+) achieving the target R conformation grade or better (Table 17). However when carcass weight was reduced to 18 kg, conformation score of Primera-sired lambs and those from Mule dams was close to or below 3.0, indicating a significant proportion of lambs failed to achieve the minimum R conformation grade at this weight.

The mean fat score of $P_{UK}$- and $P_{NZ}$-sired lambs was 0.26-0.36 units higher (P<0.001) than T-sired lambs at each of the carcass weight endpoints, indicating that Primera-cross lambs mature earlier and reach finished condition more easily from high forage diets, but at lower weights, compared with Texel-cross lambs. A similar effect was observed for the ewe breeds, with HB dams producing fat scores 0.35-0.40 units higher (P<0.001) than either M or TM dams. While this trait offers some potential to reduce concentrate inputs for finishing lambs, using HB dams or Primera sires is more likely to lead to problems with overfat lambs, especially at heavier carcass weights. When compared at a 19.5 kg carcass weight, 80.3% T-sired lambs achieved the target fat class 2 or

3L compared with just 59.9% $P_{UK}$-sired lambs and 66.5% $P_{NZ}$-sired lambs ($P<0.001$). Likewise the proportions of fat class 2 and 3L lambs was 71.0, 80.6, 63.0 and 65.9% for M, TM, HB and H dams respectively ($P<0.001$). Reducing slaughter weight to increase the proportion of lambs meeting the target specification for fat is likely to increase the proportion of lambs failing to meet the specification on conformation. The implications of these differences in carcass conformation and fat class, in terms of financial returns, are discussed in detail in Section 6.

### 5.1.12 Performance of the Focus Genetics model within an outdoor lambing system

Lambing ewes indoors is relatively labour intensive, even with the most efficient housing facilities and handling systems in place. Adopting an outdoor lambing system therefore offers much potential to reduce labour inputs and use existing labour more efficiently. Studies undertaken on commercial lowland farms around Northern Ireland by Carson et al. (2004) have demonstrated that outdoor lambing systems typically require around 30% less labour compared with lambing indoors, with no differences in lamb mortality between systems. This study also reported 4% higher growth rates up to weaning in lambs born outdoors.

In order to assess performance of the Focus Genetics Model within an outdoor lambing system, and to draw a comparison with a typical indoor lambing UK flock, 190 first- and second-cross Highlander ewes, mated to UK-bred Primera rams and carrying singleton and twin foetuses, were lambed outdoors at Queensberry from mid-April onwards. Details of their lambing and growth performance are outlined in Table 14. Comparable data from the single and twin-bearing Mule ewes from the main trial flock, which lambed indoors to Texel rams, is also presented.

The smaller litter size of the Highlander-type ewes compared with the Mules (1.63 *v.* 1.77 lambs born/ewe lambed) is consistent with data obtained from the main trial flock, although it should be noted that the younger age profile of the outdoor lambing flock is also likely to have influenced their litter size (Annett et al., 2011). The detailed lambing records (birth weight, sex, lambing difficulty score, etc) obtained for the main trial flock were not replicated with the outdoor lambing flock, in keeping with the 'easy-care' ethos of this system, so there is limited performance data for these ewes. However the shepherds at Queensberry reported very few lambing problems with the outdoor flock and were very pleased with how they had performed. The incidence of lamb mortality from lambing to weaning was very low with both systems (<5%), and was only marginally higher for the outdoor flock (+0.4%). Weather conditions were generally favourable throughout the outdoor lambing period.

All lambs were weighed on the same dates so it is not surprising that those lambs born outdoors were lighter at each weighing than their contemporaries born indoors, due to their younger age. However, average growth rate of lambs between weighings was 13% (30 g/d) higher for lambs born outdoors. While the effects of litter size and lambing date have not been accounted for here, the magnitude of this response would indicate that lamb growth rates were inherently higher for the outdoor lambing flock, probably due mainly to the superior growth performance of Primera-sired versus Texel-sired lambs, as discussed in Section 5.1.5.

In summary, this component of the trial provides evidence that the Focus Genetics (FG) Production Model can achieve high levels of lamb output from grass-based lambing systems in the UK but with much lower inputs (especially labour) compared with traditional indoor lambing systems. In short, the FG Model has the potential to deliver efficient, sustainable (economically and environmentally) lamb production for the UK sheep industry. It was not possible to compare the production costs of these two systems but the economic benefits of the FG Model are likely to be significant.

## 5.2 BREED EFFECTS ON PROCESSING OF LAMB CARCASSES

While it is important to consider the implications of new breeding strategies on farm level efficiency and animal welfare, using novel breeds is of limited value if the lambs produced by these breeds fail to meet market requirements. The wholesale value of lamb carcasses is driven mainly by the proportion of lambs meeting the target specification for conformation and fat, and by the yield of the higher priced joints such as the rack and loin. It is therefore beneficial and desirable for lamb processors to maximize the proportion of lambs that meet these criteria.

### 5.2.1 CARCASS COMPOSITION

Sire and dam breed had significant effects on the yield of meat from lamb carcasses as well as the distribution of the meat within the carcass, as shown in Table 19. When compared at a constant carcass weight, the yield of shoulder (P<0.01) and leg (P<0.001) joints from T-sired lambs was up to 0.15 kg and 0.20 kg heavier respectively compared with those of $P_{UK}$- or $P_{NZ}$-sired lambs, reflecting the differences in carcass conformation outlined in Section 5.1.11. The heavier shoulder and leg weights of T-sired lambs were even greater (+0.29 and 0.31 kg respectively, P<0.001) when lambs were compared at fat class 3L due to their heavier carcass weights. However the saddle, from which most of the higher priced joints are obtained, was up to 0.16 kg heavier (P<0.001) in $P_{UK}$- and $P_{NZ}$-sired lambs compared with T-sired lambs at the same carcass weight. The heavier saddle weights from Primera-sired lambs were associated with a mean increase (P<0.001) in saddle length by up to 13 mm (Table 21). Whereas the difference in weight of the saddle between Primera and Texel cross lambs was removed when lambs were compared at the same fat class, due to the heavier carcass weights of the Texel-cross lambs, the breed effects on saddle length remained (P<0.01). There were only small and mainly non-significant differences in meat yield between $P_{UK}$- and $P_{NZ}$-sired lambs, with the exception of leg weight which was 0.08 kg heavier (P<0.001) in $P_{NZ}$ lambs at the same carcass weight. Sire effects on meat distribution within the carcass were very similar to those noted for meat yield (Table 20), with the better conformed carcasses from T-sired lambs yielding a higher proportion of meat in the shoulder (P<0.01) and leg (P<0.001) compared with Primera-sired lambs, but a lower (P<0.001) proportion of meat in the saddle. However it should be noted that, despite the large differences in carcass conformation, sire breed effects on the distribution of meat between these different cuts was very small (0.5-1.0%). Although the relationships between meat yield and conformation grade have not been examined in this report, these observations raise questions about the benefits of a EUROP grading system for the UK lamb supply chain.

Dam effects on lamb carcass composition were of a similar magnitude to those of the sire. Dam breed had no effect on the weight of shoulder and consequently the proportion of meat recovered from the shoulder, but dam effects on carcass conformation were evident from the yield of leg meat (Table 19). When compared at a constant carcass weight, lambs from TM dams produced up to 0.20 kg more ($P<0.001$) leg meat than the other dam breeds. This came at the expense of the saddle, which was up to 0.18 kg lighter ($P<0.01$) and 10 mm shorter ($P<0.001$) for TM dams compared with either M or H dams (Tables 19 and 21). The weights of all three joints were comparable for H and M dams when compared at the same carcass weight. Dam effects on meat distribution between joints were comparable to the effects on joint weights (Table 20) but again these differences were small. The impact of sire and dam breed on the wholesale value of the lamb carcasses will be discussed in Section 6.

### 5.2.2 YIELD OF HIGH VALUE CUTS

The most desirable cuts of lamb meat are typically found in the loin (saddle) so it is not surprising that these cuts tend to achieve the highest value. Maximizing the yield of loin meat is therefore desirable to maximize the wholesale value of lamb carcasses.

After further processing of the saddle, $P_{UK}$- and $P_{NZ}$-sired lambs yielded heavier ($P<0.001$) rack (+0.09 kg) and loin (+0.10 kg) weights compared with T-sired lambs slaughtered at the same carcass weight (Table 22), which reflected the differences in saddle weight noted previously. However, the relative distribution of rack and loin within the saddle was similar for all sire breeds (Table 23). There were no differences between sires in the weights of rack or loin when lambs were slaughtered at a constant fat class. Loin chops obtained from T-sired lambs had a larger ($P<0.05$) eye muscle area than those from $P_{UK}$-sired lambs when compared at the same carcass weight, which could influence consumer choice when purchasing lamb. However from a processing perspective, the yield of high value loin meat estimated from the Loin Index (= eye muscle area x saddle length) was similar for all three sire breeds. Sire breed had no effect on the weight of trim (mainly the flanks) removed from the saddle during processing, although the relative proportion of material removed as trim was 1.6% higher ($P<0.01$) from T-sired lambs compared with $P_{UK}$- and $P_{NZ}$-sired lambs.

Lambs born to HB dams yielded heavier ($P<0.001$) rack and loin weights than those born to M or TM dams at the same carcass weight. However, when compared at fat class 3L, the weight of loin obtained from lambs with HB dams was up to 0.10 kg lighter ($P<0.001$) than those from the other dam breeds due to their lighter carcass weights. Dam breed had no effect on rack weight at a fat class 3L endpoint. Inclusion of Texel genetics in the dam had a positive effect on eye muscle area, similar to that described for T-sired lambs. The mean eye muscle area of lambs from TM dams was 1 $cm^2$ larger ($P<0.01$) than the other dam breeds at both endpoints. Despite their shorter saddle length, TM dams also produced higher ($P<0.05$) Loin Index lambs compared with HB dams as a result of their greater eye muscle area. The weight of trim was greater ($P<0.001$) in lambs born to M and TM dams compared with H dams.

## 5.3 BREED EFFECTS ON THE EATING QUALITY OF LAMB

Consistency and desirability of good eating quality are essential criteria in meeting market requirements for lamb. While breed selection and efficient production systems underpin this goal, inherent genetic diversity and inappropriate processing protocols can contribute to variation in lamb product quality as discussed below in consideration of the eating quality data obtained from this study.

Irrespective of breed and optimization of lamb production practices, it is important in the context of meat quality that carcasses undergo an appropriate chilling regime after slaughter to avoid the effects of either heat or cold shortening (Toohey and Hopkins, 2006; Hopkins et al, 2011). An initial assessment of pH/temperature declines in the loins of lamb carcasses in the chill at Linden Foods Burradon (Appendix 3) indicated that chilling was rapid, with some carcasses being exposed to mild cold shortening conditions (Jaime et al, 1992; Hopkins et al, 2011) where the deep loin pH was above pH 6.2 at a temperature below 11$^{o}$C (Bendall, 1973). The risk of cold shortening at Burradon was therefore considered borderline and it was felt safe to proceed with the processing of experimental lambs for meat quality assessment under these chilling conditions. Further assessments of pH/temperature decline on 4$^{th}$ August, when the first batch of carcasses selected for meat quality were slaughtered, and 24$^{th}$ November, the seventh of the eight slaughter dates, confirmed the probability that all 216 carcasses selected for meat quality work were within the 'processing window', avoiding the risk of either cold or heat shortening.

In assessing differences in eating quality due to sire and dam, it is worth emphasizing that while similar numbers of lambs were selected from each of the three sire breeds (70, 71 and 75 Texel, NZ-bred Primera and UK-bred Primera respectively), their dams were predominantly Highlander x Blackface (89), Mule (73) and Texel x Mule (40), with only a small number (12) the progeny of Highlander dams, reflecting the proportions of each breed within the trial flock as a whole.

### 5.3.1 INSTRUMENTAL MEAT QUALITY MEASUREMENTS

One of the major biochemical/physical factors which influence variability in appearance and eating quality of similar muscles within any red meat species is ultimate pH (pHu) (Lawrie and Ledward, 2006; Warner et al, 2010). In this study, only dam breed had a significant effect on pHu of the *M. longissimus dorsi*, lambs born to H dams having a lower pHu ($P<0.05$) than those born to HB dams (Table 24). Nevertheless, all were normal, around pH 5.6 (McGeehin et al, 2001; Warner et al, 2010), and as such would be expected to enhance optimum meat quality characteristics (Table 24). Likewise, variations in sarcomere length can have a major impact on cooked meat toughness (Hopkins et al, 2011), shortening of muscles being associated with a gradual toughening of meat, irrespective of aging period. Neither sire breed nor dam breed had any significant effect on sarcomere length (Table 24). This is not surprising since the lamb carcasses were generally of similar weight and any adverse effects of cold shortening in the pre-rigor phase of processing were avoided during chilling.

Cooking loss and shear force are useful measures of the ability of meat to retain moisture during cooking and its relative degree of tenderness respectively. Neither sire breed nor dam breed had any significant effect on cooking loss (Table 25), with values of around 18% indicating a desirable level of water retention during cooking (Kemp et al, 1976; Shackleford et al, 2004). However, significant differences in shear force values due to both sire breed (P<0.05) and dam breed (P<0.05) were found (Table 24). All were nevertheless clearly below what could tentatively be considered a minimal toughness threshold of 4.90kg (Toohey and Hopkins, 2006). Progeny of $P_{UK}$ sires produced the most tender meat (3.23 kg F) with the lowest cooking loss (17.55%), whereas progeny of $P_{NZ}$ sires produced the least tender meat (3.91 kg F) with the greatest cooking loss (18.67%), albeit cooking losses were similar. Progeny of M and H dams also had the lowest shear force values and cooking losses (Table 24).

Breed differences in shear force values of lamb have been studied over many years. For example, Oliver et al (1967) studied wether, ewe and ram lamb carcasses from Delaine, Rambouillet, Hampshire, Columbia and Southdown lambs, and from cross-bred lambs out of Delaine and Rambouillet ewes sired by Hampshire, Dorset, Suffolk, Shropshire or Columbia rams. These gave loins with mean shear force values between 4.1 to 4.7 kg F, slightly higher the range of values found in the present study. Kemp et al (1976) reported even higher mean loin shear force values of between 5.5 to 6.9 kg F on ½ Hampshire, ¼ Suffolk ¼ Rambouillet cross-bred lambs, heavier and fatter lambs having the lowest values. In contrast, studies on ¼ Dorset ¼ Romonav ½ Finnsheep cross-bred lambs of a similar slaughter age (220 to 230 days old) produced loins with very low shear force values of around 2.7 kg F under similar cooking conditions to those used in the present study (Shackleford et al, 2004). More recently, Warner et al (2010) have shown that, irrespective of genetic differences, management practices which result in higher intramuscular fat, lower pHu, as well as a moderate rate of pH/temperature decline to avoid cold shortening, all enhance tenderness of lamb loin.

Purchases of red meat in store are largely determined by its appearance, bright red being associated with freshness and desirability (Moore and Young, 1991; Lawrie and Ledward, 2006; Warner et al, 2010). Recent studies by Khliji et al (2010) concluded that the colour of fresh lamb loin was acceptable to consumers when lightness (L*) and redness (a*) values were greater than or equal to 34 and 9.5 respectively. In the present study, mean L* values ranged from 34.6 to 39.8 and a* values from 12.4 to 14.1 (Table 24). Thus it is reasonable to conclude that, irrespective of dam or sire breed, loin colour was within the acceptable range for consumers. Although these instrumental measurements of colour were similar for each parameter, significant dam breed differences were found for lightness (P< 0.01) and hue (P< 0.05). The reason for these differences is hard to explain, as considerable variation in the reflectance spectra was found amongst the various loins. Similar variations in L* a* b* values of lamb loins were found by Warner et al (2010), although mean values for this large Australian cohort were marginally lower for L*, higher for a* and lower for b*, indicating a slightly darker, redder and less yellow appearance. It is likely that the lighter colour of the lambs in the current study may be an indication of cut surface contamination by lipid and bone which occurred during the mechanical breaking of the carcasses in the boning room. Such contamination would be expected to increase reflectance and inhibit oxygen uptake through the cut surface of the muscle. It was, nevertheless, consistently observed during the subsequent preparation of loin steaks for shear force and for sensory evaluation that the deboned and trimmed loin freshly cut with a knife bloomed up quickly to a more usual desirable bright red appearance associated with oxygenated fresh lamb.

Statistical models were also used to assess the effects of finishing to constant carcass weight (18, 19 and 20 kg) and fat class (3L) on instrumental and sensory predictions of eating quality. In all cases, these adjustments had no effect on the dam and sire differences reported in Tables 24 and 25 which were maintained over this narrow finishing range of carcass weights.

### 5.3.2. Sensory Evaluation

Cooking loss and shear force measurements are also useful indicators of consumer perceptions of juiciness and tenderness respectively. The consumer data summarised in Table 25 for juiciness and tenderness follow the trends found for cooking loss and shear force respectively in Table 24, although not all these differences were significant. For example, consumers detected a marginally lower level of juiciness ($P<0.05$) in the $P_{NZ}$-sired lambs. Similar differences in consumer assessment of juiciness were found for dam breed, but these were not significant (Table 25). Likewise, it is interesting that $P_{NZ}$ -sired lamb was the least preferred ($P<0.05$) of the three sire groups. However, no significant effect of dam or sire breed was found for flavour or tenderness. As a rule or thumb, differences of 5 or more on a 0 to 100 scale might be expected to be noticeable to consumers, and the significant differences shown in Table 25 were within this range. In general, therefore, consumer perceptions of eating quality and level of satisfaction with the roast lamb were very good, irrespective of sire or dam breed origin.

