Project LS1625: Appendix 1

The MAFF/Defra Livestock Science R&D Programme 1991 – 2006

An overview

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Contents

Executive Summary

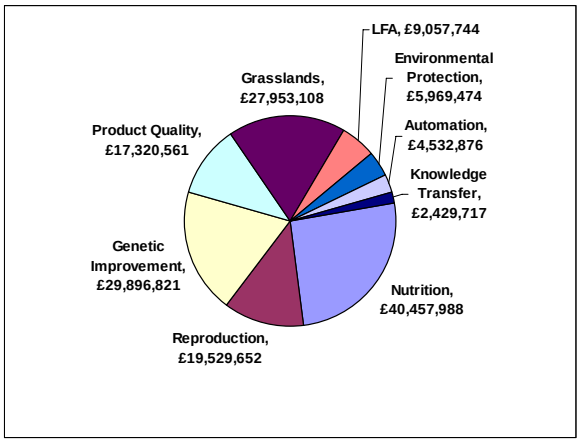
This overview of the MAFF/Defra Livestock Science research programme from 1991 to 2006, with a total contract value of around £157 million, is intended to act as a signposting document to allow users to identify programmes of research that were conducted, the individual projects within each programme, and the main deliverables from each programme. The Overview is divided into 9 thematic documents, covering the areas of Livestock Nutrition, Reproduction, Genetic Improvement, Product Quality, Grasslands, Less Favoured Areas, Environment, Automation and Knowledge Transfer. An overview of each theme, identifying the policy relevance, key targets, and main deliverables, is accompanied by a list of research projects by species and a brief commentary on each research programme.

The policy drivers for MAFF, between 1991 and the formation of Defra in 2001, were based on improving the competitive position of UK agriculture. This was reflected in the Financial Programmes that supported the Livestock Science R&D programme: CE (Competitive Economy) between 1991 and 1999 and TM (Thriving Markets) from 1999 to 2003. The three principles that were applied to research requirements were that they should meet at least one of the following criteria:

- Increase the value of the product reaching the market
- Increase the efficiency of production of that product
- Decrease the losses inherent in its production

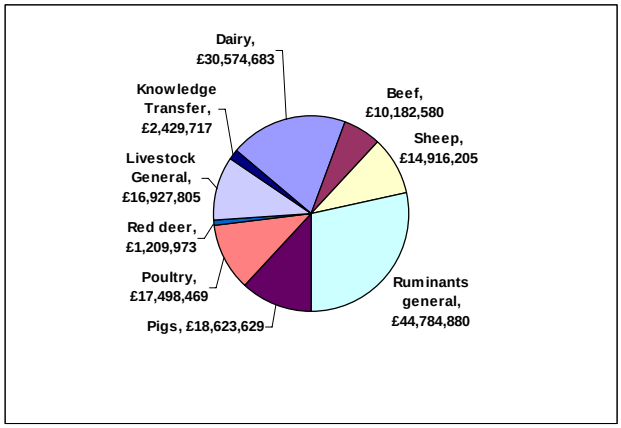
From the late 1990s, the concept of sustainability was broadened for livestock production to include not only the economic viability of the industry but its impact on the environment, and this was formalised with the formation of Defra in 2001. The research was realigned to focus on ways to reduce the environmental impact during the production of every unit of product – litre of milk / kilo of meat / kilo of eggs – while maintaining the economic viability of an industry under increasing pressure from competition on world markets. The key to this was seen as a reduction in the number of animals needed to produce the amount of high quality food required by the market, increased efficiency in the conversion of nutrients to meat, milk and eggs, and changing management practice to limit the interaction of the stock with the environment and landscape. The Financial Programmes funding the research were redefined as FS (Sustainable Farming) between 2003 and 2004 and then converted to AF (Adaptable Farming) in 2004, reflecting the higher importance placed on the environmental aspects of livestock farming.

Figure 1: Expenditure on Livestock Science R&D by theme 1991 - 2006



Note: Costs at time of contract, not corrected to 2008 values

Figure 2: Expenditure on Livestock Science R&D by sector 1991 - 2006



Note: Costs at time of contract, not corrected to 2008 values

The principle deliverables from the Livestock Science R&D Programme were:

Nutrition Research

Dairy cattle

- A broad understanding across the dairy industry on the value of home grown forages and proteins for milk production
- New standards for the nutritional requirements of the modern dairy cow
- New grass and clover varieties that reduce the carbon and nitrogen footprints of dairy farming

Beef cattle

- Recommendations for low input beef and suckler production systems
- New grass and red clover varieties that reduce the carbon and nitrogen footprints of beef cattle

Sheep

- Demonstration that new varieties of red clover are a valuable crop for lamb production
- A review of the low vitamin E status of lambs, and possible explanations for its cause

Ruminants

- Development in near infra-red reflectance spectroscopy and rumen simulation techniques to allow a more accurate and reliable analysis of forage crops for livestock rations
- An understanding of the causes of plant protein degradation in the rumen, leading to ammonia production
- A series of new measures to reduce plant protein degradation in the rumen by cross linking protein to tannins, and by meeting the energy requirements of ruminal microflora with soluble carbohydrates
- Recommendations to producers for sward management practice that encourages feed intake in grazing ruminants
- A broad understanding of ruminant digestion allowing producers and feed compounders to formulate rations more effectively

Pigs

- Recommendations for management systems that develop gut health and lifetime performance
- Controlled fermentation systems for fermented liquid feed

Poultry

- An evolving series of feeding systems that enhance bird performance and health while reducing environmental pollution per bird
- New options for feed components based on rapeseed meal and naked oats

Lowland deer

- No solution was found to the problem of winter inappetance, but recommendations were made to deer farmers for low input commercial production

General nutritional

- A range of options for home grown proteins for the industry to develop
- Options for increased use of maize and oats in to meet the dietary needs of modern livestock breeds while minimising wastage
- An up to date understanding of new applications for NIRS (near infra-red reflectance spectroscopy) in feed analysis

Reproduction Research

Dairy cattle

- Development of a milk progesterone test that identified and differentiated the causes of infertility
- Development of a genetic selection index for bovine fertility, now in use in the industry
- Formulation of dairy cow rations that doubled the rate of conception in high yielding cows, now incorporated into commercial concentrate formulations

Sheep

- Genetic selection indices within hill sheep breeds that increase lamb number and ensure better survival of the lambs born

Pigs

- A better understanding of summer anoestrus in outdoor sows
- Identification of an oviduct cell protein that prolongs the life of sperm *in vitro*, making Artificial Insemination (AI) more efficient
- Formulation of sow diets that reduce the number of runts in the litter, increasing piglet numbers and survivability

Poultry

- Understanding of the genetic basis for sex determination in birds, which is different from that in mammals, and its application to the selection of eggs carrying female chicks in layer breeder flocks to reduce wastage and improve welfare in the system
- Separation of the genetics of growth from reproductive performance in broiler breeders, which is expected to lead to new ways to improve broiler breeder efficiency without having to control excessive growth by resorting to starvation

Farmed red deer

- Attempts to develop AI for red deer were less than fully successful, due to poor sperm viability after storage and poor understanding of the oestrus cycle in deer. Sire referencing has continued within the industry by moving stags between herds

Genetic Improvement Research

Theoretical genetics and methodology

- Understanding of the principle genetic controls for muscle accretion and quality, fat deposition, and seasonality
- A range of theoretical and applied genetic methodologies now accepted as standard in the UK and international livestock breeding industries

Cattle

- Selection indices for dairy cows, including PIN, ITEM, £PLI and additional indices for fertility and lifetime performance
- A partial understanding of the genetics controlling milk composition, udder health, and fertility
- Genetic markers for QTLs (quantitative trait loci) and candidate genes associated with milk yield and composition, disease resistance, and fertility, now being taken up by the cattle breeding industry

Sheep

- Genetic selection indices within hill sheep breeds that allow more efficient growth, better health and welfare, and a more consistent carcass quality that better meets market specification
- A range of genetic markers for traits of commercial importance
- Development of computed X-ray tomography (CT scanning) to identify rams with superior carcass conformation for use in sire referencing breeding programmes
- The first demonstration that livestock can be cloned using nuclear transfer from adult cells (Dolly)

Pigs

- The pig genome map, now used by all major pig breeding companies to select for higher quality pigs
- A blood test to allow selection of pig breeding stock having a better innate immunity to disease
- Demonstration of neonatal piglet survival as a selectable genetic trait in the dam

Poultry

- A fully mapped poultry genome and marker assisted selection tools for the UK poultry industry to maintain its global market position
- Understanding of the genetic basis for sex determination in birds, which is different from that in mammals, and its application to the selection of eggs carrying female chicks in layer breeder flocks to reduce wastage and improve welfare in the system
- Separation of the genetics of growth from reproductive performance in broiler breeders, which is expected to lead to new ways to improve broiler breeder efficiency without having to control excessive growth by resorting to starvation
- Demonstration of genetic variation in dietary nutrient uptake, providing opportunities to select for livestock with lower emissions of diffuse pollutants

Product Quality Research

Milk

- Production protocols that ensure milk quality meets the required regulatory standard

Alternative management regimes whereby cows produce milk low in saturated fat and high in the essential long chain polyunsaturated fatty of the omega-3 (n-3) series and in conjugated linoleic acid (CLA)

Beef

Production protocols to improve the tenderness, flavour and fatty acid composition of beef

Recommendations for the production of 'rosy beef' from young Holstein bull calves without resorting to veal crates and a milk only diet

Sheep meat

Demonstration of the value of computed X-ray tomography for selection of rams with superior carcass characteristics

Selection indices for breeders to improve the conformation of their lambs

Demonstration that the desirable flavour of lamb raised on grass-based diets is correlated with the presence of the essential long chain polyunsaturated fatty acids important for consumer health