In a similar study to the current trial, Ellis et al (1997) found no significant effect of breed or sex on the sensory evaluation of eating quality of loin from crossbred ewe and wether lambs of Mule, Scottish Blackface and Swaledale ewes mated to Charollais, Suffolk and Texel rams, although lambs slaughtered at weaning were considered more tender than those slaughtered later in the season. It has nevertheless been shown by Lambe et al (2009) that measurement of degree of fatness in the lean Texel breed was a reasonable predictor of sensory eating quality, in particular flavour, whereas carcass size and muscling were better predictors of eating quality in the fatter Scottish Blackface (SBF) breed. However, residual correlations of carcass measurements with eating quality traits for both breeds were generally low (Lambe et al, 2009). The same group (Navajas et al, 2008) found that SBF lambs had better tenderness, a stronger flavour, and better overall liking than Texel lambs. The influence of diet and breed on the flavour of lamb was previously demonstrated by Fisher et al (2000), who found that loin from pure bred Welsh Mountain and Suffolk cross-bred lambs fed on pasture was preferred by consumers over concentrate fed lamb, while that from pure bred Soay lambs fed on lowland pasture, surprisingly, had abnormal flavours.

In view of the fact statistically significant differences were found in predicted shear force, which were reflected in non-significant trends in tenderness and a significant effect on overall liking, further statistical analysis on the effects of age at slaughter, carcass weight and fat class were undertaken to assess what hidden effects may be contributing to these breed differences. However the breed differences remained when the data was adjusted for these factors.

# 6. Economic consequences for lamb producers and processors of adopting the Focus Genetics Sheep Breeding Model in the UK

For new breeding strategies to be worthwhile, it is critical that they provide some opportunities to increase output value and/or reduce costs within the food chain.  In this section, the economic impact of adopting Highlander and Primera genetics on production and processing revenues will be examined.

## 6.1 On-farm Production

On-farm production costs in the UK have increased significantly in the past 10 years, driven mainly by the rising costs of feed, fertilizers and fuel.  Developing more efficient sheep systems, which deliver increased output from the same level of inputs or maintains output from lower levels of inputs, is therefore critical for the long-term economic sustainability of the sheep industry. Adopting new breeding strategies on-farm is one approach that can be used to tackle this issue. However changing the breeding structure of the flock is a significant financial investment so a return on this investment is crucial.

The implications of using Primera rams and Highlander-type ewes on the economic performance of sheep flocks are presented in Table 26.  Costs are considered separately for ewe and ram breeds, with the baseline data calculated for Mule ewes and Texel rams respectively, due to their dominance within the UK sheep industry. However it should be noted that these costs are additive, since there were no significant ewe breed x ram breed interactions for ewe or lamb performance data, enabling the financial implications of other ewe and ram combinations (e.g. Highlander X Primera) to be estimated.

Breed effects on lamb sales, and indeed overall net profit, were determined mainly by differences in the rearing percentage of ewes, as discussed in Section 5.1.6.  As a result of their greater prolificacy, H ewes returned an additional £14.22 worth of lamb sales and £12.46 higher net profit compared with M ewes, which equates to a 34 p/kg carcass weight reduction in production costs. Revenues were £8.54 and £13.29 lower for HB and TM ewes respectively when compared with M, again due to their lower rearing percentage, resulting in lower gross margins per ewe and higher production costs (+19 and 49 p/kg carcass weight respectively).  When gross margin was examined on a per hectare basis (Table 27), there was no difference in economic performance between M and HB ewes due to the lower body weight and feed requirements of HB ewes, which should permit a higher stocking rate.  However M ewes continued to maintain a higher net profit than HB (+£31.41/ha) since their fixed costs were divided over a larger forage area.  The heavier body weight of TM ewes had a proportionately greater impact on their gross margin and net profit per hectare compared with the other ewe breeds.  The variation in forage costs between breeds are reflective of the differences in feed requirements of the ewes, estimated from their metabolic live weight and therefore highest for TM ewes (Section 5.1.1), as well as the feed requirements of their lambs, determined from age at slaughter and rearing percentage.  The differences in concentrate and veterinary costs were related mainly to litter size. However it is worth highlighting that the added concentrate and veterinary costs associated with the more prolific breed types was more than repaid by the added income from lamb sales, resulting in their higher net profit.

Compared with the ewe breed effects, ram breed had very little impact on physical performance and the resulting economic performance. While the superior growth rates of Primera-sired versus Texel-sired lambs provided some opportunity to reduce forage costs (-£0.39/ewe or 1 p/kg carcass weight), this was insufficient to compensate for their inferior carcass conformation (-£2.01/ewe), resulting in a £1.62/ewe decrease in net profit per ewe. The lower net profit per hectare from $P_{UK}$ (-£12.26/ha) and $P_{NZ}$ (-£11.40/ha) rams was simply a multiplier effect of their decreased net profit per ewe.

High labour requirements are an important issue for many UK sheep flocks. However, with labour considered as a fixed cost, the monetary and non-monetary (lifestyle) benefits from using easier-lambing sheep breeds are more difficult to quantify. To attempt this, the economic output per labour unit was examined to provide an indication of labour-use efficiency. Results are presented in Table 28. The sheep enterprise at Bowhill has an annual labour requirement of approximately 1.35 full-time equivalents, or 1 labour unit for every 949 ewes. When compared with reported values of 200-400 ewes per labour unit (Connolly, 2001), the Bowhill flock can already be considered as highly efficient in terms of its labour use. Furthermore, the fact that the ewes were lambed indoors, as per the majority of upland/lowland ewes in the UK, significant labour inputs for feeding, bedding, etc were required so the opportunities to reduce labour inputs/costs were more limited compared with outdoor lambing systems. While economic performance is determined mainly by lamb output, and was consequently highest for H ewes, the lower incidence of lambing difficulties recorded in HB compared with M was estimated to increase gross margin per FTE by almost £700, which is equivalent to a 7% increase in flock size per labour unit (+69 ewes/FTE). TM ewes also presented fewer lambing difficulties (+50 ewes/FTE) but this saving in labour input was insufficient to compensate for their lower carcass revenues. When expressed in terms of labour costs per kilogram of carcass weight, there was no difference between M and HB, but H ewes reduced labour costs by 21 p/kg.

The major differences in carcass conformation and fat class of lambs between the various breeds, outlined in Section 5.1.11, had only a small impact on financial income. Lamb carcass values for all the ewe and ram breed combinations are examined in detail in Table 29. When sired by Texel rams, lambs born to TM dams achieved an average price premium of up to 10 p/kg carcass weight over their contemporaries, increasing carcass value by up to £1.67 relative to M ewes which had the lowest carcass value. However this small price premium was insufficient to compensate for the lower lamb output of TM. Similar trends were observed in lambs sired by $P_{UK}$ and $P_{NZ}$ rams, although the relative price premiums for lambs born to TM ewes were lower (up to 4.6 and 5.9 p/kg carcass weight respectively).

## 6.2 PROCESSING

Whereas breeding decisions are almost always based on circumstances at farm level, these decisions can have a profound effect on the quantity and quality of lamb meat supplied to the processing sector. At present, supermarket specifications for lamb typically demand 18-21 kg carcasses which achieve conformation grades E, U and R, as well as fat class 2 or 3L. Lambs falling outside of these specifications are generally sold on to less attractive markets with lower returns. Maximizing the proportion of 'in-spec' lambs is therefore beneficial to maximize returns within the entire lamb supply chain – producer, processor and retailer.

Ewe and ram breed effects on the proportion of lambs meeting supermarket specification, and on the wholesale value of lamb carcasses, are considered in Table 30. Carcasses from H ewes ranked highest (+£1.35) among the ewe breeds studied in terms of their wholesale carcass value (in-spec), followed by HB (+£0.79), M (base) and TM ewes (-£0.23). These were mainly due to the differences in meat distribution within the carcass, discussed in Section 5.2.2, with lambs from H and HB dams yielding heavier weights of the high-priced cuts (rack and loin) compared with M and TM dams. When lambs were 'out-of-spec', the relative price premium of carcasses from these dam breeds actually increased, again due to their higher yields of high value cuts. Ewe breed had little effect on the proportion of in-spec carcasses, with 75-82% lambs from M, H and HB dams reaching the target fat and conformation grades. Therefore, when pricing differentials were applied to in-spec and out-of-spec carcasses, the overall average carcass value reflected closely the differences in wholesale value. The exception was for TM ewes where the terminal sire influence increased the proportion of in-spec lambs to more than 93%, ranking it second highest overall for its weighted-average wholesale carcass value behind those of H ewes. Carcasses from M ewes ranked lowest in this regard.

Sire breed effects on carcass value were also related to differences in meat distribution with the heavier rack and loin weights from $P_{UK}$- and $P_{NZ}$-sired lambs delivering a £1.20 (6 p/kg cwt) carcass premium over T-sired lambs when classed as in-spec. However a key concern with the Primera-sired lambs was that fewer than 60% carcasses achieved the target grades for conformation and fat, compared with more than 80% Texel-sired lambs. As a result, their overall average wholesale carcass value was up to £5.37 (28 p/kg) lower than those of Texel-sired lambs. While the relationships between conformation grade, meat yield and carcass value have not been considered in detail within this report, these observations raise serious questions about the merits of the EUROP grading system for the UK sheep industry.

# 7. Effects of adopting new breeding strategies on the carbon footprint of UK lamb

The UK Climate Change Act (2008) has established legally binding targets to cut UK greenhouse gas (GHG) emissions by at least 34% by 2020, and by at least 80% by 2050, both relative to 1990 levels. This has placed an onus on UK agriculture, along with other sectors of the economy such as energy and transport, to develop and implement suitable mitigation strategies. However, unlike these other sectors, agriculture faces the added challenge of displacement due to well established global trade networks for food commodities. While the most radical approach to deal with GHG emissions from UK agriculture would be to reduce food production and rely on imported food to a greater extent, this approach merely displaces the problem elsewhere. For this reason there is a need to consider the emissions intensity (per unit of output) as well as total emissions when investigating mitigation strategies for agriculture. Both approaches are considered in this report.

The effects of ewe and ram breed on carbon emissions (as carbon dioxide equivalents) from the Bowhill flock are presented in Table 31. Enteric methane ($CH_4$) emissions were the primary source of GHG emissions from the flock, accounting for 55.6% total emissions, followed by soils (32.7%) and manure management (4.9%). Within this, breeding ewes and rams were responsible for 66.8% enteric methane, followed by the replacement ewes (22.9%) and growing lambs (10.3%). It is not surprising therefore that both ewe and ram breed effects on GHG emissions were mainly due to differences in enteric methane production. Total enteric methane emissions were more than 19 t $CO_2$-e lower from HB ewes compared with M, due mainly to their lower body weight and feed requirements. Breed effects on GHG emissions from manure management and soils, mainly as nitrous oxide ($N_2O$), were also related mainly to the differences in ewe body weight, through its relationship with N excretion. Overall, total GHG emissions from HB ewes were 47.4 t $CO_2$-e lower than those from M ewes, followed by H (-32.5 t $CO_2$-e) and TM (+33.5 t $CO_2$-e). The superior growth rates of $P_{UK}$ and $P_{NZ}$ lambs also led to reductions in enteric emissions (-7.6 and -9.2 t $CO_2$-e respectively) as well as emissions from soils and manures, although the reductions were much less than those observed from the ewes. Compared with using T rams, total emissions from $P_{UK}$ and $P_{NZ}$ rams were 10.8 and 12.9 t $CO_2$-e lower respectively.

When expressed per unit of carcass output, only H ewes managed to achieve a lower emissions intensity than M ewes (-1.57 kg $CO_2$-e/kg cwt) due to their superior carcass output. HB ewes were broadly comparable with M (+0.16 kg $CO_2$-e/kg cwt) but the higher emissions and lower lamb output of TM ewes increased emissions intensity by 2.11 kg $CO_2$-e/kg cwt. The lower emissions from $P_{UK}$ and $P_{NZ}$ rams was effective in reducing emissions intensity by 0.22 and 0.26 kg $CO_2$-e/kg cwt respectively. These observations clearly demonstrate that the main strategies to mitigate GHG emissions from sheep systems are: 1) increasing production efficiency, in terms of lamb (or carcass) output per kilogram of ewe body weight, by improving ewe fertility (see Section 5.1.6) and, 2) improving lamb growth rates through better genetics, nutrition, health and welfare.

Grassland has the ability to sequester (lock-up) carbon from the atmosphere, through plants and soil fauna, and store it in the soil. However there is considerable debate over the extent to which this process can help to reduce GHG emissions and mitigate the effects of climate change. The

Natural England Carbon Baseline Survey (Natural England, 2008) estimated that on average grassland sequesters 1.16 t $CO_2$-e/ha/year, and this value has been adopted within this report. At this level, grassland sequestration led to a 40% reduction in total GHG emissions from the Bowhill flock, equivalent to around 5 kg $CO_2$-e/kg carcass weight for Mule ewes, which is almost 3 times the level achieved through improving production efficiency by using Highlander ewes. The benefits of sequestration for reducing emissions intensity were also proportionately higher for those breeds with below average levels of lamb output (i.e. TM and HB). Considering the extensive nature of most sheep systems in the UK, grassland sequestration has significant potential to reduce the carbon footprint of lamb meat and improve its environmental credentials, although further work is needed to quantify these benefits over a wide range of soil types and management systems.

## 8. Closing Remarks

The Mule ewe, used in this study to provide an indicator of the UK sheep industry as a whole, established a very high baseline in terms of both its physical and financial performance, and it is clear to see why this breed-type is so popular in the UK. This high baseline made achieving additional performance benefits through breed substitution all the more challenging.

All four ewe breeds achieved above average performance in terms of lamb output, but of the three alternative breeds investigated (Highlander, Highlander X Blackface, Texel X Mule), only the Highlander delivered consistently superior financial performance and lower carbon emissions compared to the Mule, driven by its greater prolificacy. Encouraging greater adoption of the Highlander ewe is thus one option that should be seriously considered to help tackle the sustainability issue within the UK sheep industry. Whereas the Highlander X Blackface and Texel X Mule lagged behind the Mule in terms of profit per ewe, these breeds also have something to offer in terms of their greater lambing ease. In particular the Highlander X Blackface, with its lower body weight and lighter mature weight, is potentially more suitable than either Mule or Highlander ewes on the more marginal upland farms where forage supply and nutritional quality can make finishing lambs off grass a challenge. The Texel X Mule achieved a good level of performance but compared with the other ewe breeds it was greatly disadvantaged by its inferior fertility. While it delivered lambs with superior carcass conformation and higher value (based on the current payment grid), this price premium did not adequately compensate for their lower output. Considering that increasing conformation was associated with a redistribution of meat within the carcass in favour of the lesser value cuts, it could be difficult for the industry to generate an adequate price premium for these better conformed lambs. Indeed this raises questions about the value of the EUROP grid to the UK sheep industry.

*Photo courtesy of Reverberate PR*

Replacing Texel rams with Primera had a smaller, yet positive, impact on flock performance compared with substituting ewe breeds. In particular the superior growth performance of Primera-sired lambs represents a major forward step for the UK sheep industry. So long as retail specifications remain linked to the EUROP grid, the marginally higher fat cover and small drop in carcass conformation of Primera-sired lambs relative to Texel leads to a price penalty at the farm gate and a reduction in their average wholesale carcass value. The latter is seen despite Primera lambs having a more favourable meat distribution profile, with their higher yields of high value cuts having potential to increase revenues within the supply chain. Changing breeding strategy had no sizeable effects on meat eating quality, which was above average for all the breeds assessed. Emphasis should be placed on ensuring abattoirs and processors implement appropriate handling and chilling regimes post-slaughter in order to guarantee a high quality end product for the consumer.

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## TABLES

TABLE 1. DETAILS OF BREED AND AGE STRUCTURE OF THE QUEENSBERRY AND BOWHILL FLOCKS AND THEIR AVERAGE LIVE WEIGHT (LW) AND BODY CONDITION SCORE (BCS) AT MATING

| Ewe breed | Year of birth | Farm | | | | | |
|---|---|---|---|---|---|---|---|
| | | Queensberry | | | Bowhill | | |
| | | No. ewes | LWT | BCS | No. ewes | LWT | BCS |
| Mule | 2007 | 189 | 65.4 | 3.82 | 156 | 65.2 | 3.81 |
| | 2009 | - | - | - | 72 | 57.3 | 3.80 |
| Texel X Mule | 2007 | 225 | 71.3 | 3.83 | - | - | - |
| | 2009 | - | - | - | - | - | - |
| Highlander X Blackface | 2007 | 411 | 55.4 | 3.72 | - | - | - |
| | 2008 | 75 | 58.0 | 3.69 | 24 | 63.2 | 3.86 |
| | 2009 | - | - | - | 117 | 50.8 | 3.64 |
| Highlander | 2007 | - | - | - | 43 | 60.0 | 3.54 |
| | 2008 | - | - | - | 30 | 56.2 | 3.47 |
| | 2009 | - | - | - | 8 | 52.4 | 3.50 |

Table 2: Nutritive value of the grass silages offered to ewes pre-lambing (predicted by near infrared spectroscopy)

| | Queensberry | | | Bowhill |
|---|---|---|---|---|
| | Grass silage 1 | Grass silage 2 | Wholecrop silage | Grass silage |
| Dry-matter (DM) (g/kg) | 432.3 | 234.7 | 220.6 | 199.9 |
| pH | 4.04 | 3.91 | 4.27 | 4.04 |
| Ammonia-N (% total N) | 6.3 | 4.6 | 3.94 | 6.19 |
| Metabolizable energy (MJ/kg DM) | 10.1 | 9.2 | 9.5 | 9.2 |
| Crude protein (g/kg DM) | 117 | 93 | 148 | 127 |
| Ash (g/kg DM) | 65.8 | 62.9 | 55.5 | 70.7 |
| D-value (%)[1] | 63.4 | 57.5 | 59.4 | 57.5 |
| Acid detergent fibre (g/kg DM) | 341 | 371 | 280 | 362 |
| Neutral detergent fibre (g/kg DM) | 533 | 589 | 536 | 575 |
| Lactic acid (g/kg total acids) | 43.9 | 38.8 | 60.0 | 44.7 |
| Starch (g/kg DM) | - | - | 226 | - |