Pigmeat

Methods to produce lean pigs that have good intramuscular fat

Knowledge of the role of different myosin fibre compositions in pork eating quality

Poultry and eggs

Recommendations to broiler breeders and producers of procedures to improve chicken meat quality

Demonstration of the absence of recombinant DNA sequences capable of encoding foreign proteins in meat and organs of chickens fed on rations containing recombinant plant products

Grasslands Research

Grass breeding

Many new varieties of ryegrass and fescue/ryegrass crosses with improved characteristics, including better pest resistance, lower soil nutrient requirements, better drought tolerance, higher nutritional value, and greater persistence in diverse swards

Legume breeding

New varieties of white clover with increased persistence under grazing conditions and in mixed swards with grass, better disease resistance, more efficient N capture and usage, higher quality as a forage for ruminant livestock

New varieties of red clover that are more persistent, better suited to combine harvesting and ensiling, and rich in polyphenol oxidase (PPO) resulting in their protein being used more efficiently by cattle and sheep

Selection of new varieties of lotus (bird's-foot trefoil) better suited to low fertility swards in UK upands

Grazing studies research

Demonstration of the different sward characteristics preferred for grazing by cattle and sheep

Demonstration of the 70:30 dietary preference for clover:grass by grazing cattle

Data on the suitability of new varieties of grass and clover for grazing and their environmental impact

Less Favoured Areas (LFA) Research

Livestock Production

- Demonstration of the suitability of new varieties of grass and clover for reseeding improved pasture in the uplands
- Management practices based on varying sheep and cattle numbers and movements to maximise the sustainability of upland livestock production systems
- Improvement in hill lamb survival by increasing dietary levels of vitamin E for pregnant ewes

Biodiversity

- Prescriptions for environmental stewardship schemes that reduce sheep and sheep numbers and movement
- Management practices that allow heather seedlings to re-establish in previously over-grazed upland farms

Environmental Protection Research

Dairy cattle

- A model demonstrating the environmental benefits of management systems targeted to animal requirements.
- A comparison of the environmental footprints of different dairy cattle breeds and crosses, which showed no significant environmental benefit over continuing development of the Holstein breed

Pigs

- Engineering solutions for improved designs of pig housing to reduce aerial pollution
- Information on the lack of hazard for either pig growth or respiratory disease by the levels of ammonia and dust found in UK pig houses
- An integrated management system that monitors pig growth and tailors the ration composition and supply to meet requirements on a daily basis
- Design of paddocks and feeding systems for outdoor breeding pigs to reduce their environmental footprint

Poultry

- Recommendations for poultry house designs and ventilation systems to reduce exposure of stock and staff to aerial ammonia and dust
- An integrated management system that monitors poultry growth and tailors the ration composition and supply to meet requirements on a daily basis
- The first demonstration that different genetic lines of poultry have different levels of nutrient capture and usage efficiency, opening the possibility of breeding livestock for lower environmental footprint.

Farmed red deer

- Information suggesting that red deer produce more diffuse pollution per kilo of meat than sheep.

Automation Research

Dairy cattle

- Design and development of a robotic milking system, used as the basis for the commercially successful DeLaval Voluntary Milking System
- Development of a robotic milk sampling device and ELISA for milk progesterone was completed and has now entered commercial development stage

Cow-side tests for ketosis, detecting acetone in breath, and dietary protein efficiency, by detecting ammonia in breath, were developed. Linking these to body condition score during peak lactation, using visual image analysis, was partially successful but is ongoing

Pigs

An automated system for weight and growth assessment based on visual image analysis, integrated with feed formulation and delivery to optimise nutrient use and animal welfare

Sensors developed to monitor aerial pollutants in pig houses and ventilation systems designed to reduce the levels

Poultry

An automated system for weight and growth assessment based on electronic perches, integrated with feed formulation and delivery to optimise nutrient use and animal welfare.

Sensors developed to monitor aerial pollutants in poultry houses and ventilation systems designed to reduce the levels

Knowledge transfer

Industry activity to promote new varieties of grasses and forage legumes was supplemented with sponsored roadshows, workshops and demonstration farms to ensure that the rapid advances in sustainable grassland agriculture would reach the farming community

The extensive nature of the sheep industry, particularly in the uplands, posed problems of getting new information taken up. In collaboration with the National Sheep Association, workshops were supported around the UK

The collaborative research LINK project LK0647 studied the attitudes of livestock farmers to new information and the constraints that influenced whether this was taken up, using the theory of reasoned action. The findings of this research provided valuable information on the best routes to getting change in the farming community and have informed subsequent Defra policy. Farmer-to-farmer networking was identified as successful and was used in Southwest England (LS1609) and Gloucestershire (LS1616). Other knowledge transfer initiatives included support by the Defra Chief Scientific Adviser for the Genesis Faraday Partnership, participation in the national Foresight programme, establishment of a national standard for nutritional requirements in farmed livestock, and evaluation of the success of the Sustainable Livestock Production LINK programme

The MAFF/Defra Livestock Science R&D Programme 1991 -2006

1. Introduction

The policy drivers for MAFF, between 1991 and the formation of Defra in 2001, were based on improving the competitive position of UK agriculture. The three principles that were applied to research requirements were that they should meet at least one of the following criteria:

- Increase the value of the product reaching the market
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- Decrease the losses inherent in its production

From the late 1990s, the concept of sustainability was broadened for livestock production to include not only the economic viability of the industry but its impact on the environment, and this was formalised with the formation of Defra in 2001. The research was realigned to focus on ways to reduce the environmental impact during the production of every unit of product – litre of milk / kilo of meat / kilo of eggs – while maintaining the economic viability of an industry under increasing pressure from competition on world markets. The key to this was seen as a reduction in the number of animals needed to produce the amount of high quality food required by the market, increased efficiency in the conversion of nutrients to meat, milk and eggs, and changing management practice to limit the interaction of the stock with the environment and landscape.

The policy divisions in MAFF and Defra responsible for livestock production committed a research budget promoting these priorities. This was around £10 million pounds in the early 1990s but experienced annual reductions through to its withdrawal from funding support in 2007. During this period, the Departmental Financial Programmes supporting the research developed from CE(competitive economy) during 1991 and 1999, through TM (thriving markets) from 1999 to 2003, FS (sustainable farming) in 2003 and AF (adaptable farming) from 2004, illustrating the changing priorities given by the Department to livestock farming over that period.

Figure 1: Expenditure on R&D by theme

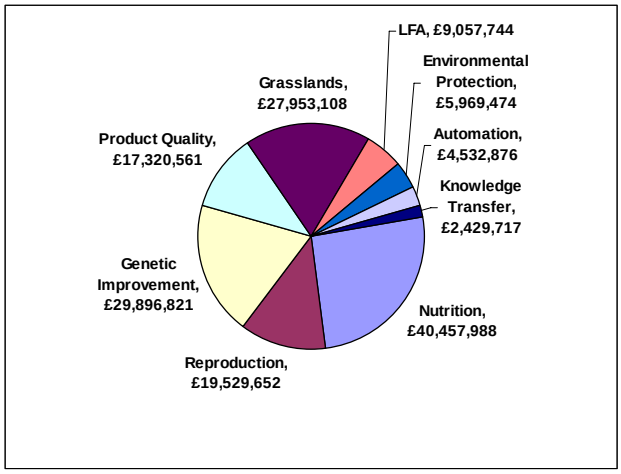

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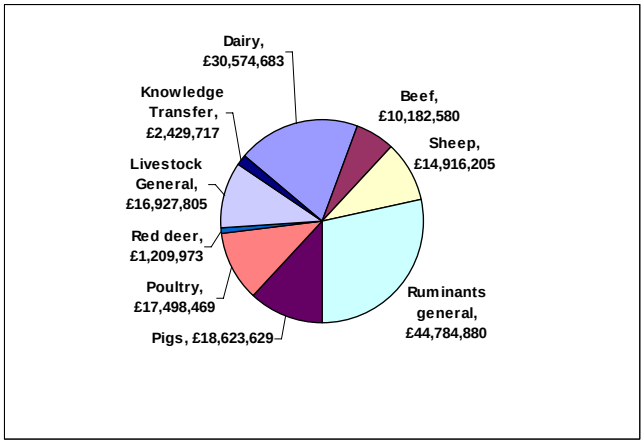
Figure 2: Expenditure on R&D by sector



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2. Livestock Nutrition

2.1 Overview

Government advisors in the 1980s had recommended that livestock nutrition research should not be supported by government but left to the industry. Because of the financially insecure state of the UK livestock industry, this resulted in a much reduced level of research in the topic, with the UK falling behind its competitors. Feeding systems and rations used in North America, such as high energy crops like maize and soya and feedlot systems, were not available or acceptable in UK. MAFF investment in nutritional science increased in the mid-1990s with the intention of returning the UK livestock industry to profitability. Towards the end of the century, the need for international competitiveness was replaced by the need to become more environmentally sustainable and the focus of the research changed accordingly.

Over the course of the Livestock Science R&D programme, the objectives were:

DAIRY CATTLE

Policy objective:

- To support the UK dairy industry to remain competitive with overseas producers
- To reduce the environmental footprint of milk production in the UK

Targets:

- To maximise the use of home-grown forages and protein sources
- To understand the biology and chemistry of dietary nutrient uptake and utilisation

Deliverables:

- A broad understanding across the dairy industry on the value of use of home grown forages and proteins for milk production
- New standards for the nutritional requirements of the modern dairy cow
- New grass and clover varieties that reduce the carbon and nitrogen footprints of dairy farming

BEEF CATTLE

Policy objective:

- To support beef producers to remain competitive with overseas producers
- To reduce the environmental footprint of the UK beef industry

Targets:

- To maximise the use of home-grown forages and protein sources
- To understand the biology and chemistry of dietary nutrient uptake and utilisation

Deliverables:

- Recommendations for low input beef and suckler production systems.
- New grass and red clover varieties that reduce the carbon and nitrogen footprints of beef cattle

SHEEP RESEARCH

Policy objective:

- To support sheep producers to remain competitive with overseas producers

Targets:

- To maximise the use of home-grown forages and protein sources

- To understand the apparent vitamin E deficiency in lambs, reported by sheep vets

Deliverables:
- Demonstration that new varieties of red clover are a valuable crop for lamb production
- A review of the low vitamin E status of lambs, and possible explanations for its cause. However, feed compounders responded by increasing the level of alpha-tocopherol acetate in their sheep feed and the research was not continued, the true cause never identified

RUMINANT RESEARCH

Policy objective:
- To support milk, beef and sheep producers to remain competitive with overseas producers
- To reduce the environmental footprint of the UK ruminant livestock industry

Targets:
- To maximise the use of home-grown forages and protein sources
- To understand rumen function to increase efficiency
- To identify ways to promote feed intake in housed and grazing ruminants
- To understand the biology and chemistry of dietary nutrient uptake and utilisation
- To identify ways to reduce methane and ammonia excretion from ruminants

Deliverables:
- Developments in near infra-red reflectance spectroscopy and rumen simulation techniques to allow a more accurate and reliable analysis of forage crops for livestock rations
- An understanding of the cause of plant protein degradation in the rumen, leading to ammonia production
- A series of new measures to reduce plant protein degradation in the rumen by cross linking protein to tannins, and by meeting the energy requirements of ruminal microflora with soluble carbohydrates
- Recommendations to producers for sward management practice that encourages feed intake in grazing ruminants
- A broad understanding of ruminant digestion allowing producers and feed compounders to formulate rations more effectively

PIG RESEARCH

Policy objective:
- To support pig producers to remain sustainable
- To reduce the environmental footprint of the UK pig industry

Targets:
- To develop pig rationing systems that are economically and environmentally sustainable

Deliverables:
- Recommendations for management systems that develop gut health and lifetime performance
- Controlled fermentation systems for fermented liquid feed

POULTRY RESEARCH

Policy objective:

- To support poultry producers to remain competitive with overseas producers
- To reduce the environmental footprint of the UK poultry industry

Targets:
- To provide underpinning information to the integrated poultry industry to allow them to exploit the benefits of genetic improvement in broiler and layer chickens using UK feed systems

Deliverables:
- An evolving series of feeding systems that enhance bird performance and health while reducing environmental pollution per bird
- New options for feed components based on rapeseed meal and naked oats.

LOWLAND DEER RESEARCH

Policy objective:
- To support livestock producers wishing to diversify their business

Targets:
- To provide underpinning information for year-round production of venison

Deliverables:
- No solution to the problems of winter inappetance were found
- Low input production systems were derived and taken up by the British Deear Farmers Association

GENERAL NUTRITIONAL RESEARCH

Policy objective:
- To support the UK livestock agriculture industry to remain competitive with overseas producers
- To reduce the environmental footprint of the UK livestock farming industry

Targets:
- To maximise the use of home-grown forages and protein sources
- To ensure that the UK is up to date with the technologies needed for sustainable farming

Deliverables:
- A range of options for home grown proteins for the industry to develop
- Options for increased use of maize and oats to meet the dietary needs of modern livestock breeds while minimising wastage
- An up to date understanding of new applications for NIRS (near infra-red reflectance spectroscopy) in feed analysis

The research that was commissioned to address these targets is covered in the remainder of this chapter

2.2 Dairy cow research

The rapid increase in the genetic potential of modern dairy cows, coinciding with the introduction of Holstein genetics into the UK Friesian herd, prompted improvement in dairy cow rations to meet the demands of high milk production. Intensification of the dairy industry led to increasing use of high energy concentrate feeds, but the decreasing financial return to the producer from the processor forced producers to look for ways to reduce costs of production, including making better use of home grown forages.

2.2.1 Ration formulation

Projects: DS0311, DS0408, DS0409, DS0410, DS0411, DS0412, DS0801, DS0802, DS0812, DS0813, DS0901, DS0902, DS0903, DS0904, LS0806, LS0813, LS3608, LS3660, LK0604

The research focused on a number of areas, including balancing the use of expensive concentrate feeds with home produced forages, making the most of grazing systems, and ensuring that the rumen functioned as effectively as possible by providing rumen microflora with readily available carbohydrates to support their growth while reducing the breakdown of dietary protein in the rumen for digestion in the small intestine. The MAFF programme was the main source of information on dairy cow nutrition and supported the steady increase in milk yield that was seen during the 1990s. This aspect of the research programme culminated in the Sustainable Livestock Production LINK project LK0604 'Feed into Milk' which redefined the dietary requirements of the modern dairy cow. This was funded by 30 industry partners and has gone on to be the UK standard used by almost all feed compounders and producers.

2.2.2 Home grown proteins

Projects: LS0805, LS0808, LS3605, LK0950

Concerns about the availability of dietary protein for dairy cow rations generated research into alternative home grown sources. Plant protein is generally low in a number of essential amino acids and this can limit animal growth and production. While the research did not find a home grown alternative to soy beans, which are the best source of plant protein, improvements were made to dairy cow rations to supply protein for milk production. The use of lupin seed as a protein source is being assessed in the Sustainable Arable LINK project LK0950.

2.2.3 Nutrient Utilisation

Projects: DS0803, DS0806, DS0807, DS0808, DS0810, DS1104, DS1108, LS0801, LS0802, LS3636, LS3639

The formulation of dairy cow rations was investigated in two complementary sub-programmes of research; the empirical 'feed it and measure the response' approach described above and a predictive approach based on an understanding of the physiology of nutrient utilisation. Research within this theme studied the partitioning of dietary nutrients into milk and body tissues and modelled their efficiencies. This improved understanding of the nutritional science was key to formulating the UK standards established in 'Feed into Milk'

Table 2.2 Livestock Nutrition: Dairy projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF / Defra Cost (£)**
DS03:	***Conservation and nutritional value of forage crops with particular emphasis on silage microbiology***			
DS0311	Effects of cracking whole crop wheat at harvest on its digestibility by lactating cows	University of Reading	1 January 1996 / 31 March 1996	8,156
DS04:	***Control of voluntary food intake in ruminants***			
DS0408	An investigation of factors influencing herbage intake rate of	ARINI	1 April 1995 / 31 March 1998	232,286

	grazed grass by lactating dairy cows			
DS0409	Development of predictive systems to relate animal and feed characteristics to amounts and patterns of forage and total food intake by cows	SAC	1 April 1995 / 31 March 1998	530,934
DS0410	Mechanisms regulating voluntary intake of conserved herbage feeds	IGER	1 April 1995 / 31 March 1998	501,413
DS0411	Optimising the balance and synchrony of supply of nutrients for silage-fed cattle by choice feeding	University of Leeds	1 April 1995 / 31 March 1998	124,816
DS0412	Co-ordination of DS0408/DS0409/DS0410/DS0411	Natural Resources Institute	1 April 1995 / 31 March 1998	31,105
DS08:	***Nutrient utilisation for lactation***			
DS0801	To manipulate nutrition partition towards milk synthesis by varying the form of concentrate supplementation of forage diets	IGER	1 April 1991 / 31 March 1995	971,000
DS0802	To quantify energy and protein supply to dairy cows	IGER	1 April 1991 / 31 March 1995	321,000
DS0803	Development of mathematical models of nutrient utilisation in dairy cows	IGER	1 April 1991 / 31 March 1996	269,000
DS0806	The effect of hepatic ureagenesis on the supply of amino acids to the lactating mammary glands of the dairy cow	IGER	1 April 1995 / 31 March 1997	214,000
DS0807	To improve amino acid utilisation for milk protein synthesis by manipulation of body protein reserves	IGER	1 April 1995 / 31 March 1997	417,000
DS0808	To investigate the source of purine derivatives in the milk and the effect of nutrient supply and partitioning within the mammary gland on milk production of the dairy cow	IGER	1 April 1995 / 31 March 1997	214,000
DS0810	Starch utilisation in post- absorptive tissue and its effect on milk constituent synthesis	University of Reading	14 February 1995 / 31 March 1995	18,648
DS0812	A database of UK forages and raw materials for Cornell net carbohydrate and protein system (CNCPS)	ADAS	1 November 1995 / 31 March 1996	59,500
DS0813	A review of European and North American protein systems for ruminants and associated feed characterisation	ADAS	1 May 1996 / 31 July 1996	8,500
DS09:	***Metabolic manipulation of milk output in dairy cows***			
DS0901	Metabolic manipulation of milk output in dairy cows: Snowball 1	Rowett Research Institute / University of Reading	1 January 1991 / 31 December 1994	500,000
DS0902	Metabolic manipulation of milk output in dairy cows: Snowball 2	Rowett Research Institute / University of Reading	1 January 1995 / 31 December 1995	151,238