[1] Digestible organic matter content of the dry matter

TABLE 3: EFFECTS OF EWE BREED ON LIVE WEIGHT AND BODY CONDITION SCORE THROUGHOUT THE YEAR

| | Live weight (kg) | | | | Body condition score | | | |
|---|---|---|---|---|---|---|---|---|
| Ewe breed | Mating | Pre-lambing | Post-lambing | Weaning | Mating | Pre-lambing | Post-lambing | Weaning |
| M | 61.3[b] | 66.8[c] | 64.1[c] | 62.4[b] | 3.79[c] | 3.75[c] | 3.67[b] | 3.56[b] |
| TM | 68.3[c] | 72.3[d] | 70.0[d] | 68.1[c] | 3.80[c] | 3.72[c] | 3.75[c] | 3.66[c] |
| HB | 53.2[a] | 57.2[a] | 56.7[a] | 54.7[a] | 3.69[b] | 3.65[b] | 3.70[b] | 3.57[b] |
| H | 54.0[a] | 60.4[b] | 60.1[b] | 55.8[a] | 3.48[a] | 3.53[a] | 3.53[a] | 3.33[a] |
| s.e.d | 0.70 | 0.80 | 0.84 | 0.95 | 0.028 | 0.031 | 0.031 | 0.051 |
| Significance[1] | *** | *** | *** | *** | *** | *** | *** | *** |

H, Highlander; HB, Highlander X Blackface; M, Mule; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 4: EFFECTS OF EWE BREED AND TYPE ON CHANGES IN LIVE WEIGHT AND BODY CONDITION SCORE THROUGHOUT THE YEAR

| Ewe breed | Live weight change (kg) | | | | Body condition score change | | | |
|---|---|---|---|---|---|---|---|---|
| | Mating to pre-lambing | Pre-lambing to post-lambing | Post-lambing to weaning | Mating to weaning | Mating to pre-lambing | Pre-lambing to post-lambing | Post-lambing to weaning | Mating to weaning |
| M | 5.3[b] | -0.6[a] | -1.7[b] | 1.7 | -0.04[a] | 0.04[a] | -0.13 | -0.19[b] |
| TM | 4.1[a] | -0.5[a] | -2.3[b] | 1.0 | -0.08[a] | 0.11[b] | -0.11 | -0.10[ab] |
| HB | 4.0[a] | 1.2[b] | -2.2[b] | 2.3 | -0.04[a] | 0.15[b] | -0.15 | -0.07[a] |
| H | 6.2[b] | 1.7[b] | -4.4[a] | 2.6 | 0.05[b] | 0.09[ab] | -0.21 | -0.09[ab] |
| s.e.d | 0.52 | 0.69 | 0.60 | 0.83 | 0.033 | 0.036 | 0.039 | 0.052 |
| Significance[1] | *** | *** | ** | NS | * | *** | NS | ** |

H, Highlander; HB, Highlander X Blackface; M, Mule; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 5: BINOMIAL ANALYSIS OF THE EFFECTS OF EWE AND RAM BREED ON CONCEPTION RATE AND LAMBING RATE OF EWES (BACK-TRANSFORMED MEANS IN BRACKETS)

| | Conception rate at scanning | Lambing rate |
|---|---|---|
| Ewe breed | | |
| M | 4.11 (0.984) | 2.91 (0.948) |
| TM | 3.32 (0.965) | 2.39 (0.916) |
| HB | 3.34 (0.966) | 2.91 (0.948) |
| H | 10.68 (1.000) | 2.20 (0.900) |
| s.e.d | 55.80 | 0.493 |
| | | |
| Ram breed | | |
| T | 3.38 (0.977) | 2.70 (0.937) |
| $P_{UK}$ | 6.12 (0.998) | 2.67 (0.935) |
| $P_{NZ}$ | 6.59 (0.999) | 2.43 (0.919) |
| s.e.d | 66.99 | 0.394 |
| | | |
| Significance[1] | | |
| Ewe breed (E) | NS | NS |
| Ram breed (R) | NS | NS |
| E X R | NS | NS |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

Table 6: Effects of ewe and ram breed on the fertility and fecundity of ewes

| | Lambs born | | Lambs reared to 6 weeks | | | Lambs weaned | | |
|---|---|---|---|---|---|---|---|---|
| | Per ewe mated | Per ewe lambed | Per ewe mated[1] | Per ewe lambed[1] | Per ewe lambed[2] | Per ewe mated[1] | Per ewe lambed[1] | Per ewe lambed[2] |
| Ewe breed | | | | | | | | |
| M | 1.91[bc] | 2.03[b] | 1.74[bc] | 1.85[b] | 1.72[ab] | 1.73[b] | 1.84[b] | 1.71[ab] |
| TM | 1.67[a] | 1.83[a] | 1.52[a] | 1.67[a] | 1.65[a] | 1.51[a] | 1.65[a] | 1.64[a] |
| HB | 1.79[ab] | 1.88[a] | 1.63[ab] | 1.72[ab] | 1.65[a] | 1.61[ab] | 1.70[ab] | 1.62[a] |
| H | 2.03[c] | 2.21[c] | 1.93[c] | 2.10[c] | 1.80[b] | 1.92[c] | 2.09[c] | 1.79[b] |
| s.e.d | 0.083 | 0.068 | 0.087 | 0.076 | 0.060 | 0.087 | 0.077 | 0.062 |
| | | | | | | | | |
| Ram breed | | | | | | | | |
| T | 1.81 | 1.94 | 1.65 | 1.77 | 1.64[A] | 1.64 | 1.76 | 1.63 |
| $P_{UK}$ | 1.95 | 2.08 | 1.82 | 1.95 | 1.76[B] | 1.80 | 1.93 | 1.73 |
| $P_{NZ}$ | 1.79 | 1.94 | 1.65 | 1.79 | 1.73[AB] | 1.63 | 1.77 | 1.71 |
| s.e.d | 0.068 | 0.058 | 0.070 | 0.065 | 0.051 | 0.073 | 0.070 | 0.054 |
| | | | | | | | | |
| Significance[3] | | | | | | | | |
| Ewe breed (E) | ** | *** | ** | *** | * | ** | *** | * |
| Ram breed (R) | NS | NS | NS | NS | * | NS | NS | NS |
| E X R | NS | NS | NS | NS | NS | NS | NS | NS |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Assumes all lambs were reared by their birth dam

[2] Excludes lambs fostered away but includes lambs fostered on

[3] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 7: EFFECTS OF SIRE AND DAM BREED ON LAMB BIRTH WEIGHT, MORTALITY AND PERFORMANCE UP TO WEANING

| | Birth weight (kg) | Weight at 6 weeks (kg) | Birth to 6 weeks LWG (g/d) | Weight at weaning (kg) | Birth to weaning LWG (g/d) |
|---|---|---|---|---|---|
| Dam breed | | | | | |
| M | $4.8^{b}$ | $22.9^{b}$ | 302 | 34.3 | 242 |
| TM | $4.9^{b}$ | $23.3^{b}$ | 313 | 35.1 | 246 |
| HB | $3.9^{a}$ | $21.7^{ab}$ | 296 | 33.7 | 242 |
| H | $4.0^{a}$ | $21.2^{a}$ | 289 | 32.5 | 243 |
| s.e.d | 0.08 | 0.87 | 13.6 | 1.24 | 10.6 |
| | | | | | |
| Sire breed | | | | | |
| T | 4.5 | 22.1 | 298 | $33.0^{A}$ | $235^{A}$ |
| $P_{UK}$ | 4.4 | 22.3 | 301 | $34.2^{B}$ | $247^{B}$ |
| $P_{NZ}$ | 4.4 | 22.3 | 302 | $34.5^{B}$ | $247^{B}$ |
| s.e.d | 0.07 | 0.26 | 3.9 | 0.42 | 3.4 |
| | | | | | |
| Significance[1] | | | | | |
| Dam breed (E) | *** | ** | NS | NS | NS |
| Sire breed (R) | NS | NS | NS | *** | *** |
| E X R | NS | NS | NS | NS | NS |

FP, foster and pet lambs; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

Table 8: Binomial analysis of the effects of sire and dam breed on lamb mortality at birth, 6 weeks post-lambing and at weaning (back-transformed means in brackets)

| | Mortality at birth (prop. lambs born) | Mortality at 6 weeks (prop. lambs born) | | Mortality at weaning (prop. lambs born) | |
|---|---|---|---|---|---|
| | | Incl. FP | Excl. FP | Incl. FP | Excl. FP |
| Dam breed | | | | | |
| M | -3.35 (0.034) | -3.10 (0.043) | -2.12 (0.108) | -3.04 (0.046) | -2.11 (0.108) |
| TM | -3.77 (0.023) | -2.46 (0.079) | -2.21 (0.099) | -2.47 (0.078) | -2.19 (0.101) |
| HB | -3.32 (0.035) | -3.13 (0.042) | -2.35 (0.087) | -2.82 (0.056) | -2.18 (0.101) |
| H | -4.47 (0.011) | -3.29 (0.036) | -1.93 (0.127) | -3.14 (0.041) | -1.92 (0.128) |
| s.e.d | 0.378 | 0.426 | 0.335 | 0.392 | 0.322 |
| | | | | | |
| Sire breed | | | | | |
| T | -3.48 (0.030) | -2.75 (0.060) | -2.19 (0.101) | -2.80 (0.058) | -2.23 (0.097) |
| $P_{UK}$ | -3.79 (0.022) | -3.28 (0.036) | -2.20 (0.100) | -2.98 (0.048) | -2.00 (0.111) |
| $P_{NZ}$ | -3.91 (0.020) | -2.95 (0.050) | -2.06 (0.113) | -2.82 (0.056) | -2.08 (0.120) |
| s.e.d | 0.324 | 0.380 | 0.294 | 0.351 | 0.277 |
| | | | | | |
| Significance[1] | | | | | |
| Dam breed (E) | NS | NS | NS | NS | NS |
| Sire breed (R) | NS | NS | NS | NS | NS |
| E X R | NS | NS | NS | NS | NS |

FP, foster and pet lambs; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 9: EFFECTS OF EWE AND RAM BREED ON LAMB OUTPUT AND OUTPUT EFFICIENCY OF EWES

| | Total birth weight (kg) | Total 6 week weight (kg/ewe) | | Total weight weaned (kg) | | Lamb output efficiency(kg)[1] | | |
|---|---|---|---|---|---|---|---|---|
| | | Born[1] | Reared[2] | Born[1] | Reared[2] | Per kg LW | Per kg LW$^{0.75}$ | Per kg LW put to the ram |
| Ewe breed | | | | | | | | |
| M | 9.7$^{c}$ | 41.1$^{c}$ | 39.5$^{b}$ | 63.7$^{bc}$ | 61.5$^{b}$ | 1.04$^{b}$ | 2.91$^{c}$ | 0.99$^{b}$ |
| TM | 9.1$^{b}$ | 39.9$^{bc}$ | 39.9$^{b}$ | 60.0$^{b}$ | 60.3$^{b}$ | 0.88$^{a}$ | 2.53$^{a}$ | 0.81$^{a}$ |
| HB | 7.5$^{a}$ | 34.2$^{a}$ | 34.0$^{a}$ | 53.8$^{a}$ | 53.4$^{a}$ | 1.03$^{b}$ | 2.77$^{b}$ | 0.98$^{b}$ |
| H | 8.6$^{b}$ | 38.0$^{b}$ | 34.9$^{a}$ | 59.0$^{b}$ | 54.6$^{a}$ | 1.11$^{b}$ | 3.00$^{c}$ | 1.00$^{b}$ |
| s.e.d | 0.27 | 1.43 | 0.99 | 2.34 | 1.56 | 0.039 | 0.106 | 0.037 |
| Ram breed | | | | | | | | |
| T | 8.7 | 38.1 | 36.3 | 57.4 | 55.3$^{A}$ | 0.99 | 2.73 | 0.93 |
| $P_{UK}$ | 9.0 | 39.6 | 37.5 | 61.9 | 58.7$^{B}$ | 1.06 | 2.92 | 0.99 |
| $P_{NZ}$ | 8.6 | 37.2 | 37.3 | 58.1 | 58.3$^{B}$ | 1.00 | 2.76 | 0.92 |
| s.e.d | 0.24 | 1.28 | 0.76 | 2.26 | 1.25 | 0.038 | 0.104 | 0.036 |
| Significance[3] | | | | | | | | |
| Ewe breed (E) | *** | *** | *** | *** | *** | *** | *** | *** |
| Ram breed (R) | NS | NS | NS | NS | ** | NS | NS | NS |
| E X R | NS | NS | NS | NS | NS | NS | NS | NS |

H, Highlander; HB, Highlander X Blackface; LW, ewe live weight at mating; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Assumes all lambs were reared by their birth dam

[2] Excludes lambs fostered away but includes lambs fostered on

[3] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 10: EFFECTS OF EWE AND RAM BREED ON THE LEVEL OF DYSTOCIA IN EWES

| | Proportions of ewes given | | |
|---|---|---|---|
| | No assistance | Minor assistance | Moderate or major assistance |
| Ewe breed | | | |
| M | 0.832[a] | 0.068[d] | 0.101[c] |
| TM | 0.905[c] | 0.042[b] | 0.054[a] |
| HB | 0.932[d] | 0.030[a] | 0.038[a] |
| H | 0.861[b] | 0.058[c] | 0.081[b] |
| s.e.d | 0.0130 | 0.0051 | 0.0079 |
| | | | |
| Ram breed | | | |
| T | 0.875 | 0.052 | 0.073 |
| $P_{UK}$ | 0.902 | 0.041 | 0.057 |
| $P_{NZ}$ | 0.900 | 0.042 | 0.058 |
| s.e.d | 0.0111 | 0.0042 | 0.0069 |
| | | | |
| Significance[1] | | | |
| Ewe breed (E) | ** | | |
| Ram breed (R) | NS | | |
| E X R | NS | | |

H, Highlander; HB, Highlander X Blackface; M, Mule $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

Table 11: Effects of ewe and ram breed on the mothering ability of ewes (back-transformed means in brackets, where applicable)

| | Proportions of ewes | | | Mean following score | Proportions of ewes with | | | Mean colostrum score |
|---|---|---|---|---|---|---|---|---|
| | Follow closely | Follow at a distance | Leave lambs | | Adequate colostrum | Limited colostrum | No colostrum | |
| Ewe breed | | | | | | | | |
| M | $0.959^{b}$ | $0.039^{c}$ | $0.002^{b}$ | $1.09^{b}$ | $0.951^{b}$ | $0.043^{c}$ | $0.006^{b}$ | $1.07^{ab}$ |
| TM | $0.995^{c}$ | $0.005^{b}$ | $0.000^{a}$ | $1.02^{a}$ | $0.966^{c}$ | $0.031^{b}$ | $0.004^{a}$ | $1.05^{a}$ |
| HB | $0.605^{a}$ | $0.366^{d}$ | $0.029^{c}$ | $1.44^{c}$ | $0.908^{a}$ | $0.080^{d}$ | $0.011^{c}$ | $1.11^{b}$ |
| H | $1.000^{d}$ | $0.000^{a}$ | $0.000^{a}$ | $1.11^{b}$ | $0.974^{d}$ | $0.023^{a}$ | $0.003^{a}$ | $1.04^{a}$ |
| s.e.d | 0.0019 | 0.0018 | 0.0001 | 0.046 | 0.0027 | 0.0023 | 0.0003 | 0.033 |
| Ram breed | | | | | | | | |
| T | 0.830 | 0.158 | 0.011 | 1.14 | 0.945 | 0.048 | 0.007 | 1.06 |
| $P_{UK}$ | 0.794 | 0.191 | 0.015 | 1.17 | 0.940 | 0.053 | 0.007 | 1.06 |
| $P_{NZ}$ | 0.783 | 0.201 | 0.017 | 1.17 | 0.919 | 0.071 | 0.010 | 1.08 |
| s.e.d | 0.0133 | 0.0123 | 0.0010 | 0.036 | 0.0023 | 0.0020 | 0.0003 | 0.027 |
| Significance[1] | | | | | | | | |
| Ewe breed (E) | *** | | | *** | * | | | * |
| Ram breed (R) | NS | | | NS | NS | | | NS |
| E X R | NS | | | NS | NS | | | NS |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 12: EFFECTS OF SIRE AND DAM BREED ON THE PROPORTIONS OF LAMBS REQUIRING INTERVENTION AT LAMBING AND THE MAIN REASONS FOR INTERVENING

| | Lambing difficulty score | | | Reasons for intervening | | |
|---|---|---|---|---|---|---|
| | Unassisted | Minor assistance | Moderate or major assistance | Management | Oversized | Malpresented |
| Dam breed | | | | | | |
| M | 0.879[a] | 0.045[c] | 0.076[d] | 0.315[b] | 0.378[b] | 0.306[a] |
| TM | 0.934[c] | 0.027[b] | 0.039[b] | 0.324[b] | 0.325[a] | 0.361[a] |
| HB | 0.959[d] | 0.017[a] | 0.025[a] | 0.147[a] | 0.279[a] | 0.573[b] |
| H | 0.924[b] | 0.030[b] | 0.046[c] | 0.447[b] | 0.287[a] | 0.266[a] |
| s.e.d | 0.0032 | 0.0012 | 0.0020 | 0.0669 | 0.0321 | 0.0649 |
| | | | | | | |
| Sire breed | | | | | | |
| T | 0.921 | 0.031 | 0.049 | 0.293[B] | 0.366[B] | 0.341[A] |
| $P_{UK}$ | 0.936 | 0.025 | 0.039 | 0.386[C] | 0.322[A] | 0.292[A] |
| $P_{NZ}$ | 0.924 | 0.030 | 0.047 | 0.183[A] | 0.321[A] | 0.496[B] |
| s.e.d | 0.0034 | 0.0012 | 0.0022 | 0.0389 | 0.0210 | 0.0443 |
| | | | | | | |
| Significance[1] | | | | | | |
| Dam breed (E) | *** | | | * | | |
| Sire breed (R) | NS | | | ** | | |
| E X R | NS | | | ** | | |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 13: EFFECTS OF SIRE AND DAM BREED ON THE VIABILITY OF THEIR LAMBS AT BIRTH

| | Proportion of lambs | | | Mean viability score |
|---|---|---|---|---|
| | Up and suckled | Slow to suckle | Helped to suckle | |
| Dam breed | | | | |
| M | 0.967 | 0.017 | 0.016 | 1.05 |
| TM | 0.987 | 0.007 | 0.006 | 1.04 |
| HB | 0.974 | 0.014 | 0.012 | 1.05 |
| H | 0.944 | 0.029 | 0.027 | 1.08 |
| s.e.d | 0.0029 | 0.0014 | 0.0015 | 0.026 |
| | | | | |
| Sire breed | | | | |
| T | 0.968 | 0.016 | 0.015 | 1.05 |
| $P_{UK}$ | 0.974 | 0.014 | 0.012 | 1.05 |
| $P_{NZ}$ | 0.973 | 0.014 | 0.013 | 1.07 |
| s.e.d | 0.0019 | 0.0010 | 0.0010 | 0.021 |
| | | | | |
| Significance[1] | | | | |
| Dam breed (E) | NS | | | NS |
| Sire breed (R) | NS | | | NS |
| E X R | NS | | | NS |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 14: EWE AND LAMB PERFORMANCE DATA AT QUEENSBERRY ESTATE COMPARING THE FOCUS GENETICS PRODUCTION MODEL LAMBING OUTDOORS WITH A 'TYPICAL' LOWLAND FLOCK LAMBING INDOORS

| | Outdoor lambing | Indoor lambing |
|---|---|---|
| No. ewes | 190 | 232 |
| Ewe breed(s) | 1st-cross Highlander X Blackface ewes (67)<br>2nd-cross Highlander X Blackface gimmers (123) | Mule |
| Ram breed | UK-bred Primera | Texel |
| Litter sizes | Singles & twins | Singles & twins |
| Lambs born/ewe | 1.63 | 1.77 |
| Lambing period | 15th April – 20th May | 20th March – 30th April |
| Level of supervision | 3x daily checks | Constant |
| Degree of assistance given | Minimal | 7.3% ewes assisted |
| Lambs reared to 6 weeks/ewe | 1.55 | 1.70 |
| Lambs weaned/ewe | 1.52 | 1.69 |
| Lamb mortality from birth | 4.9% | 4.5% |
| Av. lamb weight on 1st June (kg) | 16.3 kg | 20.9 |
| Av. lamb weight on 2nd August (kg) | 30.7 kg | 33.2 |
| Est. lamb growth rate (June - August) (g/d) | 232 | 202 |