DS0903	Co-operative research on manipulating protein content of milk protein: Snowball 3	Rowett Research Institute / University of Reading	1 January 1996 / 31 December 1999	349,943
DS0904	Monitoring of Snowball (DS0903) research	Dr Fred Perry	1 January 1996 / 31 December 2000	26,300
DS11:	***Sward/animal interactions – cattle***			
DS1104	Efficiency of milk production in low-input systems	IGER	1 April 1992 / 1 July 1996	126,000
DS1108	To understand the relationships between supplementation and intake and production in grazing dairy cows	IGER	1 April 1996 / 31 March 2000	879,000
LS08:	***To improve nutrient utilisation for growth and lactation***			
LS0801	Diagnostic test of rumen function in milk	IGER	1 April 1997 / 31 March 2002	534,082
LS0802	Protein and energy nutrition of the periparturient dairy cow	IGER	1 April 1997 / 31 March 2002	1,068,750
LS0805	Efficient milk production using UK grown proteins and forages	ADAS	1 November 1996 / 31 March 1997	55,700
LS0806	Further development of the UK CNCPS database	ADAS	1 October 1996 / 31 March 1997	37,100
LS0808	The use of dried lucerne as a partial replacement for dairy concentrate supplement and its effect on feed intake and milk production	University of Reading	1 December 1996 / 31 March 1997	16,000
LS0813	9000 litres from UK-grown proteins - the unanswered questions	ADAS	1 October 1999 / 30 June 2000	16,500
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3605	Managing body energy balance in high yielding dairy cows Nutritional quality of UK produced lupin seeds and forage	University of Reading	1 November 2001 / 31 October 2005	225,784
LS3608	A Nutrient Based Feeding System for Dairy cows	University of Reading	1 July 2000 / 29 February 2004	192, 066
LS3636	The relationship between size at birth and subsequent metabolic parameters in Holstein/Friesian dairy calves	Royal Veterinary College	1 October 2001 / 30 September 2003	17,734
LS3639	Use of the dairy cow metabolome in plasma and milk to improve health, fertility, and nutrient utilisation for milk production	IGER	1 April 2002 / 31 March 2007	577,500
LS3660	Diet composition, milk fatty acids and fertility in dairy cows	University of Nottingham	1 January 2005 / 31 December 2006	135,737
LK06:	***LINK Sustainable Livestock Production***			
LK0604	An improved system for characterising ruminant feeds leading to the development of a nutritional model for dairy cows (Feed into Milk)	ADAS, ARINI & SAC	1 April 1997 / 31 March 2001	439,081

LK09:	***Sustainable Arable LINK***			
LK0950	Lupins in sustainable agriculture (LISA)	IGER	1 January 2004 / 21 December 2008	376,960
			Total cost	**9,077,807**

2.3 Beef cattle research

Nutritional research into beef cattle requirements closely followed the dairy cow research but focussed on low input, forage based systems and the benefits that this brought to the quality of the meat.

2.3.1 Protein requirements

Projects: MS0805, MS0807, LS0811

The concept of metabolisable protein was developed during the early 1990s and referred to the amount of dietary protein reaching the small intestine. It had been demonstrated for dairy cows and this research confirmed its value for beef cattle. Lucerne (alfalfa) is a legume that is used in other EU member states and in North America. It is a valuable source of nutrients, including protein, but the UK climate is not ideal for it growth and storage.

2.3.2 Forage systems

Projects: LS0803, LS0809, LS0811, LS3604, LS3628, LS3659

Research into forages for beef production, rather than relying up expensive cereal-based concentrate rations, was aimed at reducing cost of production while retaining carcass quality. The findings of this research, which helped to get best value from grass, forages, and maize silage, became even more valuable after headage payments were removed from beef production in England and Wales.

2.3.3 Suckler performance

Projects: MS0101, MS0102, MS0103, MS0104, MS0105, MS0112, LS0101, LS0102, LS0103, LS0104

These studies compared the nutritional requirements of different cross-bred dams and calves with performance and the carcase quality achieved at finishing condition. The costs of bringing the cattle to market condition and the value of the carcase were recorded and recommendations made to beef suckler producers.

Table 2.3 Livestock Nutrition: Beef projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF / Defra Cost (£)**
MS01	***Improvement of beef suckler cows***			
MS0101	Improved performance and output of autumn calving hill suckler cows	ADAS	1 April 1991 / 31 March 1999	937,931
MS0102	Improved performance and output of summer calving hill suckler cows	ADAS	1 April 1991 / 30 November 1992	49,000
MS0103	Oestrus detection in maiden heifers	ADAS	1 April 1991 / 31 March 1994	31,000
MS0104	Physiological monitoring of hill suckler cow performance	ADAS	1 April 1991 / 31 March 1995	81,000
MS0105	Improved performance of suckler cows - finishing calves	ADAS	1 April 1993 / 31 March 1999	297,514

MS0112	Improved performance of suckler cows - endocrine patterns	ADAS	1 April 1996 / 31 March 1999	89,942
MS08:	***Nutrient utilisation for growth***			
MS0805	Validation of the metabolisable protein system for beef cattle	ADAS	1 April 1993 / 31 March 1994	23,000
MS0807	Maximising protein supply to the small intestine in forage fed cattle for growth	IGER	1 April 1995 / 30 June 1997	180,500
LS01:	***Improvement of suckler cows***			
LS0101	Composition of gain during feed restriction and its effect on compensatory growth at grass	ADAS	1 July 1998 / 28 February 2002	395,100
LS0102	Improved performance and output of suckler cows: finishing performance of progeny	ADAS	1 March 1999 / 30 June 2000	52,119
LS0103	Improved performance and output of suckler cows: dam performance	ADAS	1 April 1999 / 30 September 1999	46,000
LS0104	Improved performance and output of suckler cows	ADAS	1 April 1999 / 30 September 2003	375,266
LS08:	***To improve nutrient utilisation for growth and lactation***			
LS0803	Forages for beef production	IGER	1 July 1997 / 30 June 2001	1,207,944
LS0809	Nutrient utilisation, carcass composition and meat-eating quality of beef cattle fed maize-silage based diets	University of Reading	1 April 1997 / 31 March 2000	134,634
LS0811	Lucerne for beef production	IGER	1 April 1998 / 31 March 2001	165,458
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3604	The effects of gender and nutritional regime on the development of profitable beef systems using maize silage	University of Reading	1 December 2000 / 31 November 2003	141,435
LS3628	Optimising low input forage beef production systems	IGER	1 July 2001 / 30 June 2006	786,107
LS3659	Optimising nutrient use efficiency in beef cattle grazing lowland semi-natural pastures	IGER	1 July 2004 / 30 June 2007	280,611
			Total cost	**5,274,561**

2.4 Sheep research

Most of the nutritional science relevant to sheep was conducted in a generic 'Ruminant research' programme, described below. The only projects specific to sheep were LS3622 and LS3635.

Project: LS3622
Red clover was shown to be an excellent source of protein for beef cattle but it contains phyto-estrogens, chemicals that can interfere with female reproduction. This project demonstrated that inclusion of red clover in the diet of growing lambs brought no health problems to either the lamb or the consumer.

Project: LS3635
Sheep farmers and veterinarians had reported an increase in the cases of nutritional muscular dystrophy, also known as white muscle disease, in lambs, a condition usually caused by inadequate dietary vitamin E. The review showed this to be true but the cause of the deficiency was never identified as levels in rations were considered adequate. The industry reacted by increasing levels of vitamin E in their compounded rations.

Table 2.4 Livestock Nutrition: Sheep projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3622	Forage legumes for improved growth rates of finishing lambs	IGER	1 July 2000 / 30 June 2003	180,673
LS3635	Review of Vitamin E Deficiency Survey	British Society of Animal Science	February 2002 / March 2002	2,555
			Total cost	**183,228**

2.5 Ruminant research

The advantage that the rumen brings, allowing animals to utilise lower quality plants material for growth and production, is common across dairy and beef cattle and sheep. The research in this section is aimed at improving the efficiency of the rumen for the benefit of the animal and to reduce levels of diffuse pollution that are characteristic of rumen fermentation.

2.5.1 Forage composition

Projects: DS0101, DS0102, DS0103, DS0104, LS2101, LS3632, LK0615, LK0658
This research developed new techniques to evaluate the nutritional value of forage crops, including Near Infra-red Reflectance Spectroscopy (NIRS) and rumen simulation technologies. For monogastric livestock, such as pigs and poultry, chemical analysis of the feed is sufficient but this is not adequate for ruminants because the composition of microflora in the rumen will be influenced by the diet and different ruminal populations will ferment the dietary components differently. The techniques developed by this research are now in use across the industry.

2.5.2 Rumen function

Projects: DS0304, DS0305, LS0302, LS0303, LS3602, LS3641
Research to understand the functioning of the rumen and make it more predictable made slow progress due to wide variations between animals in their microflora. This research demonstrated, however, that degradation of plant protein in the rumen, the main cause of ammonia production, is due to cellular proteases in the forage plant material, opening up the possibility of breeding plants that are more stable during transit through the rumen.

2.5.3 Feed intake

Projects: DS0404, DS0405, DS0406, DS0407, DS1101, DS1102, DS1103, DS1106, DS1107

It was recognised that high milk yields required high levels of dietary energy. The relatively low energy density of grass and forage restricted the amount of energy available to the high yielding dairy cow, so this research looked at what could be done to increase the appetence and feed intake of dairy cows. Management of swards to maintain grass height and clover content promoted feed intake of grazing cattle. Intake of forages such as silage depended on continual availability, composition and quality, all of which would influence how much ration is taken up by the cow.

2.5.4 Nutrient utilisation efficiency

Projects: MS0801, MS0802, MS0803, MS0806, MS0807, MS0808, MS0810, MS0811, LS3629

This research mirrored the studies on nutrient use by dairy cows but focused on muscle accretion and growth. The knowledge that came from this research underpins most of the principles of sheep and cattle nutrition and rationing in use today.

2.5.5 Diffuse pollution

Projects: LS3625, LS3631, LS3638, LS3640, LS3642, LS3653, LS3654, LS3656, LK0638

Rumen activity is the main source of methane and ammonia in livestock farming. Research in this programme studied ways to reduce the amount of carbon and nitrogen lost during rumen fermentation. The two main ways to achieve this were identified as ensuring that an adequate supply of fermentable carbohydrate is present in the ration, to avoid microbial degradation of dietary protein for energy, and the incorporation of natural plant products that protect dietary proteins from bacterial fermentation, such as tannins and polyphenol oxidase (PPO). The introduction of Sweet Grass, commercial varieties of forage grasses having higher levels of water soluble carbohydrate, was shown to reduce ammonia production by ruminants while promoting growth and milk production.