TABLE 15: EFFECTS OF SIRE AND DAM BREED ON THE LIFETIME PERFORMANCE, SLAUGHTER WEIGHT AND SLAUGHTER AGE OF LAMBS AT A RANGE OF ENDPOINTS

| | Lifetime LWG (g/d) | | | | Slaughter weight (kg) | | | | Age at slaughter (days) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| End point | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L |
| Dam breed | | | | | | | | | | | | |
| M | 210$^{ab}$ | 208$^{ab}$ | 207$^{ab}$ | 207 | 39.8 | 41.1 | 42.4 | 41.6$^{ab}$ | 176$^{ab}$ | 185$^{ab}$ | 194$^{ab}$ | 190 |
| TM | 211$^{ab}$ | 209$^{ab}$ | 208$^{ab}$ | 206 | 39.7 | 41.0 | 42.3 | 41.9$^{ab}$ | 173$^{a}$ | 182$^{a}$ | 192$^{a}$ | 191 |
| HB | 189$^{a}$ | 188$^{a}$ | 186$^{a}$ | 189 | 39.2 | 40.5 | 41.8 | 40.4$^{a}$ | 193$^{b}$ | 203$^{b}$ | 212$^{b}$ | 200 |
| H | 215$^{b}$ | 213$^{b}$ | 212$^{b}$ | 214 | 39.1 | 40.4 | 41.7 | 42.1$^{b}$ | 180$^{ab}$ | 190$^{ab}$ | 199$^{ab}$ | 197 |
| s.e.d | 15.3 | | | 16.7 | 0.59 | | | 0.91 | 14.4 | | | 16.0 |
| | | | | | | | | | | | | |
| Sire breed | | | | | | | | | | | | |
| T | 192$^{A}$ | 191$^{A}$ | 189$^{A}$ | 188$^{A}$ | 38.9$^{A}$ | 40.2$^{A}$ | 41.5$^{A}$ | 41.4 | 192$^{B}$ | 201$^{B}$ | 210$^{B}$ | 212$^{B}$ |
| $P_{UK}$ | 211$^{B}$ | 210$^{B}$ | 208$^{B}$ | 211$^{B}$ | 39.5$^{B}$ | 40.8$^{B}$ | 42.1$^{B}$ | 41.3 | 177$^{A}$ | 186$^{A}$ | 195$^{A}$ | 187$^{A}$ |
| $P_{NZ}$ | 215$^{B}$ | 214$^{B}$ | 212$^{B}$ | 214$^{B}$ | 39.9$^{B}$ | 41.2$^{B}$ | 42.5$^{B}$ | 41.8 | 174$^{A}$ | 183$^{A}$ | 192$^{A}$ | 186$^{A}$ |
| s.e.d | 5.0 | | | 5.7 | 0.24 | | | 0.36 | 4.4 | | | 4.7 |
| | | | | | | | | | | | | |
| Significance | | | | | | | | | | | | |
| Dam breed (E) | * | | | NS | NS | | | ** | ** | | | NS |
| Sire breed (R) | *** | | | *** | ** | | | NS | *** | | | *** |
| E X R | NS | | | NS | NS | | | NS | NS | | | * |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule;
Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).
[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 16: EFFECTS OF SIRE AND DAM BREED ON CARCASS WEIGHT, CONFORMATION AND FAT SCORE OF LAMBS SLAUGHTERED AT A RANGE OF ENDPOINTS

| | Carcass weight (kg) | Conformation Score | | | | Fat score | | | Killing-out % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| End point | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L |
| Dam breed | | | | | | | | | | | | |
| M | 19.4$^{ab}$ | 2.93$^{a}$ | 3.08$^{a}$ | 3.23$^{a}$ | 3.16$^{a}$ | 2.65$^{a}$ | 2.84$^{a}$ | 3.04$^{a}$ | 45.4 | 46.3 | 47.2 | 46.8 |
| TM | 19.7$^{ab}$ | 3.57$^{b}$ | 3.72$^{b}$ | 3.87$^{b}$ | 3.85$^{b}$ | 2.52$^{a}$ | 2.71$^{a}$ | 2.91$^{a}$ | 45.5 | 46.4 | 47.3 | 47.2 |
| HB | 18.8$^{a}$ | 3.12$^{a}$ | 3.27$^{a}$ | 3.42$^{a}$ | 3.24$^{a}$ | 2.92$^{b}$ | 3.12$^{b}$ | 3.31$^{b}$ | 46.1 | 47.0 | 47.9 | 46.8 |
| H | 20.2$^{b}$ | 3.18$^{a}$ | 3.34$^{a}$ | 3.49$^{a}$ | 3.49$^{ab}$ | 2.78$^{ab}$ | 2.97$^{ab}$ | 3.17$^{ab}$ | 46.2 | 47.1 | 48.0 | 48.1 |
| s.e.d | 0.45 | 0.170 | | | 0.195 | 0.158 | | | 0.68 | | | 0.82 |
| | | | | | | | | | | | | |
| Sire breed | | | | | | | | | | | | |
| T | 20.0$^{B}$ | 3.58$^{B}$ | 3.73$^{B}$ | 3.88$^{B}$ | 3.89$^{B}$ | 2.51$^{A}$ | 2.70$^{A}$ | 2.90$^{A}$ | 46.4$^{B}$ | 47.3$^{B}$ | 48.3$^{B}$ | 48.3$^{B}$ |
| $P_{UK}$ | 19.3$^{A}$ | 3.06$^{A}$ | 3.21$^{A}$ | 3.36$^{A}$ | 3.24$^{A}$ | 2.87$^{B}$ | 3.06$^{B}$ | 3.26$^{B}$ | 45.7$^{A}$ | 46.7$^{A}$ | 47.6$^{A}$ | 46.9$^{A}$ |
| $P_{NZ}$ | 19.4$^{A}$ | 2.97$^{A}$ | 3.12$^{A}$ | 3.27$^{A}$ | 3.17$^{A}$ | 2.77$^{B}$ | 2.97$^{B}$ | 3.16$^{B}$ | 45.2$^{A}$ | 46.2$^{A}$ | 47.1$^{A}$ | 46.5$^{A}$ |
| s.e.d | 0.16 | 0.073 | | | 0.078 | 0.052 | | | 0.27 | | | 0.30 |
| | | | | | | | | | | | | |
| Significance[1] | | | | | | | | | | | | |
| Dam breed (E) | *** | *** | | | *** | *** | | | NS | | | NS |
| Sire breed (R) | *** | *** | | | *** | *** | | | ** | | | *** |
| E X R | NS | * | | | ** | NS | | | NS | | | NS |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule;
Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).
[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

Table 17: Effects of sire and dam breed on the proportions of lambs achieving each conformation grade (EUROP) and fat class (MLC classification system) when slaughtered at a constant carcass weight (19.5 kg)

| | Conformation grade | | | | Fat class | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | E | U | R | O | 2 | 3L | 3H | 4L | 4H/5 |
| Dam breed | | | | | | | | | |
| M | 0.032[a] | 0.203[a] | 0.670[c] | 0.095[c] | 0.208[b] | 0.502[ab] | 0.198[b] | 0.080[b] | 0.013[b] |
| TM | 0.182[c] | 0.367[c] | 0.429[a] | 0.021[a] | 0.321[c] | 0.485[a] | 0.139[a] | 0.048[a] | 0.007[a] |
| HB | 0.059[b] | 0.273[b] | 0.610[b] | 0.059[b] | 0.144[a] | 0.486[a] | 0.238[c] | 0.112[d] | 0.021[c] |
| H | 0.041[a] | 0.233[a] | 0.652[c] | 0.075[b] | 0.146[a] | 0.513[b] | 0.232[c] | 0.095[c] | 0.015[b] |
| s.e.d | 0.0075 | 0.0123 | 0.0148 | 0.0095 | 0.0118 | 0.0095 | 0.0084 | 0.0063 | 0.0010 |
| | | | | | | | | | |
| Sire breed | | | | | | | | | |
| T | 0.159[C] | 0.429[C] | 0.399[A] | 0.014[A] | 0.292[C] | 0.511[B] | 0.144[A] | 0.046[A] | 0.007[A] |
| $P_{UK}$ | 0.032[B] | 0.214[B] | 0.686[B] | 0.069[B] | 0.130[A] | 0.469[A] | 0.254[C] | 0.124[C] | 0.023[C] |
| $P_{NZ}$ | 0.021[A] | 0.153[A] | 0.714[C] | 0.112[C] | 0.166[B] | 0.499[B] | 0.223[B] | 0.096[B] | 0.016[B] |
| s.e.d | 0.0045 | 0.0072 | 0.0086 | 0.0032 | 0.0088 | 0.0071 | 0.0059 | 0.0048 | 0.0014 |
| | | | | | | | | | |
| Significance[1] | | | | | | | | | |
| Dam breed (E) | *** | | | | *** | | | | |
| Sire breed (R) | *** | | | | *** | | | | |
| E X R | NS | | | | NS | | | | |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 18: EFFECTS OF SIRE AND DAM BREED ON THE PROPORTIONS OF LAMBS ACHIEVING EACH CONFORMATION GRADE (EUROP) WHEN SLAUGHTERED AT A CONSTANT FAT CLASS (3L)

| | Conformation grade | | | |
|---|---|---|---|---|
| | E | U | R | O |
| Dam breed | | | | |
| M | $0.032^{a}$ | $0.203^{a}$ | $0.669^{c}$ | $0.096^{d}$ |
| TM | $0.184^{c}$ | $0.370^{d}$ | $0.425^{a}$ | $0.021^{a}$ |
| HB | $0.059^{b}$ | $0.273^{c}$ | $0.609^{b}$ | $0.060^{b}$ |
| H | $0.041^{a}$ | $0.237^{b}$ | $0.646^{c}$ | $0.076^{c}$ |
| s.e.d | 0.0067 | 0.0111 | 0.0135 | 0.0042 |
| | | | | |
| Sire breed | | | | |
| T | $0.161^{C}$ | $0.430^{C}$ | $0.395^{A}$ | $0.014^{A}$ |
| $P_{UK}$ | $0.032^{B}$ | $0.216^{B}$ | $0.683^{B}$ | $0.069^{B}$ |
| $P_{NZ}$ | $0.021^{A}$ | $0.153^{A}$ | $0.714^{C}$ | $0.113^{C}$ |
| s.e.d | 0.0040 | 0.0062 | 0.0074 | 0.0026 |
| | | | | |
| Significance[1] | | | | |
| Dam breed (E) | *** | | | |
| Sire breed (R) | *** | | | |
| E X R | * | | | |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 19: EFFECTS OF SIRE AND DAM BREED ON THE WEIGHTS OF PRIMAL JOINTS (UNTRIMMED) FROM LAMB CARCASSES SLAUGHTERED AT A RANGE OF ENDPOINTS

| | Shoulder (kg) | | | | Saddle (kg) | | | | Legs (kg) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| End point | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L |
| Dam breed | | | | | | | | | | | | |
| M | 6.41 | 6.69 | 6.96 | 6.83$^{b}$ | 5.08$^{b}$ | 5.39$^{b}$ | 5.71$^{b}$ | 5.61$^{b}$ | 6.21$^{ab}$ | 6.48$^{ab}$ | 6.75$^{ab}$ | 6.64$^{b}$ |
| TM | 6.46 | 6.73 | 7.01 | 6.99$^{b}$ | 4.92$^{a}$ | 5.23$^{a}$ | 5.55$^{a}$ | 5.62$^{b}$ | 6.38$^{c}$ | 6.65$^{c}$ | 6.92$^{c}$ | 6.95$^{c}$ |
| HB | 6.40 | 6.67 | 6.95 | 6.57$^{a}$ | 5.10$^{b}$ | 5.42$^{b}$ | 5.73$^{b}$ | 5.32$^{a}$ | 6.18$^{a}$ | 6.45$^{a}$ | 6.72$^{a}$ | 6.37$^{a}$ |
| H | 6.31 | 6.58 | 6.86 | 6.61$^{a}$ | 5.05$^{b}$ | 5.36$^{b}$ | 5.68$^{b}$ | 5.38$^{a}$ | 6.28$^{b}$ | 6.55$^{b}$ | 6.82$^{b}$ | 6.59$^{b}$ |
| s.e.d | 0.054 | | | 0.082 | 0.058 | | | 0.078 | 0.042 | | | 0.070 |
| Sire breed | | | | | | | | | | | | |
| T | 6.49$^{B}$ | 6.76$^{B}$ | 7.04$^{B}$ | 6.93$^{B}$ | 4.94$^{A}$ | 5.26$^{A}$ | 5.57$^{A}$ | 5.54 | 6.37$^{C}$ | 6.64$^{C}$ | 6.91$^{C}$ | 6.82$^{B}$ |
| $P_{UK}$ | 6.35$^{A}$ | 6.63$^{A}$ | 6.90$^{A}$ | 6.68$^{A}$ | 5.10$^{B}$ | 5.42$^{B}$ | 5.73$^{B}$ | 5.47 | 6.17$^{A}$ | 6.44$^{A}$ | 6.71$^{A}$ | 6.51$^{A}$ |
| $P_{NZ}$ | 6.34$^{A}$ | 6.62$^{A}$ | 6.89$^{A}$ | 6.64$^{A}$ | 5.07$^{B}$ | 5.38$^{B}$ | 5.69$^{B}$ | 5.45 | 6.25$^{B}$ | 6.52$^{B}$ | 6.79$^{B}$ | 6.57$^{A}$ |
| s.e.d | 0.041 | | | 0.060 | 0.046 | | | 0.082 | 0.032 | | | 0.059 |
| Significance[1] | | | | | | | | | | | | |
| Dam breed (E) | NS | | | *** | ** | | | *** | *** | | | *** |
| Sire breed (R) | ** | | | *** | *** | | | NS | *** | | | *** |
| E X R | NS | | | NS | NS | | | NS | NS | | | NS |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule;
Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).
[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 20: EFFECTS OF SIRE AND DAM BREED ON THE DISTRIBUTION OF SALEABLE MEAT WITHIN CARCASSES (UNTRIMMED) OF LAMBS SLAUGHTERED AT A RANGE OF ENDPOINTS

| | Shoulder (%) | | | | Saddle (%) | | | | Leg (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| End point | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L |
| Dam breed | | | | | | | | | | | | |
| M | 36.2 | 36.0 | 35.8 | 35.9 | $28.6^{b}$ | $29.0^{b}$ | $29.4^{b}$ | $29.4^{b}$ | $35.1^{a}$ | $34.9^{a}$ | $34.8^{a}$ | $34.8^{a}$ |
| TM | 36.3 | 36.1 | 35.9 | 35.8 | $27.7^{a}$ | $28.0^{a}$ | $28.4^{a}$ | $28.6^{a}$ | $36.0^{c}$ | $35.8^{c}$ | $35.6^{c}$ | $35.5^{b}$ |
| HB | 36.3 | 36.1 | 35.9 | 36.2 | $28.7^{b}$ | $29.1^{b}$ | $29.5^{b}$ | $29.0^{ab}$ | $34.9^{a}$ | $34.8^{a}$ | $34.6^{a}$ | $34.8^{a}$ |
| H | 35.9 | 35.7 | 35.5 | 35.7 | $28.6^{b}$ | $29.0^{b}$ | $29.4^{b}$ | $28.9^{ab}$ | $35.6^{b}$ | $35.4^{b}$ | $35.2^{b}$ | $35.4^{b}$ |
| s.e.d | 0.23 | | | 0.24 | 0.28 | | | 0.28 | 0.18 | | | 0.18 |
| | | | | | | | | | | | | |
| Sire breed | | | | | | | | | | | | |
| T | $36.5^{B}$ | $36.3^{B}$ | $36.1^{B}$ | $36.1^{B}$ | $27.7^{A}$ | $28.1^{A}$ | $28.5^{A}$ | $28.6^{A}$ | $35.8^{C}$ | $35.6^{C}$ | $35.4^{C}$ | $35.3^{B}$ |
| $P_{UK}$ | $36.1^{A}$ | $35.9^{A}$ | $35.7^{A}$ | $35.9^{AB}$ | $28.8^{B}$ | $29.2^{B}$ | $29.6^{B}$ | $29.2^{B}$ | $35.1^{A}$ | $34.9^{A}$ | $34.7^{A}$ | $34.9^{A}$ |
| $P_{NZ}$ | $35.9^{A}$ | $35.7^{A}$ | $35.5^{A}$ | $35.7^{A}$ | $28.7^{B}$ | $29.1^{B}$ | $29.5^{B}$ | $29.2^{B}$ | $35.4^{B}$ | $35.2^{B}$ | $35.0^{B}$ | $35.2^{AB}$ |
| s.e.d | 0.18 | | | 0.20 | 0.22 | | | 0.26 | 0.15 | | | 0.17 |
| | | | | | | | | | | | | |
| Significance[1] | | | | | | | | | | | | |
| Dam breed (E) | NS | | | NS | *** | | | * | *** | | | *** |
| Sire breed (R) | ** | | | * | *** | | | * | *** | | | * |
| E X R | NS | | | NS | NS | | | NS | NS | | | NS |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule;
Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 21: EFFECTS OF SIRE AND DAM BREED ON THE LENGTH OF SADDLE, EYE MUSCLE AREA AND LOIN INDEX (LI) OF LAMB CARCASS SLAUGHTERED AT A RANGE OF ENDPOINTS

| | Saddle length (mm) | | | | Eye muscle area ($cm^2$) | | | | Loin Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| End point | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L |
| Dam breed | | | | | | | | | | | | |
| M | $359^{c}$ | $364^{c}$ | $369^{c}$ | $367^{c}$ | $13.1^{a}$ | $13.5^{a}$ | $13.9^{a}$ | $13.9^{a}$ | $466^{ab}$ | $490^{ab}$ | $514^{ab}$ | $514^{ab}$ |
| TM | $349^{a}$ | $354^{a}$ | $359^{a}$ | $359^{ab}$ | $14.2^{b}$ | $14.6^{b}$ | $15.0^{b}$ | $15.2^{b}$ | $495^{b}$ | $519^{b}$ | $543^{b}$ | $551^{b}$ |
| HB | $353^{ab}$ | $357^{ab}$ | $362^{ab}$ | $356^{a}$ | $13.1^{a}$ | $13.5^{a}$ | $13.9^{a}$ | $13.6^{a}$ | $457^{a}$ | $481^{a}$ | $504^{a}$ | $487^{a}$ |
| H | $358^{bc}$ | $363^{bc}$ | $368^{bc}$ | $364^{bc}$ | $13.3^{a}$ | $13.7^{a}$ | $14.1^{a}$ | $14.1^{a}$ | $473^{ab}$ | $497^{ab}$ | $521^{ab}$ | $516^{ab}$ |
| s.e.d | 2.5 | | | 2.8 | 0.44 | | | 0.49 | 17.6 | | | 20.5 |
| Sire breed | | | | | | | | | | | | |
| T | $347^{A}$ | $352^{A}$ | $357^{A}$ | $356^{A}$ | $14.0^{B}$ | $14.5^{B}$ | $14.9^{B}$ | 14.8 | 480 | 504 | 527 | 522 |
| $P_{UK}$ | $357^{B}$ | $362^{B}$ | $365^{B}$ | $363^{B}$ | $12.9^{A}$ | $13.3^{A}$ | $13.7^{A}$ | 13.8 | 461 | 485 | 508 | 511 |
| $P_{NZ}$ | $360^{B}$ | $365^{B}$ | $370^{B}$ | $366^{B}$ | $13.4^{AB}$ | $13.8^{AB}$ | $14.2^{AB}$ | 14.1 | 478 | 502 | 526 | 518 |
| s.e.d | 2.2 | | | 2.7 | 0.36 | | | 0.47 | 13.5 | | | 18.5 |
| Significance[1] | | | | | | | | | | | | |
| Dam breed (E) | *** | | | *** | ** | | | *** | * | | | *** |
| Sire breed (R) | *** | | | ** | * | | | NS | NS | | | NS |
| E X R | NS | | | NS | NS | | | NS | NS | | | NS |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule;
Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).
[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 22: EFFECTS OF SIRE AND DAM BREED ON THE WEIGHTS OF THE RACK, LOIN AND TRIM OBTAINED FROM THE TRIMMED SADDLE.

| | Rack (kg) | | | | Loin (kg) | | | | Trim (kg)[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| End point | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L |
| Dam breed | | | | | | | | | | | | |
| M | $1.44^{ab}$ | $1.56^{ab}$ | $1.67^{ab}$ | 1.63 | $1.92^{b}$ | $2.06^{b}$ | $2.20^{b}$ | $2.16^{b}$ | $1.72^{c}$ | $1.78^{c}$ | $1.84^{c}$ | $1.82^{b}$ |
| TM | $1.42^{a}$ | $1.53^{a}$ | $1.64^{a}$ | 1.67 | $1.83^{a}$ | $1.97^{a}$ | $2.11^{a}$ | $2.15^{b}$ | $1.68^{bc}$ | $1.74^{bc}$ | $1.80^{bc}$ | $1.81^{b}$ |
| HB | $1.52^{c}$ | $1.63^{c}$ | $1.74^{c}$ | 1.60 | $1.97^{c}$ | $2.11^{c}$ | $2.25^{c}$ | $2.07^{a}$ | $1.62^{ab}$ | $1.68^{ab}$ | $1.74^{ab}$ | $1.66^{a}$ |
| H | $1.50^{bc}$ | $1.62^{bc}$ | $1.73^{bc}$ | 1.63 | $2.01^{c}$ | $2.16^{c}$ | $2.30^{c}$ | $2.17^{b}$ | $1.54^{a}$ | $1.60^{a}$ | $1.66^{a}$ | $1.60^{a}$ |
| s.e.d | 0.032 | | | 0.039 | 0.025 | | | 0.034 | 0.041 | | | 0.044 |
| | | | | | | | | | | | | |
| Sire breed | | | | | | | | | | | | |
| T | $1.42^{A}$ | $1.53^{A}$ | $1.64^{A}$ | 1.62 | $1.86^{A}$ | $2.01^{A}$ | $2.15^{A}$ | 2.13 | 1.67 | 1.73 | 1.79 | 1.78 |
| $P_{UK}$ | $1.51^{B}$ | $1.62^{B}$ | $1.73^{B}$ | 1.64 | $1.97^{B}$ | $2.11^{B}$ | $2.25^{B}$ | 2.14 | 1.63 | 1.69 | 1.75 | 1.70 |
| $P_{NZ}$ | $1.49^{B}$ | $1.60^{B}$ | $1.71^{B}$ | 1.62 | $1.96^{B}$ | $2.10^{B}$ | $2.25^{B}$ | 2.14 | 1.62 | 1.68 | 1.74 | 1.69 |
| s.e.d | 0.026 | | | 0.037 | 0.024 | | | 0.031 | 0.032 | | | 0.040 |
| | | | | | | | | | | | | |
| Significance | | | | | | | | | | | | |
| Dam breed (E) | *** | | | NS | *** | | | *** | *** | | | *** |
| Sire breed (R) | *** | | | NS | *** | | | NS | NS | | | NS |
| E X R | NS | | | NS | NS | | | NS | NS | | | NS |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule;
Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Predominantly the flanks plus some bone and excess fat removed.

[2] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

## TABLE 23: EFFECTS OF SIRE AND DAM BREED ON THE COMPOSITION OF THE TRIMMED SADDLE TAKEN FROM LAMBS SLAUGHTERED AT A RANGE OF ENDPOINTS

| | Rack (%) | | | | Loin (%) | | | | Trim (%)[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| End point | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L | 18 kg CWT | 19 kg CWT | 20 kg CWT | Fat class 3L |
| Dam breed | | | | | | | | | | | | |
| M | 28.6[a] | 28.9[a] | 29.2[a] | 29.1[a] | 37.9[ab] | 38.3[ab] | 38.7[ab] | 38.5[a] | 33.5[c] | 32.8[c] | 32.2[c] | 32.4[c] |
| TM | 29.0[ab] | 29.3[ab] | 29.6[ab] | 29.6[ab] | 37.4[a] | 37.8[a] | 38.2[a] | 38.2[a] | 33.7[c] | 33.0[c] | 32.3[c] | 32.2[bc] |
| HB | 29.7[b] | 30.0[b] | 30.3[b] | 29.9[ab] | 38.6[b] | 39.0[b] | 39.4[b] | 38.9[a] | 31.7[b] | 31.0[b] | 30.3[b] | 31.2[b] |
| H | 29.9[b] | 30.2[b] | 30.5[b] | 30.2[b] | 39.8[c] | 40.2[c] | 40.6[c] | 40.2[b] | 30.5[a] | 29.8[a] | 29.1[a] | 29.7[a] |
| s.e.d | 0.48 | | | 0.51 | 0.44 | | | 0.47 | 0.55 | | | 0.59 |
| | | | | | | | | | | | | |
| Sire breed | | | | | | | | | | | | |
| T | 28.8 | 29.1 | 29.4 | 29.3 | 37.9 | 38.3 | 38.7 | 38.6 | 33.4[B] | 32.7[B] | 32.0[B] | 32.1[B] |
| $P_{UK}$ | 29.6 | 29.9 | 30.2 | 30.0 | 38.7 | 39.1 | 39.5 | 39.1 | 31.8[A] | 31.1[A] | 30.4[A] | 31.0[A] |
| $P_{NZ}$ | 29.5 | 29.8 | 30.1 | 29.9 | 38.7 | 39.1 | 39.5 | 39.2 | 31.9[A] | 31.2[A] | 30.5[A] | 31.0[A] |
| s.e.d | 0.43 | | | 0.48 | 0.38 | | | 0.39 | 0.42 | | | 0.43 |
| | | | | | | | | | | | | |
| Significance[1] | | | | | | | | | | | | |
| Dam breed (E) | ** | | | * | *** | | | ** | *** | | | *** |
| Sire breed (R) | NS | | | NS | NS | | | NS | ** | | | * |
| E X R | NS | | | NS | * | | | * | NS | | | NS |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule;
Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Predominantly the flanks plus some bone and excess fat removed.

[2] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

TABLE 24: EFFECTS OF SIRE AND DAM BREED ON PREDICTED INSTRUMENTAL MEAT QUALITY PARAMETERS

| | Biochemical / biophysical[2] | | | | CIE Lab Colour[3] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | pHu | SL µm | SF kg | CL % | L* | a* | b* | Hue | Chroma |
| Dam breed (n) | | | | | | | | | |
| M (73) | 5.60$^{ab}$ | 1.79 | 3.44$^{ab}$ | 18.07 | 37.52$^{bc}$ | 13.20 | 9.84 | 36.48$^{ab}$ | 16.54 |
| TM (40) | 5.61$^{ab}$ | 1.77 | 3.90$^{c}$ | 18.24 | 36.11$^{ab}$ | 14.14 | 10.75 | 37.03$^{b}$ | 17.82 |
| HB (89) | 5.64$^{b}$ | 1.77 | 3.64$^{ab}$ | 18.53 | 34.58$^{a}$ | 14.01 | 9.79 | 34.53$^{a}$ | 17.20 |
| H (14) | 5.57$^{a}$ | 1.79 | 3.33$^{a}$ | 18.15 | 39.83$^{c}$ | 12.37 | 9.81 | 38.54$^{b}$ | 15.85 |
| s.e.d - | 0.03 | 0.03 | 0.19 | 0.78 | 1.49 | 0.67 | 0.65 | 1.52 | 0.83 |
| | | | | | | | | | |
| Sire breed (n) | | | | | | | | | |
| T (70) | 5.62 | 1.79 | 3.59$^{B}$ | 18.53 | 36.16 | 13.80 | 10.02 | 35.75 | 17.15 |
| $P_{UK}$ (75) | 5.60 | 1.77 | 3.23$^{A}$ | 17.55 | 37.13 | 13.08 | 9.89 | 36.90 | 16.46 |
| $P_{NZ}$ (71) | 5.60 | 1.78 | 3.91$^{C}$ | 18.67 | 37.74 | 13.42 | 10.24 | 37.30 | 16.95 |
| s.e.d - | 0.02 | 0.02 | 0.17 | 0.70 | 1.32 | 0.56 | 0.54 | 1.32 | 0.69 |
| | | | | | | | | | |
| Significance[1] | | | | | | | | | |
| Dam breed (E) | * | NS | * | NS | ** | NS | NS | * | NS |
| Sire breed (R) | NS | NS | * | NS | NS | NS | NS | NS | NS |
| E X R | NS | NS | * | NS | NS | NS | NS | NS | NS |

n, number of carcases of each dam or sire breed; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

[2] Biochemical & biophysical properties determined were: ultimate pH (pHu), sarcomere length (SL), Warner Bratzler shear force after 14 days aging (SF) and Cooking Loss after 14 days aging (CL).

[3] Colour properties assessed from lamb samples were: lightness (L*), redness (a*) and yellowness (b*)

TABLE 25: EFFECTS OF SIRE AND DAM BREED ON PREDICTED CONSUMER ASSESSMENTS OF MEAT EATING QUALITY PARAMETERS

| | Aroma[2] | Flavour[2] | Tenderness[2] | Juiciness[2] | Overall Liking[2] | Satisfaction[3] |
|---|---|---|---|---|---|---|
| Dam breed (n) | | | | | | |
| M (73) | 61.4 | 64.0 | 64.3 | 64.2 | 64.5 | 2.6 |
| TM (40) | 61.3 | 61.2 | 59.8 | 61.1 | 61.0 | 2.5 |
| HB (89) | 61.8 | 62.4 | 63.0 | 63.5 | 62.9 | 2.6 |
| H (14) | 61.3 | 64.1 | 64.1 | 64.2 | 64.3 | 2.6 |
| s.e.d - | 1.7 | 2.0 | 2.3 | 2.1 | 2.0 | 0.1 |
| | | | | | | |
| Sire breed (n) | | | | | | |
| T (70) | 61.8 | 64.6 | 63.8 | $63.6^{A}$ | $64.6^{A}$ | 2.7 |
| $P_{UK}$ (75) | 62.1 | 63.3 | 64.7 | $64.5^{A}$ | $64.4^{A}$ | 2.6 |
| $P_{NZ}$ (71) | 60.5 | 60.9 | 59.9 | $61.6^{B}$ | $60.5^{B}$ | 2.5 |
| s.e.d - | 1.6 | 1.8 | 2.2 | 1.9 | 1.9 | 0.1 |
| | | | | | | |
| Significance[1] | | | | | | |
| Dam breed (E) | NS | NS | NS | NS | NS | NS |
| Sire breed (R) | NS | NS | NS | * | * | NS |
| E X R | NS | NS | NS | NS | NS | NS |

n, number of carcases of each dam or sire breed; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule; Pairs of means within columns sharing the same superscript are not significantly different (P>0.05).

[1] Probabilities are denoted * (P<0.05), ** (P<0.01), *** (P<0.001) or NS (P>0.05)

[2] Attributes scored on a 0 - 100 horizontal line where 0 is dislike extremely and 100 is like extremely.

[3] Satisfaction rated on a on a scale of 1 = unsatisfactory, 2 = satisfactory everyday quality, 3 = better than everyday quality, and 4 = premium quality

TABLE 26 EFFECTS OF ADOPTING NEW EWE AND RAM BREEDS ON ECONOMIC PERFORMANCE PER EWE (£/EWE) AND ON-FARM PRODUCTION COSTS (P/KG CARCASS WEIGHT) [1]

| | Ewe breed | | | | Ram breed | | |
|---|---|---|---|---|---|---|---|
| | M | TM | HB | H | T | $P_{UK}$ | $P_{NZ}$ |
| INCOME | | | | | | | |
| Lamb sales[2] | base | -13.29 | -8.54 | +14.22 | BASE | -2.08 | -1.93 |
| Wool sales | base | - | - | - | BASE | - | - |
| Total receipts | base | -13.29 | -8.54 | +14.22 | BASE | -2.08 | -1.93 |
| VARIABLE COSTS[3] | | | | | | | |
| Forage costs | base | +0.62 | -0.80 | -0.65 | BASE | -0.35 | -0.42 |
| Concentrate costs | base | -1.70 | -1.48 | +1.16 | BASE | - | - |
| Veterinary & medicine | base | -1.38 | -1.04 | +1.24 | BASE | - | - |
| Miscellaneous | base | - | - | - | BASE | - | - |
| Replacement cost | base | - | - | - | BASE | - | - |
| Total variable costs | base | -2.46 | -3.31 | +1.76 | BASE | -0.35 | -0.42 |
| Gross margin | base | -10.83 | -5.22 | +12.46 | BASE | -1.72 | -1.51 |
| FIXED COSTS[4] | | | | | | | |
| Common fixed costs | base | - | - | - | BASE | - | - |
| Labour, finance & conacre | base | - | - | - | BASE | - | - |
| Total fixed costs | base | - | - | - | BASE | - | - |
| NET MARGIN[3,4] | base | -10.83 | -5.22 | +12.46 | BASE | -1.72 | -1.51 |
| NET PROFIT[3,4] | base | -10.83 | -5.22 | +12.46 | BASE | -1.72 | -1.51 |
| | | | | | | | |
| Price per kg cwt (£) | base | +0.10 | +0.01 | +0.01 | BASE | -0.06 | -0.06 |
| Variable costs per kg cwt (£)[3] | base | +0.14 | +0.01 | -0.10 | BASE | -0.01 | -0.01 |
| Fixed costs per kg cwt (£)[4] | base | +0.33 | +0.17 | -0.22 | BASE | - | - |
| Total costs per kg cwt (£)[3,4] | base | +0.49 | +0.19 | -0.34 | BASE | -0.01 | -0.01 |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule

[1] Baseline costs for ewe and ram breeds determined as the mean of Mule ewes (base) and Texel rams (BASE) respectively. Cost estimates for the various ewe and ram breed combinations (relative to Mule crossed with Texel) can be estimated by adding the appropriate cost combinations.