Table 2.5 Livestock Nutrition: Ruminant projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
DS01:	***Animal feedstuff***			
DS0101	NIRS to evaluate ruminant feedstuff	ADAS	1 April 1991 / 31 December 1995	680,000
DS0102	Estimation of fermentable energy in compound feed ingredients for ruminants	ADAS	18 April 1995 / 31 March 1998	75,000
DS0103	Development of techniques for measuring fermentable energy value of forages for ruminants	ADAS	1 January 1995 / 31 March 1998	152,000
DS0104	Provide a reliable scientific basis for the use of NIRS for evaluation of forages for ruminants	ADAS	1 April 1995 / 31 March 1999	646,765
DS03:	***Conservation and nutritional value of forage crops with particular emphasis on silage microbiology***			
DS0304	Rumen efficiency: synchrony of energy and nitrogen supply	IGER	1 April 1992 / 30 June 1997	502,000
DS0305	Rumen efficiency: manipulation of proteolysis	IGER	1 April 1992 / 30 June 1997	613,000

DS04:	***Control of voluntary food intake in ruminants***			
DS0404	Development of mechanistic models for the prediction of intake	IGER	1 April 1991 / 31 March 1995	98,000
DS0405	Identification and evaluation of silage components affecting ingestive behaviour and feed intake	IGER	1 April 1992 / 31 March 1995	549,000
DS0406	Identify and evaluate specific chemical, physical and anatomical components of herbage plants controlling eating behaviour and voluntary food intake	IGER	1 April 1992 / 31 March 1995	385,000
DS0407	Development of rapid methodology for estimation of components limiting intake	IGER	1 April 1992 / 31 March 1995	217,000
DS11:	***Sward/animal interactions – cattle***			
DS1101	To understand factors influencing dietary selection, energy expenditure and intake by grazing cattle	IGER	1 April 1991 / 31 March 1996	832,000
DS1102	To understand morphological adaptation by plant species to grazing cattle	IGER	1 April 1991 / 31 March 1996	422,000
DS1103	Behavioural responses of cattle in different physiological states to changes in sward morphology and structure	IGER	1 April 1991 / 31 March 1996	862,000
DS1106	To develop mathematical models to predict herbage intake and nutrient supply to grazing cows	IGER	1 April 1996 / 31 March 2000	363,000
DS1107	To understand factors influencing dietary selection, energy expenditure and intake by grazing cattle	IGER	1 April 1996 / 31 March 2000	823,250
MS08:	***Nutrient utilisation for growth***			
MS0801	To determine the cause of low efficiency of energy and protein retention for growth in forage fed animals	IGER	1 April 1991 / 31 March 1996	582,000
MS0802	To regulate the growth of mean body mass by nutritional and endocrine manipulation	IGER	1 April 1991 / 31 March 1996	523,000
MS0803	The efficiency of nutrient absorption and utilisation	IGER	1 April 1992 / 31 March 1996	433,000
MS0806	Nutrient metabolism of the gastro-intestinal tract in growing ruminants	IGER	1 April 1995 / 30 June 1997	353,750
MS0807	Maximising protein supply to the small intestine in forage fed cattle for growth	IGER	1 April 1995 / 30 June 1997	180,500
MS0808	NMRS as a non-invasive technique to study carbon and energy flow *in vivo* in ruminants	IGER	1 April 1995 / 30 June 1997	178,000
MS0810	Metabolism of forage-fed ruminants: the effects of pattern of nutrient supply to the tissues	IGER	1 December 1995 / 31 March 1996	55,000
MS0811	A review of previous nutritional work on growing cattle relevant to the metabolisable protein system	ADAS	1 January 1996 / 31 July 1996	15,000
LS03:	***Clinical, microbiological and nutritional determinants of efficient conservation by silage***			

LS0302	Alternative forages in sustainable livestock production: rumen function and animal response	IGER	1 July 1997 / 30 June 2002	751,044
LS0303	Plant enzymes and protein digestion in ruminants	IGER	1 July 1997 / 30 June 2002	482,810
LS21:	***To characterise the feeding value of forage and silage using new technologies for predicting nutrient value***			
LS2101	A review of the in vitro gas production technique	ADAS	1 December 1998 / 12 March 1999	8,139
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3602	A non-invasive alternative to the *in sacco* technique for determining extent of degradation in the rumen	University of Reading	1 March 2000 / 31 August 2001	51,410
LS3625	Reducing losses of nitrogen to the environment with diets based on red clover silage	ADAS	1 October 2000 / 30 September 2001	83,000
LS3629	Understanding metabolic nutrient partitioning in livestock species	SAC	1 November 2001 / 28 February 2002	25,085
LS3631	High sugar ryegrasses for improvement production efficiency of ruminant livestock & reduce environmental N-pollution	IGER	1 January 2001 / 31 March 2002	153,839
LS3632	Effects of genotype and processing technology on the protein quality for ruminants and poultry of UK rapeseed	ADAS	1 April 2002 / 31 March 2004	84,430
LS3638	Reducing N losses from ruminants by understanding the effects of plant attributes on rumen proteolysis and microbial protein synthesis	IGER	1 April 2002 / 31 March 2007	1,007,144
LS3640	Reducing losses of nitrogen to the environment with diets based on red clover silage	IGER	1 July 2002 / 28 February 2007	800,244
LS3641	A non-invasive approach for the determination of rumen pH	University of Reading	1 September 2002 / 31 August 2004	115,136
LS3642	Optimising nutrient budgets for livestock systems based on alternative forage crops	IGER	1 July 2002 / 30 November 2007	599,667
LS3653	The potential of non-toxic tannins to improve the utilisation of nitrogen compounds in grass silage by ruminants	University of Reading	1 February 2004 / 31 July 2006	246,104
LS3654	Exploiting the beneficial effects of PPO on the utilisation of protein and lipids in grazed forages	IGER	1 September 2004 / 31 August 2007	245,315
LS3656	Optimising nutrition to increase carbon and nitrogen capture in ruminant products	University of Reading	1 October 2004 / 31 September 2009	953,922
LK06:	***LINK Sustainable Livestock Production***			
LK0615	Impact of novel forage characteristics on productive output and efficiency	IGER	1 January 1998 / 31 December 2001	225,000

LK0638	High-sugar ryegrass for sustainable production of ruminant livestock and reduced environmental N-pollution	IGER	1 April 2002 / 31 December 2004	207,297
LK0658	Measurement of the nutrient value of whole crop wheat and barley silages using NIRS	University of Reading	1 December 2003 / 30 November 2005	61,824
			Total cost	**15,641,675**

2.6 Conserved forage research

Projects: DS0306, DS0307, DS0308, DS0309, DS0311, LS0301

Silage has become the dominant form of conserved grass and forage crops in UK livestock farming, replacing hay. This research was to improve the reliability and quality of ensiling and is the basis for modern ensiling technologies.

The feasibility of ensiling a range of novel forage crops, other than grass and grass/white clover for conservation was tested in LS0301, including red clover, lucerne, lotus, sainfoin, kale, peas, beans and lupins. With the possible exception of sainfoin, all of these crops could be successfully ensiled and fed to stock.

Table 2.6 Livestock Nutrition: Conserved forage projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
DS03:	***Conservation and nutritional value of forage crops with particular emphasis on silage microbiology***			
DS0306	Microbiological factors affecting silage fermentation	IGER	1 April 1994 / 30 June 1997	221,000
DS0307	The silage/rumen interface	IGER	1 April 1994 / 30 June 1997	199,000
DS0308	Silage proteolysis and its control	IGER	1 April 1994 / 30 June 1997	221,000
DS0309	Effect of silage additives on big bale silage	ADAS	1 March 1995 / 31 March 1995	4,500
DS0311	Effects of cracking whole crop wheat at harvest on its digestibility by lactating cows	University of Reading	1 January 1996 / 31 March 1996	8,156
LS03:	***Clinical, microbiological and nutritional determinants of efficient conservation by silage***			
LS0301	Conservation of protein/energy rich alternatives to forages	IGER	1 July 1997 / 30 June 2002	536,441
			Total cost	**1,190,097**

2.7 Pig research

Projects: LS0812, LS3601, LS3626, LS3651, LS3652, LS3657, LS3658, LK0652

Dietary formulation for breeding and growing/finishing pigs has been established by the UK industry, so did not have a high priority for MAFF during the 1990s. Towards the end of the century, the focus on sustainable production prompted new research on ways to reduce the environmental footprint of pig production and to improve the lifetime performance of UK pig herds. It was recognised that efficient gut function was key to nutrient capture and utilisation, and research was aimed at feeding

pregnant sows and their offspring to promote gut health. This included the use of fermented liquid feeds, where the low pH achieved during fermentation and the presence of lactic acid bacteria were shown to suppress the growth of bacterial pathogens in the pig gut.

Table 2.7 Livestock Nutrition: Pig projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
LS08:	***To improve nutrient utilisation for growth and lactation***			
LS0812	Fermented liquid feed for pigs: potential for improving productivity and reducing environmental impact	University of Plymouth	1 October 1998 / 30 September 2001	197,510
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3601	Finishing pigs: Systems research	Meat & Livestock Commission	1 September 2000 / 31 August 2005	929,231
LS3626	Maternal nutrition during late pregnancy and lactation: consequences for neonatal health and development (pigs)	Imperial College, University of London	1 May 2001 / 31 July 2003	162,426
LS3651	Sustainable management of the weaner pig through nutrition	University of Nottingham	1 August 2003 / 31 December 2006	169,961
LS3652	Production of summary of Nutrient tables (energy, amino acid, vitamins & minerals) for pigs	British Society of Animal Science	15 October 2002 / 25 March 2003	9,750
LS3657	Increasing nitrogen retention in saleable meat to benefit the environment and improve eating quality in pigs	University of Bristol / Harper Adams University College	1 November 2004 / 31 October 2007	603,460
LS3658	The impact of intensive and extensive rearing environment on mucosal immunity in the piglet (Gutwean)	University of Bristol	1 April 2005 / 31 March 2008	356,036
LK06:	***LINK Sustainable Livestock Production***			
LK0652	Sustainable systems for weaner management, package 2: Nutritional management towards sustainable production	SAC and the Universities of Leeds, Newcastle and Nottingham	1 September 2003 / 31 August 2007	644,086
			Total cost	**3,072,460**

2.8 Poultry research

Projects: MS0901, MS0902, MS0903, MS0904, MS0905, MS0906, MS0907, MS0908, MS0909, MS0910, MS0911, LS0901, LS0902, LS0903, LS0904, LS0905, LS3603, LS3607, LS3623, LS3625, LS3632, LK0641

The rate of genetic improvement achieved by the poultry breeding industry during the 1990s was high and knowledge of the nutrition required to meet the needs of the new genotypes was required by the UK industry. The research programme at Roslin Institute provided the underpinning for the development of modern poultry production systems. More recently, alternative home-grown crops have been trialled to reduce our reliance on imported feed such as soy beans. Rapeseed meal was shown to be a valuable component of poultry diets, while the use of naked oats in layer hen diets promoted bird performance as well as adding health-enhancing essential oils to the consumer diet

Table 2.8 Livestock Nutrition: Poultry projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS09:	***Feed chemistry and digestive processes in poultry***			
MS0901	To develop new biological and chemical methods	Roslin Institute	1 April 1991 / 31 March 1994	188,000
MS0902	To develop a net energy system for poultry	Roslin Institute	1 April 1991 / 31 March 1994	189,000
MS0903	To investigate the feed chemistry of and potential toxins in novel ingredients	Roslin Institute	1 April 1991 / 31 March 1994	218,000
MS0904	To investigate factors limiting digestive processes in poultry	Roslin Institute	1 April 1991 / 31 March 1994	203,000
MS0905	To characterise the metabolic role of vitamins	Roslin Institute	1 April 1991 / 31 March 1994	80,000
MS0906	To determine the effect of dietary fatty acids on hormonal activities	Roslin Institute	1 April 1991 / 31 March 1994	79,000
MS0907	To develop new biological and chemical methods to evaluate poultry nutrition	Roslin Institute	1 April 1994 / 31 March 1997	209,000
MS0908	To develop a net energy system and computer prediction model for poultry	Roslin Institute	1 April 1994 / 31 March 1997	209,000
MS0909	To investigate the feed chemistry of and potential toxins in novel poultry feed ingredients	Roslin Institute	1 April 1994 / 31 March 1997	240,000
MS0910	Factors limiting digestive processes in poultry	Roslin Institute	1 April 1994 / 31 March 1997	226,000
MS0911	To study the molecular regulation of metabolism by vitamins and other nutrients	Roslin Institute	1 April 1994 / 31 March 1997	211,000
LS09:	***Feed chemistry and digestive processes in poultry***			
LS0901	Matching mineral and vitamin composition and supply to the needs of modern poultry genotypes	Roslin Institute	1 April 1997 / 31 March 2000	244,359
LS0902	Determination of the optimal composition of feed protein for poultry, in relation to genotype and stage of growth	Roslin Institute	1 April 1997 / 31 March 2000	246,864
LS0903	Underexploited and new UK sources of dietary protein and energy for poultry	Roslin Institute	1 April 1997 / 31 March 2000	246,864
LS0904	Development, refinement and validation of management systems for prediction of poultry responses to	Roslin Institute	1 April 1997 / 31 March 2000	246,864

	diets			
LS0905	Optimising the efficiency of energy, calcium and phosphorus utilisation in layers fed on vegetable sources of protein	ADAS / University of Leeds	1 April 1997 / 31 March 2000	95,466
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3603	Performance and egg quality in laying hens fed on naked oats	Roslin Institute	1 October 2000 / 31 March 2004	232,726
LS3607	Optimising the use of home grown oilseeds and pulses for poultry	ADAS	1 May 2002 / 31 November 2004	167,464
LS3623	Avian efficiency from naked oats (AFENO)	Roslin Institute	1 October 2000 / 30 September 2003	351,198
LS3625	Effects of genotype and processing technology on the protein quality for ruminants and poultry of UK rapeseed	ADAS	1 October 2000 / 30 September 2001	83,000
LS3632	Effects of genotype and processing technology on the protein quality for ruminants and poultry of UK rapeseed	ADAS	1 April 2002 / 31 March 2004	84,430
LK06:	***LINK Sustainable Livestock Production***			
LK0641	Vitamin and mineral nutrition to optimise efficiency and quality in modern poultry genotypes	Roslin Institute	1 April 2000 / 31 March 2003	435,000
			Total cost	**4,486,235**

2.9 Lowland deer research

Projects:MS0301, MS0303, MS0305, MS0308, MS0309, MS0312

Farmed lowland red deer were identified as an opportunity for ruminant farmers to diversify. The lack of domestication of the stock presented problems for producers, notably reduced appetence over the winter period and the resulting lack of growth. This seasonality meant that UK venison supplies from farmed red deer were limited to a narrow window in late spring / early summer. The research in this programme was aimed at understanding this behaviour and looking for ways to overcome it, using artificial day length. This had limited success and the remaining research was focused on low input systems to reduce the cost of production. The findings were taken up by the industry via close collaboration with the British Deer Farmers Association.

Table 2.9 Livestock Nutrition: Lowland deer projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS03:	***Lowland deer***			
MS0301	Lowland deer: winter inappetance studies	ADAS	1 April 1991 / 31 August 1994	144,000
MS0305	Lowland deer: trace element studies	ADAS	1 April 1991 / 1 November 1994	56,000

MS0308	Lowland Deer: Winter inappetance studies	ADAS	30 September 1994 / 31 March 1995	30,000
MS0309	Lowland deer: low input systems	ADAS	1 April 1995 / 31 October 1998	230,789
MS0312	Lowland deer: low input systems for venison production	ADAS	1 October 1998 / 31 March 2002	178,367
			Total cost	**639,156**

2.10 General nutritional research

A small amount of nutrition research was appropriate to all livestock species, such as opportunities for home grown proteins and reviews of newly emerging dietary components or technologies.

2.10.1 Home-grown proteins

Projects: LS0810, LS3606, LS3610, LK0950

The ENTEC review compared the likely dietary value of a range of protein-rich crops with the agronomic and economic feasibility of large scale production in the UK. The front runners from this review, supported by the later data from the amino acid analysis, including lupins and red clover, became the focus for further research, described above.

2.10.2 Emerging dietary components

Projects: LS0807, LK0954

Maize varieties capable of flourishing in the UK became available in the early 1990s, prompting a rapid increase in the number of livestock producers willing to grow them. The European tour was conducted by the Maize Growers Association to ensure that UK producers were fully informed by the experience of procedures in warmer parts of Europe who had used maize for a longer period.

The breeding of naked varieties oats at IGER during the 1990s provided an opportunity to introduce this energy-rich crop into livestock feeds. The Sustainable Arable LINK project supported a breeding programme for additional traits to further improve its use in sustainable agriculture, such as economic competitiveness, high oil content, amino acid content, and suitability for organic production.

2.10.3 New technologies

Projects: LS3609, LS3629

NIRS has become a valuable tool in the analysis of feed composition but more research has been dedicated to exploiting it overseas than in the UK. The fact finding mission updated users on new applications and methodologies.

The gap analysis conducted in LS3629 recommended those areas where further investment in research should be made. The main thrust was that genotype x nutrition interactions should be the focus of new research, with the health and welfare of the animal receiving as much attention as its performance.

Table 2.10 Livestock Nutrition: General nutrition projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
LS08:	***To improve nutrient utilisation for growth and lactation***			
LS0807	Maize- European R&D Appraisal tour	D Thomson	21 October 1996 / 31 December 1996	5,500
LS0810	Home produced protein sources	ENTEC	1 May 1997 / 30 July 1997	4,429
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3606	Nutritional quality of UK produced lupin seeds and forage	ADAS	1 June 2000 / 31 October 2001	64,500
LS3609	New developments in near infrared reflectance spectroscopy: a fact finding mission	ADAS	1 February 2000 / 31 March 2001	14,026
LS3610	Measurement of amino acid digestibilities from UK protein sources and incorporation in a Net Energy model	Roslin Institute	1 April 2000 / 31 August 2000	70,557
LS3629	Understanding metabolic nutrient partitioning in livestock species	SAC	1 November 2001 / 28 February 2002	25,085
LK09:	***Sustainable Arable LINK***			
LK0950	Lupins in sustainable agriculture (LISA)	IGER	1 January 2004 / 21 December 2008	376,960
LK0954	The incorporation of important traits underlying sustainable development of the oat crop through combining 'conventional' phenotypic selection with molecular marker technologies ('OatLink')	IGER	1 April 2004 / 31 March 2009	331,712
			Total cost	**892,769**

For further project details and publications, see the Defra Science Information System web pages and the following R&D Reviews:

MAFF R&D Review - Physiology and Nutrition: June/July 1993

MAFF Physiology and Nutrition Scientific Review: 15 November 1995

MAFF Livestock Nutrition R&D Review: 22 & 23 April 1999

Defra Livestock Science R&D Review – Improving sustainability of UK livestock production through optimal nutrition: 18 & 19 February 2004

3. Reproduction

3.1 Overview

Reproductive efficiency was identified as an area for investment as it is responsible for significant financial and environmental losses in all farmed livestock species. Reduced reproductive efficiency results in

- more breeding animals being required to produce replacements for production stock
- reduced lifetime performance of breeding stock leading to a shorter breeding life and the need to generate more replacement breeding stock
- higher costs of production, and
- lower standards of welfare involved in higher levels of veterinary intervention and involuntary culling of infertile stock.