[2] Determined at a 19 kg carcass weight endpoint; [3] Assumes no breed effects on replacement costs; [4] Assumes no breed effects on labour costs

TABLE 27 EFFECTS OF ADOPTING NEW EWE AND RAM BREEDS ON ECONOMIC PERFORMANCE PER HECTARE (£/HA)[1]

| | Ewe breed | | | | Ram breed | | |
|---|---|---|---|---|---|---|---|
| | M | TM | HB | H | T | $P_{UK}$ | $P_{NZ}$ |
| INCOME | | | | | | | |
| Lamb sales[2] | base | -107.79 | -2.71 | +126.66 | BASE | -12.26 | -11.40 |
| Wool sales | base | -0.60 | +0.87 | +0.70 | BASE | - | - |
| Total receipts | base | -108.40 | -1.84 | +127.36 | BASE | -12.26 | -11.40 |
| VARIABLE COSTS[3] | | | | | | | |
| Forage costs | base | - | - | - | BASE | - | - |
| Concentrate costs | base | -13.29 | -3.47 | +11.62 | BASE | - | - |
| Veterinary & medicine | base | -8.15 | -6.11 | +7.33 | BASE | - | - |
| Miscellaneous | base | -3.43 | +4.96 | +3.97 | BASE | - | - |
| Replacement cost | base | -1.45 | +2.10 | +1.68 | BASE | - | - |
| Total variable costs | base | -26.32 | -2.53 | +24.60 | BASE | - | - |
| Gross margin | base | -82.07 | +0.69 | +102.76 | BASE | -12.26 | -11.40 |
| FIXED COSTS[4] | | | | | | | |
| Common fixed costs | base | -5.34 | +7.72 | +6.18 | BASE | - | - |
| Labour, finance & conacre | base | -16.87 | +24.38 | +19.52 | BASE | - | - |
| Total fixed costs | base | -22.22 | +32.10 | +25.70 | BASE | - | - |
| NET MARGIN[3,4] | base | -76.73 | -7.03 | +96.58 | BASE | -12.26 | -11.40 |
| NET PROFIT[3,4] | base | -59.85 | -31.41 | +77.06 | BASE | -12.26 | -11.40 |
| | | | | | | | |
| Carcass output (kg/ha) | 209 | -35.2 | -1.2 | +35.6 | 209 | - | - |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule

[1] Baseline costs for ewe and ram breeds determined as the mean of Mule ewes (base) and Texel rams (BASE) respectively. Cost estimates for the various ewe and ram breed combinations (relative to Mule crossed with Texel) can be estimated by adding the appropriate cost combinations.

[2] Determined at a 19 kg carcass weight endpoint

[3] Assumes no breed effects on replacement costs per ewe

[4] Assumes no breed effects on labour costs per ewe

TABLE 28 EFFECTS OF ADOPTING NEW EWE AND RAM BREEDS ON ECONOMIC PERFORMANCE PER FULL-TIME LABOUR UNIT (£/FTE)[1]

| | Ewe breed | | | | Ram breed | | |
|---|---|---|---|---|---|---|---|
| | M | TM | HB | H | T | $P_{UK}$ | $P_{NZ}$ |
| INCOME | | | | | | | |
| Lamb sales[2] | base | -6,519.38 | +384.56 | +15,661.55 | BASE | -1,965.70 | -1,827.63 |
| Wool sales | base | +108.58 | +151.78 | +41.77 | BASE | - | - |
| Total receipts | base | -6,410.80 | +536.34 | +15,703.32 | BASE | -1,965.70 | -1,827.63 |
| VARIABLE COSTS | | | | | | | |
| Forage costs | base | +1211.52 | +80.15 | -364.53 | BASE | -335.42 | -398.82 |
| Concentrate costs | base | -1609.18 | -1399.85 | +1098.66 | BASE | - | - |
| Veterinary & medicine | base | -636.02 | -48.65 | +1,424.46 | BASE | - | - |
| Miscellaneous | base | +619.89 | +866.52 | +238.48 | BASE | - | - |
| Replacement cost | base | +262.57 | +367.03 | +101.01 | BASE | - | - |
| Total variable costs | base | -151.22 | -134.80 | +2,498.08 | BASE | -335.42 | -398.82 |
| Gross margin | base | -6,259.58 | +671.14 | +13,205.25 | BASE | -1,630.29 | -1,428.81 |
| FIXED COSTS | | | | | | | |
| Common fixed costs | base | +965.37 | +1,349.45 | +371.39 | BASE | - | - |
| Labour, finance & conacre | base | +10.86 | +15.18 | +4.18 | BASE | - | - |
| Total fixed costs | base | +976.23 | +1,364.63 | +375.56 | BASE | - | - |
| NET MARGIN | base | -7,224.95 | -678.31 | +12,833.86 | BASE | -1,630.29 | -1,428.81 |
| NET PROFIT | base | -7,235.81 | -693.49 | +12,829.69 | BASE | -1,630.29 | -1,428.81 |
| | | | | | | | |
| Total labour input (FTE) | 1.35 | -0.07 | -0.10 | -0.03 | 1.35 | - | - |
| No. ewes per FTE | 949 | +50 | +69 | +19 | 949 | - | - |
| Carcass output (t/FTE) | 33.49 | -2.64 | +0.04 | +4.36 | 33.49 | - | - |
| Labour costs (p/kg cwt) | 176 | +15 | +0 | -21 | 176 | - | - |

FTE, full-time equivalents; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule

[1] Baseline costs determined as the mean of Mule ewes (base) and Texel rams (BASE) respectively. Cost estimates for the various ewe and ram breed combinations (relative to Mule crossed with Texel) can be estimated by adding the appropriate cost combinations.

[2] Determined at a 19 kg carcass weight endpoint

TABLE 29 EFFECTS OF SIRE AND DAM BREED ON THE FARM-GATE VALUE OF LAMB CARCASSES (19 KG CARCASS WEIGHT END-POINT)[1]

| Sire breed | Dam breed | % lambs in payment band[2] | | | | | | | Carcass value above base price (p/kg)[3] | Carcass value (£)[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 to 10 | | |
| T | M | 5.2 | 27.6 | 57.1 | 7.7 | 1.2 | 1.0 | 0.3 | +3.0 | 72.76 |
| | TM | 42.3 | 44.0 | 12.8 | 0.7 | 0.1 | 0.1 | 0.03 | +12.8 | 74.63 |
| | HB | 6.8 | 31.7 | 52.9 | 6.6 | 1.0 | 0.8 | 0.2 | +3.8 | 72.92 |
| | H | 6.9 | 31.1 | 52.8 | 7.0 | 1.1 | 0.9 | 0.3 | +3.7 | 72.90 |
| $P_{UK}$ | M | 0.9 | 6.4 | 50.1 | 28.0 | 6.6 | 6.1 | 1.9 | -3.3 | 71.56 |
| | TM | 3.0 | 18.6 | 61.2 | 12.7 | 2.2 | 1.8 | 0.5 | +1.0 | 72.39 |
| | HB | 1.0 | 7.2 | 49.1 | 27.1 | 6.9 | 6.6 | 2.1 | -3.4 | 71.55 |
| | H | 0.9 | 6.3 | 48.6 | 28.3 | 7.1 | 6.7 | 2.1 | -3.6 | 71.51 |
| $P_{NZ}$ | M | 1.0 | 6.9 | 52.3 | 26.8 | 6.0 | 5.4 | 1.6 | -2.9 | 71.65 |
| | TM | 4.3 | 23.8 | 58.7 | 9.9 | 1.6 | 1.3 | 0.4 | +2.1 | 72.61 |
| | HB | 0.8 | 6.1 | 47.9 | 28.7 | 7.3 | 7.0 | 2.2 | -3.8 | 71.48 |
| | H | 1.2 | 8.3 | 55.9 | 24.0 | 5.0 | 4.3 | 1.3 | -2.1 | 71.80 |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{NZ}$, NZ-bred Primera; $P_{UK}$, UK-bred Primera; T, Texel; TM, Texel X Mule

[1] Predicted from the dynamic model described in Section 4.6. Data presented are the mean values of males and females predicted for lambs slaughtered at 19 kg carcass weight

[2] See Appendix 2 for details of payment bands

[3] Assumes a base lamb price of 380 p/kg

TABLE 30 EFFECTS OF SIRE AND DAM BREED ON THE WHOLESALE VALUE OF LAMB CARCASSES

| | Ewe breed[2] | | | | Ram breed[3] | | |
|---|---|---|---|---|---|---|---|
| | M | TM | HB | H | T | $P_{UK}$ | $P_{NZ}$ |
| *In-spec carcasses*[1] | | | | | | | |
| % lambs slaughtered | 81.8 | 93.6 | 74.9 | 82.0 | 81.8 | 59.8 | 56.6 |
| Joint value (£)[4] | | | | | | | |
| Shoulder (@£5.20/kg) | 34.68 | +0.10 | +0.10 | -0.29 | 34.97 | -0.39 | -0.58 |
| Rack (@£14.60/kg) | 22.67 | -0.48 | +0.94 | +1.02 | 22.12 | +1.50 | +1.34 |
| Loin (@£9.25/kg) | 19.03 | -0.90 | +0.41 | +0.94 | 18.44 | +1.12 | +1.06 |
| Leg (@£7.40/kg) | 47.84 | +1.23 | -0.14 | +0.69 | 48.80 | -0.96 | -0.55 |
| Flanks (@£4.00/kg) | 7.05 | -0.20 | -0.36 | -0.64 | 6.81 | -0.08 | -0.08 |
| Total wholesale value (£) | 131.27 | -0.25 | +0.95 | +1.72 | 131.14 | +1.20 | +1.19 |
| Av. wholesale value (p/kg) | 6.91 | -0.01 | +0.05 | +0.09 | 6.90 | +0.06 | +0.06 |
| *Out-of-spec carcasses*[1] | | | | | | | |
| % lambs slaughtered | 18.2 | 6.4 | 25.1 | 18.0 | 18.2 | 40.2 | 43.4 |
| Joint value (£)[4] | | | | | | | |
| Shoulder (@£3.30/kg) | 22.01 | +0.06 | +0.06 | -0.18 | 22.19 | -0.24 | -0.37 |
| Rack (@£12.85/kg) | 19.95 | -0.42 | +0.83 | +0.90 | 19.47 | +1.32 | +1.18 |
| Loin (@£7.50/kg) | 15.43 | -0.73 | +0.34 | +0.77 | 14.95 | +0.91 | +0.86 |
| Leg (@£6.60/kg) | 42.67 | +1.10 | -0.12 | +0.61 | 43.53 | -0.86 | -0.49 |
| Flanks (@£3.00/kg) | 5.29 | -0.15 | -0.27 | -0.48 | 5.11 | -0.06 | -0.06 |
| Total wholesale value (£) | 105.35 | -0.14 | +0.83 | +1.61 | 105.24 | +1.07 | +1.12 |
| Av. wholesale value (p/kg) | 5.54 | -0.01 | +0.04 | +0.08 | 5.54 | +0.06 | +0.06 |
| Weighted av. wholesale value (£) | 126.54 | +2.82 | -0.86 | +1.75 | 126.41 | -4.54 | -5.37 |
| Weighted av. wholesale value (p/kg) | 6.66 | +0.15 | -0.05 | +0.09 | 6.65 | -0.24 | -0.28 |

H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule

[1] Predicted from the dynamic model described in Section 4.6. Data presented are the mean for males and females achieving EUR conformation grades at fat class 2 & 3L, predicted for a 19 kg carcass weight; [2] Assumes all lambs are sired by Texel rams; [3] Assumes all lambs were born to Mule dams; [4] Based on the average wholesale value of lamb joints mid-season (August and September 2011)

TABLE 31 EFFECTS OF SIRE AND DAM BREED ON TOTAL CARBON EMISSIONS (AS $CO_2$-EQUIVALENTS) FROM AN UPLAND SHEEP FLOCK

| | Ewe breed[2] | | | | Ram breed[3] | | |
|---|---|---|---|---|---|---|---|
| | M | TM | HB | H | T | $P_{UK}$ | $P_{NZ}$ |
| *Total emissions (t $CO_2$-e)* | | | | | | | |
| Enteric fermentation | 394.6 | +14.2 | -19.1 | -14.4 | 395.6 | -7.6 | -9.2 |
| Manure management | 34.5 | +5.5 | -5.9 | -5.3 | 33.0 | -0.2 | -0.2 |
| Managed soils | 231.6 | +13.8 | -22.4 | -12.9 | 227.8 | -3.1 | -3.5 |
| Concentrate manufacture | 2.8 | - | - | - | 2.8 | - | - |
| Fertilizer manufacture | 26.2 | - | - | - | 26.2 | - | - |
| Burning of residues | 0 | - | - | - | 0 | - | - |
| Fuel use | 19.6 | - | - | - | 19.6 | - | - |
| Waste incineration | 0 | - | - | - | 0 | - | - |
| TOTAL | 709.3 | +33.5 | -47.4 | -32.5 | 705.0 | -10.8 | -12.9 |
| Grassland sequestration | -255.2 | - | - | - | -255.2 | - | - |
| TOTAL INCLUDING SEQUESTRATION | 454.1 | +33.5 | -47.4 | -32.5 | 449.7 | -10.8 | -12.9 |
| *Emissions intensity (kg $CO_2$-e/kg carcass output)[1]* | | | | | | | |
| Excluding sequestration | | | | | | | |
| Lamb only | 16.91 | +3.38 | +0.05 | -2.37 | 17.18 | -0.26 | -0.32 |
| Lamb + mutton | 14.07 | +2.11 | +0.16 | -1.57 | 14.32 | -0.22 | -0.26 |
| Sequestration included | | | | | | | |
| Lamb only | 10.83 | +2.49 | -0.41 | -1.77 | 10.96 | -0.26 | -0.32 |
| Lamb + mutton | 9.01 | +1.61 | -0.27 | -1.22 | 9.13 | -0.22 | -0.26 |

CWT, carcass weight; H, Highlander; HB, Highlander X Blackface; M, Mule; $P_{UK}$, UK-bred Primera; $P_{NZ}$, NZ-bred Primera; T, Texel; TM, Texel X Mule

[1] Includes both lamb meat and mutton

# APPENDICES

## Appendix 1 Statistical models used to analyse the ewe and lamb performance data

| Animal type | Data type | Response variate | Analysis | Fixed terms | Random terms |
|---|---|---|---|---|---|
| Ewes | Quantitative | LWT at mating<br>BCS at mating | LM | Farm + Age + Ewe Breed | |
| | | LWT pre-lambing<br>BCS pre-lambing<br>LW change mating to pre-lambing<br>BCS change mating to pre-lambing<br>Lambs born<br>Total birth weight<br>Lambs reared to 6 wks<br>Lambs weaned<br>Following score<br>Colostrum score | LMM | Farm + Age + Ewe Breed + Ram Breed +Ewe Breed X Ram Breed | Farm X Ram ID + Farm X Ram ID X Ewe ID |
| | | LW post-lambing<br>BCS post-lambing<br>LW change pre-lambing to post-lambing<br>BCS change pre-lambing to post-lambing<br>LW at weaning<br>BCS at weaning<br>LW change post-lambing to weaning<br>BCS change post-lambing to weaning<br>LW change mating to weaning<br>BCS change mating to weaning | LMM | Farm + Age + Grazing group post-lambing + Ewe Breed + Ram Breed +Ewe Breed X Ram Breed | Farm X Ram ID + Farm X Ram ID X Ewe ID |
| | | Total 6 wk weight | LMM | Farm + Age + Grazing group post-lambing + Av. days to 6 weeks + Ewe Breed + Ram Breed +Ewe Breed X Ram Breed | Farm X Ram ID + Farm X Ram ID X Ewe ID |
| | | Total weaning wt<br>Lamb output efficiency | LMM | Farm + Age + Grazing group post-lambing + Av. days to weaning + Ewe Breed + Ram Breed +Ewe Breed X Ram Breed | Farm X Ram ID + Farm X Ram ID X Ewe ID |
| | Binomial | Productive at scanning<br>Productive at lambing | GLMM | Farm + Age + Ewe Breed + Ram Breed + Ewe Breed X Ram Breed | Farm X Ram ID + Farm X Ram ID X Ewe ID |
| | | Assisted at lambing | GLMM | Farm + Age + Lambs born + Ewe Breed + Ram Breed + Ewe Breed X | Farm X Ram ID + Farm X Ram |