Selection of breeding stock for improved production efficiency was shown to have resulted in lower reproductive efficiency, so the research was aimed at two fronts: identification of the causes of the infertility and development of ways to stop the decline in fertility and restore it to levels closer to the biological potential for that species.

The issue for poultry was not reproductive efficiency but the moral and welfare problem of male chicks hatched in layer flocks. These birds are of no value to the industry and are destroyed after hatching.

In summary, the key policy objectives, targets and deliverables for each species were:

DAIRY CATTLE

Policy objective:

- Reduction in the size of the UK dairy herd with no reduction in the milk quota, thereby reducing the diffuse pollution per litre of milk

Targets:

- Reversing the decline in the percentage of heifer calves born reaching maturity and yielding milk as adults
- Reversing the decline in the percentage of cows becoming pregnant to AI or natural service during their first or subsequent lactations

Deliverables:

- Development of a milk progesterone test that identified and differentiated the causes of infertility
- Development of a genetic selection index for bovine fertility, now in use in the industry
- Formulation of dairy cow rations that doubled the rate of conception in high yielding cows, now incorporated into commercial concentrate formulations

SHEEP

Policy objective:

- Reduction in the number of barren ewes in hill sheep flocks, allowing reduction in flock size with fitter, better quality lambs, reducing damage to upland biodiversity

Targets:
- Increasing the number of lambs born and surviving in hill breeds

Deliverables:
- Genetic selection indices within hill sheep breeds that increase lamb number and ensure better survival of the lambs born

PIGS

Policy objective:
- Larger litters of piglets, reducing the number of breeding sows needed for the UK pig industry and the level of N and P emitted from the breeding herd

Targets:
- Preventing summer anoestrus in outdoor pigs
- Increasing the efficiency of artificial insemination in sows
- Increasing the number of piglets born per litter

Deliverables:
- A better understanding of summer anoestrus in outdoor sows
- Identification of an oviduct cell protein that prolongs the life of sperm *in vitro*, making AI more efficient
- Formulation of sow diets that reduce the number of runts in the litter, increasing piglet numbers and survivability

POULTRY

Policy objectives:
- Improved welfare resulting from a reduction in the need to destroy male layer chicks
- Improved welfare in broiler breeder hens by restoring normal fertility without the need to reduce their dietary intake

Targets:
- Identifying the genetic control of gender in birds in an attempt to reduce the numbers of male chicks hatched in layer breeder flocks
- Identifying alternatives to food reduction in broiler breeder hens to manage their fertility

Deliverables:
- Understanding of the genetic basis for sex determination in birds, which is different from that in mammals, and its application to the selection of eggs carrying female chicks in layer breeder flocks to reduce wastage and improve welfare in the system
- Separation of the genetics of growth from reproductive performance in broiler breeders, which is expected to lead to new ways to improve broiler breeder efficiency without having to control excessive growth by resorting to starvation

FARMED RED DEER

Policy objective:
- Improve the efficiency of farmed red deer production in the UK to encourage diversification of livestock farm enterprises

Targets:
- o Developing artificial insemination for use in farmed red deer to facilitate genetic improvements using a sire referencing scheme

Deliverables:
- o Attempts to develop AI for red deer were less than fully successful, due to poor sperm viability after storage and poor understanding of the oestrus cycle in deer. Sire referencing has continued within the industry by moving stags between herds

The research that was commissioned to address these targets is covered in the remainder of this chapter

3.2 Dairy cow research

3.2.1 Understanding the causes of dairy cow infertility

Projects: DS0203, LK0605, LK0621, OC9217, OC9605

The research examined the oestrus cycle in dairy cows, comparing fertile animals with those with impaired fertility. It was found that several types of disturbance could occur in the oestrus cycle and this allowed subsequent research to focus on the causes and ways to prevent them. The collaboration of industry with the researchers in the LINK project LK0605 led to the 3-pronged approach in subsequent LINK projects LK0639, LK0645 and LK0646 (funded by SEERAD) which had the greatest impact on dairy cow infertility and are discussed in more detail below.

3.2.2 Selection for increased fertility

Projects: LS3203, LS3204, LK0639

The heritability of fertility traits was shown to be relatively low, with genetics accounting for only around 20% of the variability, but this was considered to be sufficient to make a worthwhile improvement. Early attempts to select bulls that would have fertile daughters on the basis of their response to gonadotrophin releasing hormone (GnRH) failed to deliver a reliable test in commercial herds. The collaboration of academia, industry and government in the Fertility Index LINK project LK0639 was successful and resulted in a set of criteria that have been incorporated into current selection indices used in UK cattle breeding schemes.

3.2.3 Management for better reproductive performance

Projects: DS0201, DS0202, DS0206, DS0208, MS0506, LS0204, LS0205, LS2401, LS3306, LS3310, LS3312, LK0645, OC9427, OC9430, OC9431, OC9432

Much of the early work in these research projects was limited in its success because the causes of the increasing infertility in dairy cows were not understood. Identification of different causes of infertility by differences in the milk progesterone profile was developed for automatic analysis but uptake by the industry has been slow because of financial constraints on the UK dairy industry. Development of an 'electronic nose' to detect cows in oestrus was not successful as the only chemical that was identified was not unique to cows in heat. The most promising approach was that identified in LS3306 which showed that the nutritional requirements of cows prior to mating, while the oocytes are developing, are different from those required by the developing embryo in early pregnancy. Feeding these diets to cows at the correct time resulted in a more than doubling of the pregnancy rate. This was

translated into commercial rations in the SLP LINK project LK0646 “Nutritional improvement of fertility in dairy cows” and is now being used by the UK dairy industry.

3.2.4 Large Offspring Syndrome

Projects: LS3305, OC9320

The use of multiple ovulation with embryo transfer (MOET) was seen in the early 1990s as a way to speed up the genetic improvement of the UK dairy herd by selecting the best maternal and paternal genes across dairy herds. The production of over-sized and misshapen calves was not uncommon, however, and much research was aimed at finding the cause and a means of prevention. The research findings showed that incorrect gene imprinting occurred during the *in vitro* cultivation required to mature the embryos before implantation but that this could not be controlled. It did allow a test for early embryos that would become over-sized, allowing these to be selected against prior to re-implantation into the surrogate dam. This test is still being developed but the use of MOET has become less popular in the dairy industry, and improvements in the *in vitro* phase of the MOET process have reduced the frequency of oversized offspring.

Table 3.2 Reproduction: Dairy cow projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF / Defra Cost (£)**
DS02:	***Endocrine control and manipulation of reproduction***			
DS0201	Control of ovulation rate in cattle	University of Reading	1 April 1992 / 31 March 1996	651,000
DS0202	Maternal recognition of pregnancy in the cow	University of Reading	1 April 1992 / 31 March 1996	817,000
DS0203	The components of sub-fertility in milked dairy cows	University of Nottingham	1 April 1992 / 31 March 1996	66,160
DS0206	Increasing reproductive efficiency through improved control of follicular growth, oocyte quality and embryo survival	Roslin Institute	1 April 1996 / 31 March 1999	1,018,036
DS0208	Extended lactation in dairy cows	Hannah Research Institute	1 July 1996 / 30 June 1999	269,018
MS05:	***Molecular, cellular and genetic analysis of reproduction in farm animals***			
MS0506	Endocrine mechanisms controlling ovarian follicular growth, ovulation and luteal function in sheep and cattle	Roslin Institute	1 April 1991 / 31 March 1996	1,147,000
LS02:	***Reproductive technologies in livestock***			
LS0204	Bridge LINK: Improvement in the reproductive efficiency of cattle through the short-term manipulation of nutrition	University of Nottingham	1 April 1999 / 31 March 2000	566,562
LS0205	Bridge LINK: Improving dairy cow fertility	University of Nottingham	1 April 1999 / 31 December 2000	258,179

LS24:	***Improvement of suckler cows***			
LS2401	Automatic ovulation prediction in dairy cows	Silsoe Research Institute	1 April 1999 / 31 March 2002	329,582
LS32:	***Improving efficiency and quality of UK dairy cattle through genetics***			
LS3203	Genetics of dairy cow fertility	University of Nottingham	1 August 2000 / 31 December 2000	25,019
LS3204	Prepubertal selection of daughter fertility in dairy bulls	University of Nottingham / University of Liverpool	1 September 2002 / 31 December 2005	197,807
LS33:	***Improving sustainability of UK livestock production through enhanced reproductive performance***			
LS3305	Identification of factors and mechanisms in embryo culture associated with the large offspring syndrome	Roslin Institute	1 August 2000 / 31 July 2003	619,000
LS3306	Increasing dairy cow fertility through the precise control of nutrition	University of Nottingham	1 January 2001 / 31 December 2005	2,021,000
LS3310	Reducing the wastage in the dairy herd	Royal Veterinary College	1 August 2003 / 31 July 2008	321,092
LS3312	Reducing the numbers of unproductive and poorly productive animals in suckler beef and sheep production systems: a review	ADAS	1 December 2004 / 31 March 2005	27,795
LK06:	***LINK Sustainable Livestock Production***			
LK0605	Sub-fertility in dairy cattle: causes and strategies for remedial treatment	University of Nottingham / Royal Veterinary College	1 April 1996 / 31 March 1999	404,098
LK0621	Embryo viability and development in cows fed diets containing high levels of quickly degraded rumen nitrogen	ADAS / Royal Veterinary College	3 September 1998 / 28 February 2001	172,673
LK0639	Developing a fertility index (DFI)	University of Nottingham / Roslin Institute	1 January 2001 / 31 December 2005	696,705
LK0645	Endocrine management of bovine infertility	University of Nottingham	1 January 2001 / 31 December 2005	373,000
OC projects:	***Opening Contracting Scheme funded from the budget of Dr David Shannon, Shannon, Chief Scientist***			
OC9217	Trophoblast interferons and embryo mortality in ruminants	University of Nottingham	1 June 1993 / 31 May 1997	104,293
OC9320	Influence Of Embryo Manipulation, Culture And Transfer On Foetal Growth And Size At Birth	Babraham Institute	1 November 1994 / 31 October 1996	66,867