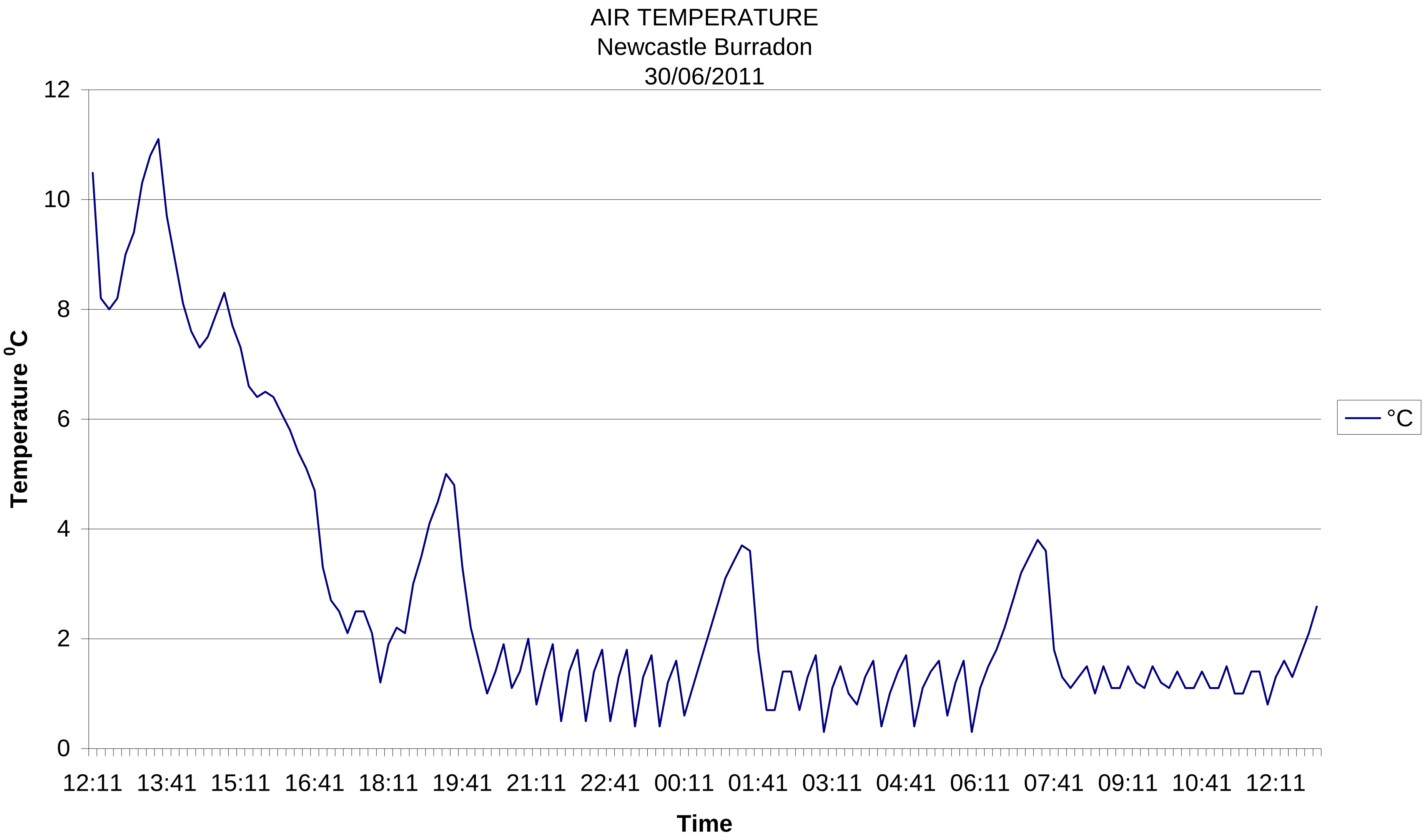
| | | | | | |
|---|---|---|---|---|---|
| | | | | Ram Breed | ID X Ewe ID |
| | Multinomial | Following score<br>Colostrum score | GLM | Farm + Age + Ewe Breed + Ram breed + Ewe Breed X Ram Breed | |
| Lambs | Quantitative | Birth wt | LMM | Farm + Dam Age + Born as + Sex + Dam Breed + Sire Breed + Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | | 6 week wt | LMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to 6 wks + Age at 6 weeks + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | | LWG to 6 weeks | LMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to 6 wks + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | | Weaning wt | LMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to weaning + Age at weaning + Birth Dam age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | | LWG to weaning | LMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to weaning + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | Binomial | Mortality at birth<br>Mortality at 6 weeks<br>Mortality at weaning | GLMM | Farm + Birth dam age + Born as + Sex + Dam Breed + Sire breed + Dam breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | Multinomial | Lambing difficulty score<br>Lamb viability score<br>Reasons of intervention | GLMM | Farm + Birth dam age + Born as + Sex + Dam Breed + Sire breed + Dam breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| Lamb carcass | Quantitative | Slaughter wt<br>Birth to slaughter LWG<br>Age at slaughter<br>Conformation score<br>Killing-out %<br>Shoulder wt<br>Leg wt<br>Saddle wt<br>Shoulder %<br>Leg %<br>Saddle %<br>Saddle length<br>Rack wt | LMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to weaning + Carcass wt (or Fat score) + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |

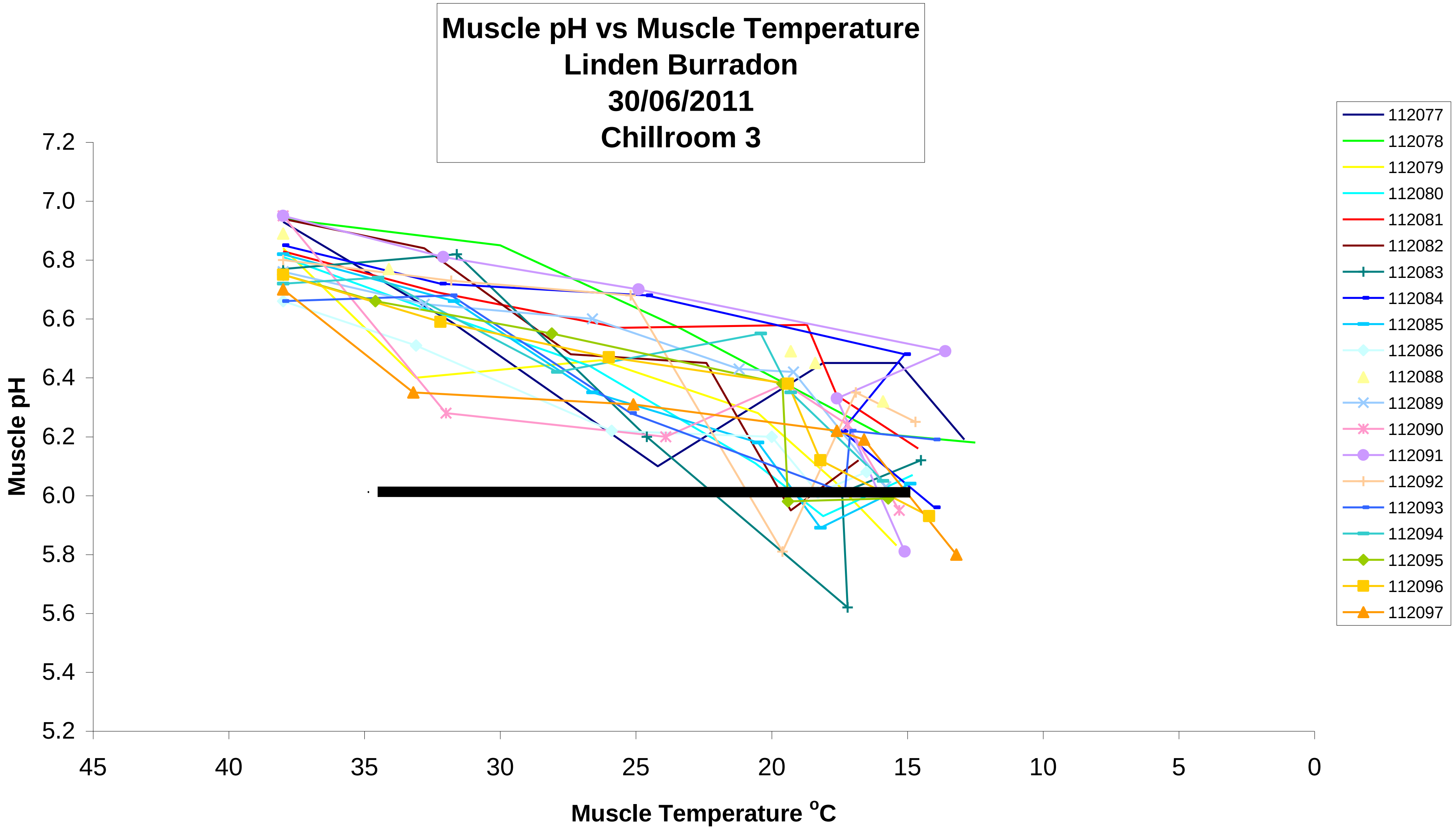
| | | | | | |
|---|---|---|---|---|---|
| | | Short loin wt<br>Trim wt<br>Rack%<br>Short loin%<br>Trim% | | | |
| | | Fat score | LMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to weaning + Carcass wt + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | | Carcass wt | LMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to weaning + Fat score + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | Multinomial | Conformation score | GLMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to weaning + Carcass wt (or Fat score) + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| | | Fat score | GLMM | Farm + Rearing Dam Age + Rearing Dam Breed + Grazing group post-lambing + Sex + Born as + Reared to weaning + Carcass wt + Birth Dam Age + Birth Dam Breed + Sire Breed + Birth Dam Breed X Sire Breed | Farm X Sire ID + Farm X Sire ID X Dam ID |
| Meat quality | Quantitative | Ultimate pH<br>Sarcomere length<br>Shear force<br>Cooking loss<br>L*<br>a*<br>b*<br>Hue<br>Chroma<br>Aroma score<br>Flavour score<br>Tenderness score<br>Juiciness score<br>Overall liking<br>Satisfaction score | LMM | Sex + Birth Dam Breed + Sire breed + Sex X Birth Dam Breed + Sex X Sire Breed + Birth Dam Breed X Sire Breed | Farm + Farm X Sire ID + Farm X Sire ID X Dam ID |

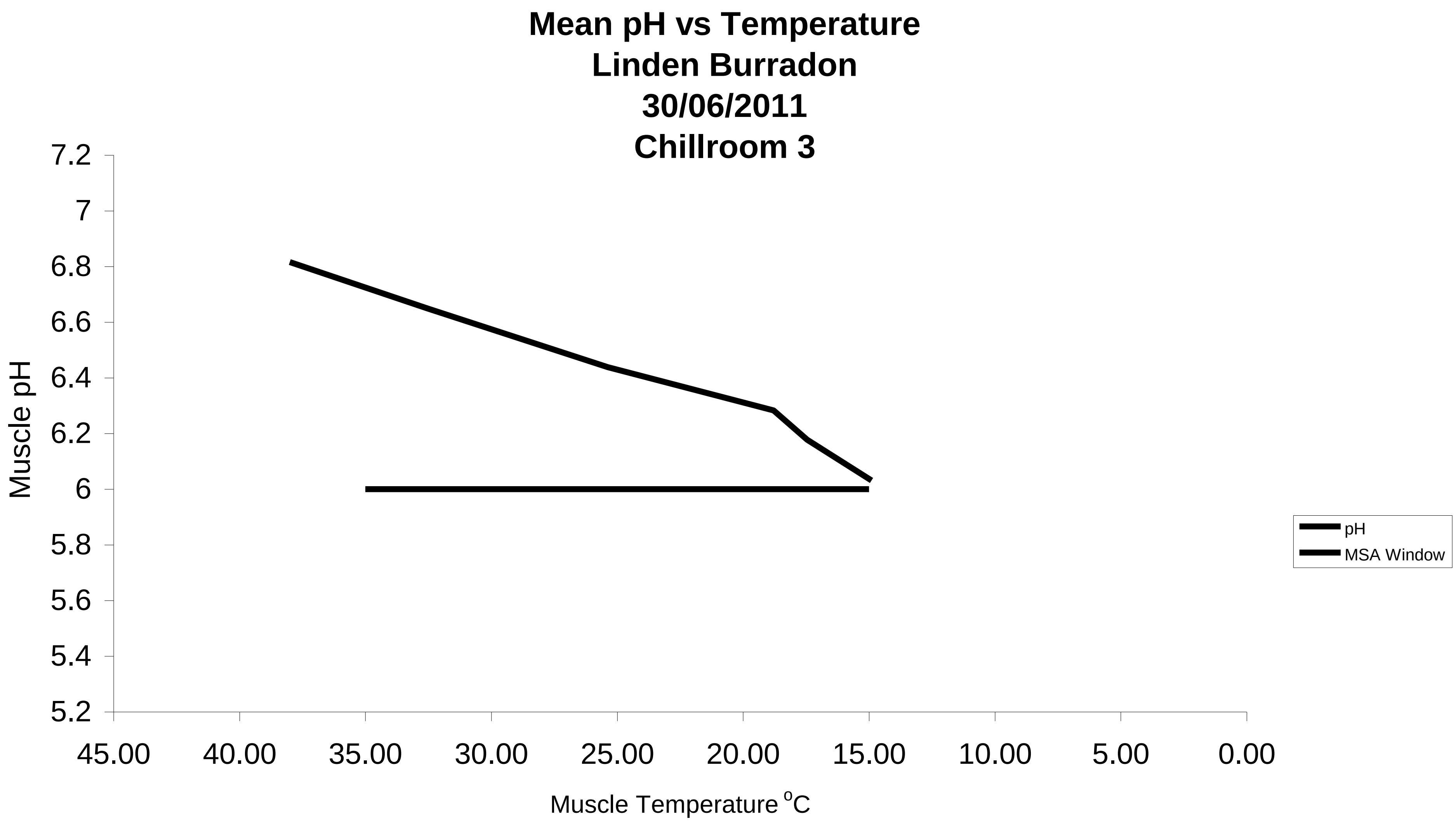
## Appendix 2 Payment grid used for the economic analyses

| Payment Band | Qualifying Grades | Price paid |
|---|---|---|
| 1 | E2, E3L | Base plus 20 p/kg |
| 2 | U2, U3L | Base plus 5 p/kg |
| 3 | E3H, U3H, R2, R3L | Base |
| 4 | R3H, O2, O3L | Base minus 5 p/kg |
| 5 | E4L, U4L, O3H | Base minus 15 p/kg |
| 6 | E1, U1, R4L | Base minus 20 p/kg |
| 7 | E4H, U4H, R1 | Base minus 30 p/kg |
| 8 | R4H, O4L | Base minus 40 p/kg |
| 9 | O1 | Base minus 50 p/kg |
| 10 | E5, U5, R5, O4H, O5 | Base minus 60 p/kg |

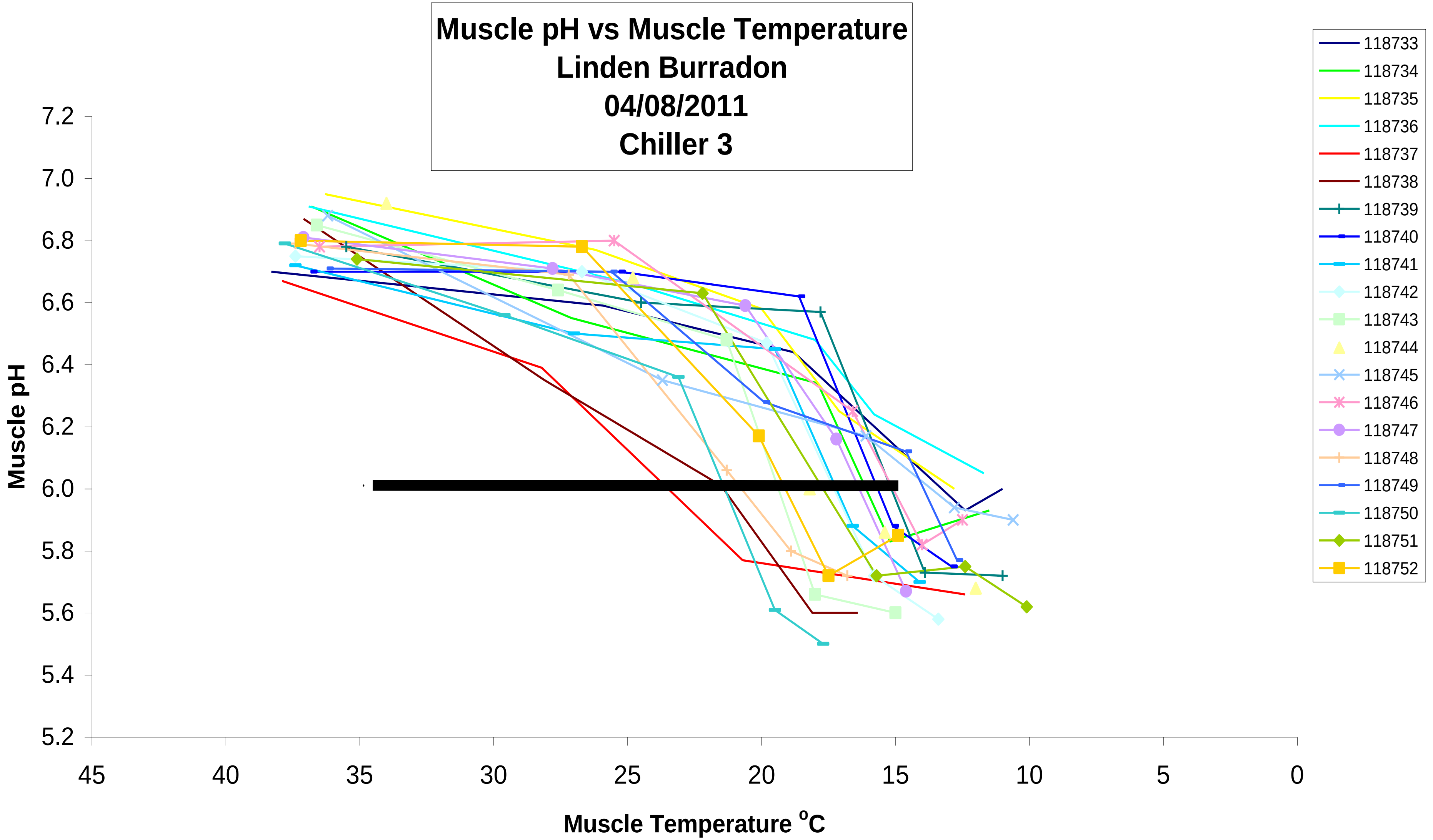
APPENDIX 3 CHILL ROOM AIR TEMPERATURE AND pH AND TEMPERATURE DECLINE MEASUREMENTS AT LINDEN FOODS BURRADON



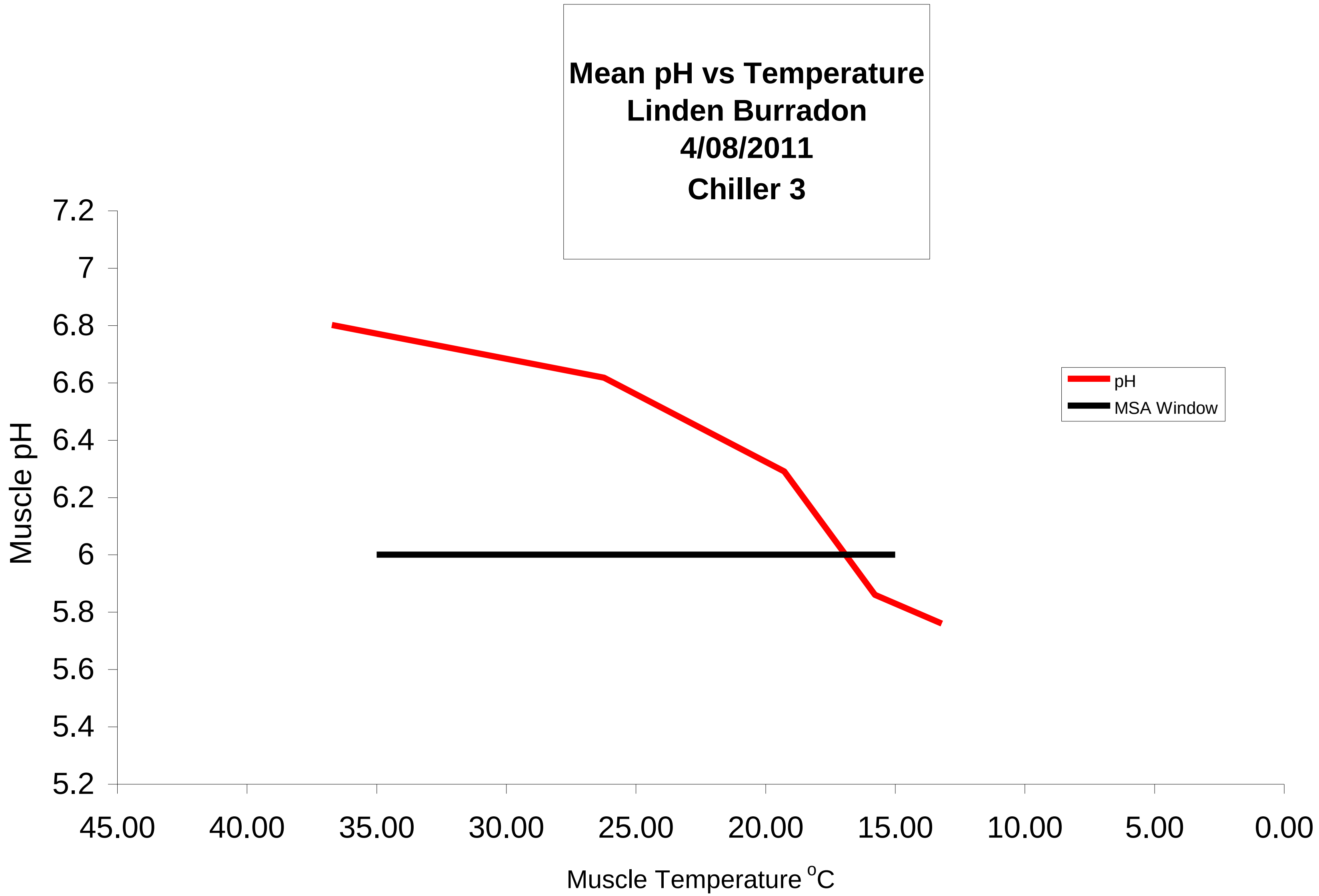

Muscle pH vs Muscle Temperature
Linden Burradon
30/06/2011
Chillroom 3
Muscle pH
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
45
40
35
30
25
20
15
10
5
0
Muscle Temperature °C
112077
112078
112079
112080
112081
112082
112083
112084
112085
112086
112088
112089
112090
112091
112092
112093
112094
112095
112096
112097

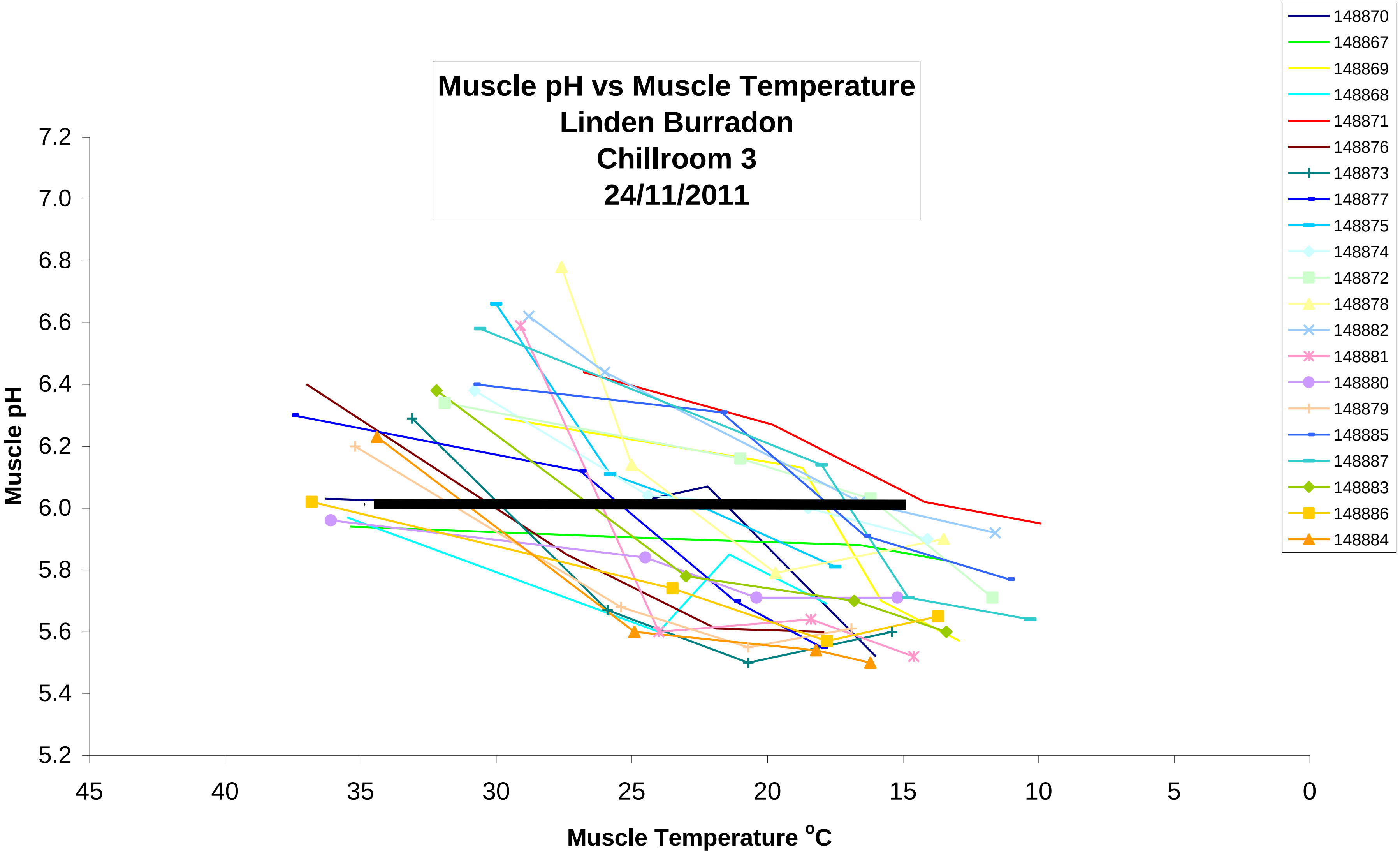


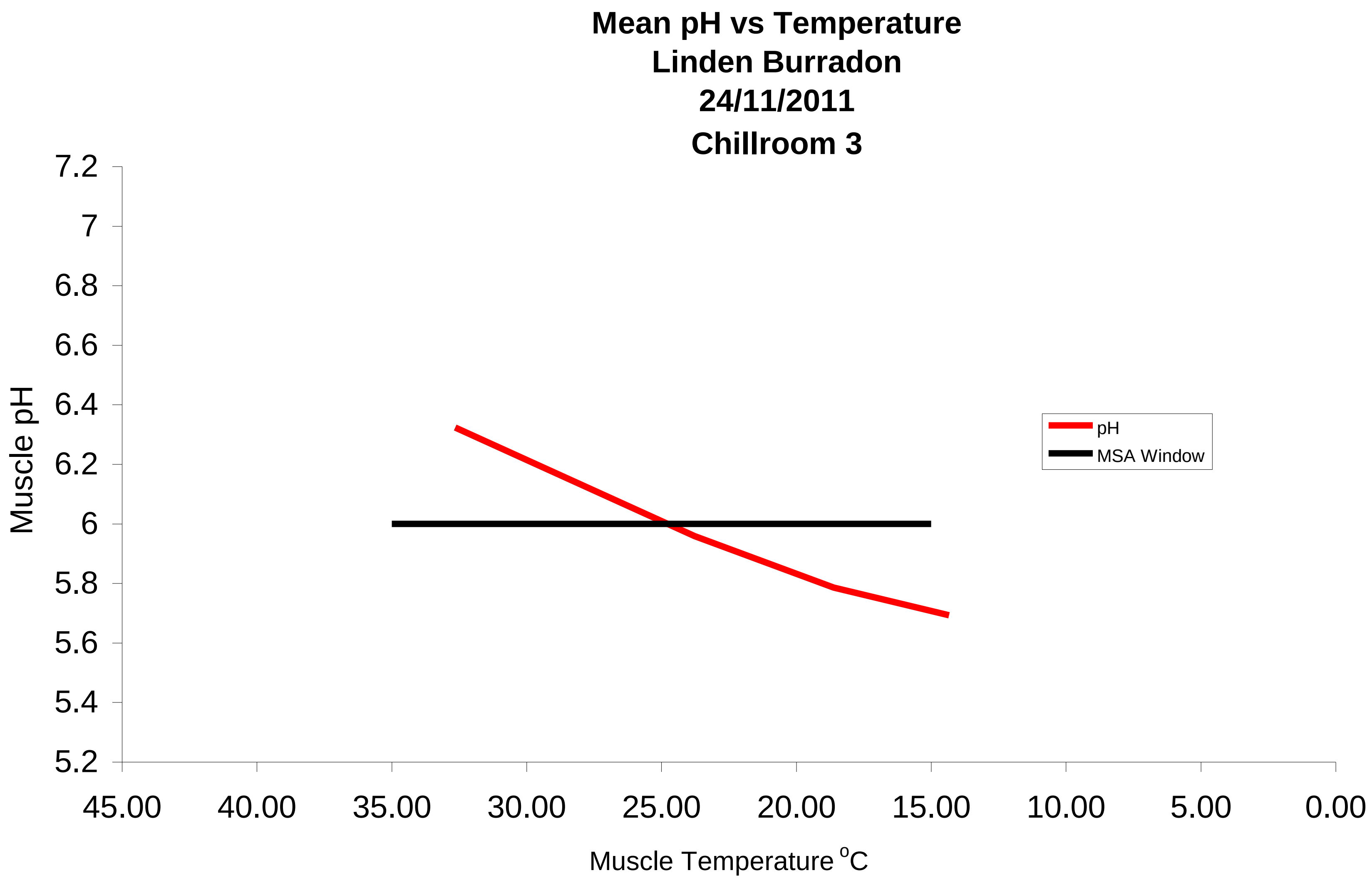
Mean pH vs Temperature
Linden Burradon
30/06/2011
Chillroom 3
Muscle pH
7.2
7
6.8
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Muscle Temperature °C
pH
MSA Window



Muscle pH vs Muscle Temperature
Linden Burradon
04/08/2011
Chiller 3
Muscle pH
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
45
40
35
30
25
20
15
10
5
0
Muscle Temperature °C
118733
118734
118735
118736
118737
118738
118739
118740
118741
118742
118743
118744
118745
118746
118747
118748
118749
118750
118751
118752


Mean pH vs Temperature
Linden Burradon
4/08/2011
Chiller 3
Muscle pH
7.2
7
6.8
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Muscle Temperature $^{o}$C
pH
MSA Window


Muscle pH vs Muscle Temperature
Linden Burradon
Chillroom 3
24/11/2011
Muscle pH
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
45
40
35
30
25
20
15
10
5
0
Muscle Temperature °C
148870
148867
148869
148868
148871
148876
148873
148877
148875
148874
148872
148878
148882
148881
148880
148879
148885
148887
148883
148886
148884


Mean pH vs Temperature
Linden Burradon
24/11/2011
Chillroom 3
Muscle pH
7.2
7
6.8
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Muscle Temperature °C
pH
MSA Window

## CAFRE Benchmarking Input Form - Core Details

CAFRE | Ai SERVICES

| | | | |
|---|---|---|---|
| *Date of Visit* | / / | *Data Collector* | |
| *Date Approved* | / / | *Signed* | |

### User Details

*Year Ended* / /

| | | |
|---|---|---|
| *Business ID Number* | *Name* | |
| *Address* | | *BT* |
| *Telephone* | *Mobile* | *E-mail* |

### Farm Details

| | |
|---|---|
| Farm Type (SDA, DA or L) | |
| Full-Time / Part-Time | |
| Land Owned (ha) | |
| Land Leased In (ha) | |
| Land Leased Out (ha) | |
| Area of Non-Forage Crops | |
| Family Labour (Labour Units) | |
| Paid Labour (Labour Units) | |

### Depreciation Costs

| | |
|---|---|
| *Self-Propelled Machinery* | |
| Opening Valuation | £ |
| Purchases During the Year | £ |
| Sales During the Year | £ |
| *Non Self-Propelled Machinery* | |
| Opening Valuation | £ |
| Purchases During the Year | £ |
| Sales During the Year | £ |
| Net Cost of Farm Buildings (Last 10 Years) | £ |

### Overhead Costs

| | |
|---|---|
| Machinery Running Costs | £ |
| Forage Contractor Costs | £ |
| Business Electricity | £ |
| Business Telephone | £ |
| Water & Rates | £ |
| Property Repairs | £ |
| Property Insurance | £ |
| Professional Fees | £ |
| Miscellaneous Overheads | £ |
| Paid Labour and NIC | £ |
| Conacre | £ |
| Total Finance Repayments | £ |
| of which Interest Charges are | £ |
| Do you have an intensive Enterprise for example: pigs, poultry or mushrooms | |
| Pigs % | |
| Poultry % | |
| Mushrooms % | |

### Average Livestock Numbers

| | |
|---|---|
| Dairy Cows | |
| Dairy Stock Bulls | |
| Suckler Cows | |
| Suckler Stock Bulls | |
| Other Cattle 0-1 yr | |
| Other Cattle1-2 yr | |
| Other Cattle over 2 yr | |
| Purchased Beef 0-1 yr | |
| Purchased Beef 1-2 yr | |
| Purchased Beef over 2 yr | |
| Dairy Heifers 0-1 yr | |
| Dairy Heifers 1-2 yr | |
| Dairy Heifers over 2 yr | |
| Sheep - Ewes | |
| Rams | |
| Lambs over 6 Mths | |
| Store Lambs | |

### Land Type (Forage Area)

| | |
|---|---|
| In-Bye (ha) | |
| Mountain (ha) | |
| Lowland Adjustment | |
| In-Bye Adjustment | |
| Mountain Adjustment | |

### Forage Costs

| | |
|---|---|
| Fertiliser | £ |
| Sprays | £ |
| Seed Costs | £ |
| Silage Additive | £ |
| Silage Covers | £ |
| Purchase of Hay | £ |
| Purchase of Silage | £ |

### Sundry Receipts

| | |
|---|---|
| Single Farm Payment | £ |
| LFA Compensatory Allowance | £ |
| ESA Payments | £ |
| CSMS Payments | £ |
| Short Courses Attended | £ |
| Sales of Silage & Hay | £ |
| Land/Quota Leased Out | £ |
| Payment for Contracting Work | £ |
| Miscellaneous Receipts | £ |

| Business ID | |
|---|---|

# Sheep Flock Input Pages

## Opening & Closing Valuation

**Opening Valuation -**

| | |
|---|---|
| Number of Ewes | . |
| £/head of Ewes | £ |
| Number of Rams | |
| £/head of Rams | £ |
| Number of Lambs over 6 months (Breeding) | |
| £/head of Lambs over 6 months (Breeding) | £ |
| Number of Lambs over 6 months (Finishing) | |
| £/head of Lambs over 6 months (Finishing) | £ |

**Closing Valuation -**

| | |
|---|---|
| Number of Ewes | |
| Number of Rams | |
| £/head of Rams | £ |
| Number of Lambs over 6 months (Breeding) | |
| Number of Lambs over 6 months (Finishing) | |

## Purchases

**Concentrates -**

| | |
|---|---|
| Ewe Concentrates (Kgs) | |
| Total cost of Ewe Concentrates | £ |
| Lamb Concentrates (Kgs) | |
| Total cost of Lamb Concentrates | £ |

**Replacements -**

*Home Bred Ewe Lambs*

| | |
|---|---|
| Number of Retained Lambs | |
| Value £/hd | £ |

*Purchased Ewes & Ewe Lambs*

| | |
|---|---|
| Number | |
| Cost £/hd | £ |
| Number of Rams Purchased | |
| Cost £/hd | £ |
| Cost of Vet & Medicines | £ |
| Sundry Costs | £ |
| Cost of Quota Leased | £ |

## Sales & Receipts

| | |
|---|---|
| Number of Rams and Ewes Culled | |
| Total Receipts of Rams and Ewes Culled | £ |
| Sheep Annual Premium | £ |
| Total Value of Supplements Claimed & Wool | £ |

## Lamb Sales

**Store Lamb Sales -**

| | |
|---|---|
| Number | |
| Total Kgs Carcase | |
| Total Receipts | £ |

**Finished Lamb Sales**

| | |
|---|---|
| Number | |
| Total Kgs Carcase | |
| Total Receipts | £ |
| Number of Retained Ewe Lambs | |
| Total Value of Retained Ewe Lambs | £ |
| Number of Ewes put to Ram | |
| Number of Lambs born alive | |

## Purchased Store Lambs

**Purchases -**

| | |
|---|---|
| Number of Lambs | |
| Total Cost | £ |
| Total Cost of Concentrates | £ |
| Sundry Costs | £ |
| Total Costs of Vet and Medicines | £ |

**Lamb Sales -**

| | |
|---|---|
| Number | |
| Total Receipts | £ |

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