OC9427	Implications of emerging reproductive technologies (Continuation)	University of Reading	1 September 1994 / 31 August 1997	96,928
OC9430	Portable odour analysers for oestrus detection in cattle	Silsoe Research Institute	1 February 1996 / 31 January 1999	122,400
OC9431	Development of a second-generation electronic nose system for specific applications to agriculture and veterinary science	University of Glasgow	1 February 1996 / 31 January 1999	237,767
OC9432	Odour analysis for oestrus detection in cattle: biological applications	Royal Veterinary College	1 January 1996 / 31 December 1997	100,219
OC9605	Effects of altering dietary fatty acid composition on prostaglandin metabolism and fertility	Royal Veterinary College / ADAS	12 May 1997 / 11 August 1999	197,978
			Total cost	**10,907,178**

3.3 Sheep research

3.3.1 Understanding sheep fertility

Projects: MS0503, MS0506, LS1005, LS3312

Research in the early 1990s had shown that a lambing index of between 1.5 – 2 lambs per ewe per year was required for a sustainable hill sheep component to the stratified UK sheep industry. Research in the MS05 programme was aimed at understanding factors controlling fertility in the ewe. Genetic selection was identified as the way forward using sire referencing schemes.

3.3.2 Genetic selection for improved fertility:

Projects: MS0502, MS0509, LS2203, LK0661

Genetic variation in fertility had been identified in several sheep breeds across the world and the work in MS0502 and MS0509 helped to explain this. The establishment of sire referencing schemes for hill sheep breeds allowed the genetics of fertile rams to be disseminated across flocks within a small area but restrictions on stock movements caused by diseases such as foot-and-mouth made this increasingly difficult. Artificial insemination could only be used by licensed veterinarians and ram semen could not be stored efficiently. The LINK project LK0661 built on the earlier work with pig semen in which an oviduct cell wall protein had been shown to significantly extend the life of semen. The work with ram semen is being field trialled during 2008.

Table 3.3 Reproduction: Sheep projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS05:	***Molecular, cellular and genetic analysis of reproduction in farm animals***			
MS0502	Mechanisms by which major genes control fecundity in sheep	Roslin Institute	1 April 1991 / 31 March 1994	166,000

MS0503	To identify the mechanisms controlling gonadotrophin synthesis and secretion in sheep	Roslin Institute	1 April 1991 / 31 March 1994	235,000
MS0506	Endocrine mechanisms controlling ovarian follicular growth, ovulation and luteal function in sheep and cattle	Roslin Institute	1 April 1991 / 31 March 1996	1,147,000
MS0509	Mechanisms by which major genes control fecundity in sheep	Roslin Institute	1 April 1994 / 31 March 1997	203,000
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1005	Effect of nutrition in early life on the subsequent lifetime reproductive performance of ewes	ADAS	1 October 1996 / 1 March 1997	14,000
LS22:	***To underpin the genetic improvement of sheep***			
LS2203	Development of a new prolificacy strategy for UK sheep	Roslin Institute	1 April 1997 / 31 March 2000	316,625
LS33:	***Improving sustainability of UK livestock production through enhanced reproductive performance***			
LS3312	Reducing the numbers of unproductive and poorly productive animals in suckler beef and sheep production systems: a review	ADAS	1 December 2004 / 31 March 2005	27,795
LK06:	***LINK Sustainable Livestock Production***			
LK0661	The development of modern long-life storage diluent for fresh ram semen	Royal Veterinary College	1 January 2005 / 31 March 2008	327,224
			Total cost	**2,436,644**

3.4 Pig research

3.4.1 Understanding and preventing summer anoestrus

Projects: MS0507, MS0512, LS3307

There is a tendency for outdoor sows to stop ovulating at the height of summer, significantly reducing the number of piglets born per sow per year. Research in the MS05 programme showed that this was related to levels of melatonin. Apart from hormonal intervention, the best solution was considered to be maintaining a boar in close proximity to the sows, which reduced the incidence of anoestrus. The later study on a larger number of pigs was unable to detect evidence of changes in oestrus activity over the year. The causes for this were not determined although they may relate to differences in management practices between pig producers.

3.4.2 Improving the efficiency of artificial insemination

Projects: LS3302, LS3304, LS3309, OC9520

Artificial Insemination is seen as the key to improving the genetic potential of pig herds but boar semen loses viability on storage and oestrus detection in sows is difficult.

Oestrus detection by measuring oestradiol levels in saliva was shown to be feasible but the cost of installation made it commercially unattractive.
Research into components of oviduct cell membranes that capacitate sperm and prolong their life at 37^{o}C led to the identification of a member of the heat shock family of proteins which can achieve this. The procedure has been patented, is being taken up by the AI industry and is being applied in other species, including sheep (see above).

3.4.3 Increasing litter size

Projects: MS0505, MS1602, LK0617
Piglet loss in utero and the production of runts limits the reproductive potential of sows. Research demonstrated that dietary composition, such as the level of fibre in the ration, could have a influence on the number of viable piglets born and the LINK project allowed pig breeding and nutrition companies to take this into the industry.

Table 3.4 Reproduction: Pig projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS05:	***Molecular, cellular and genetic analysis of reproduction in farm animals***			
MS0505	Genes regulating ovulation rate and embryo survival in Meishan pigs	Roslin Institute	1 April 1991 / 31 March 1995	389,000
MS0507	Amelioration of summer infertility in outdoor pigs	University of Oxford	1 April 1993 / 30 September 1994	91,208
MS0512	Amelioration of summer infertility in outdoor pigs - Oxford trials	University of Oxford	1 October 1994 / 31 December 1994	26,655
MS16:	***Physiology of reproduction and nutrition in pigs***			
MS1602	Nutritional and hormonal control of ovulation end embryonic survival in sows	University of Bristol	1 November 1991 / 31 July 1995	277,000
LS33:	***Improving sustainability of UK livestock production through enhanced reproductive performance***			
LS3302	Enhancement of sperm survival by epididymal and oviduct epithelial cells	Institute of Zoology	1 July 2000 / 30 June 2002	158,000
LS3304	Automatic ovulation prediction for pigs	Silsoe Research Institute	30 September 2000 / 31 March 2004	313,000
LS3307	Seasonal infertility in the domestic pig: database analyses to evaluate factors responsible	University of Nottingham	1 January 2000 / 31 May 2003	141,000
LS3309	Enhancement of sperm survival for improved efficiency of artificial insemination in pigs	Institute of Zoology	1 January 2002 / 31 August 2005	27,309
OC projects:	***Opening Contracting Scheme funded from the budget of Dr David Shannon, Shannon, Chief Scientist***			

OC9520	Enhancement of sperm survival by epididymal and oviductal epithelial cells	Institute of Zoology	1 December 1996 / 31 March 2000	189,000
LK06:	***LINK Sustainable Livestock Production***			
LK0617	Nutritional effects on oocyte quality, pre-natal survival and within-litter variability in pigs	SAC	1 October 1999 / 30 September 2002	245,000
			Total cost	**1,857,172**

3.5 Poultry research

3.5.1 Gender determination in poultry

Projects: MS0501, MS0508, LS2003, LS3301, LS3311, OC9423

Destruction of millions of newly hatched male chicks from the layer flocks every year is of concern to the public and to MAFF/Defra ministers. Early attempts to influence the gender ratio in eggs from layer breeders were unsuccessful as the genetic determination of gender in birds was not understood and was not similar to that in mammals. Male mammals have a single gene, missing in the female, which switches on the male traits. Changes to this gene can cause an animal carrying the male XY chromosomes to develop as a functional female. The genetic basis for sex determination in birds was shown to be based on the number of Z sex chromosomes in each cell nucleus, where WZ specifies female and ZZ specifies male. The later research identified the molecular genetics of sex determination and provided a method for newly laid eggs to be screened for the presence of proteins encoded by the W chromosome and hence the sex of the embryo, allowing male eggs to be removed before the embryo developed any further.

Manipulation of egg incubation temperature, which causes male alligator embryos to become phenotypic females, was not successful in poultry.

3.5.2 Fertility in broiler breeder hens

Projects: MS0504, MS0510, LS2002, LS3106

Genetic selection of broiler lines for rapid growth has resulted in the high levels of growth hormone causing infertility problems in the breeder hens. The industry solution to overcome this is to reduce the feed levels to broiler breeder hens to reduce their growth rate. This is considered to be a welfare problem by many organisations and alternatives were sought.

The research findings have demonstrated that the genes controlling reproduction and growth are linked but separate, allowing genetic selection for growth to proceed without co-selecting for reproductive inefficiency. This is now being applied to the selection of broiler lines in which hen fertility is not compromised.

Table 3.5 Reproduction: Poultry projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS05:	***Molecular, cellular and genetic analysis of reproduction in farm animals***			
MS0501	Molecular genetics of sex-determination in birds	Roslin Institute	1 April 1991 / 31 March 1994	235,000

MS0504	Molecular genetics of reproductive efficiency in poultry	Roslin Institute	1 April 1991 / 31 March 1994	198,000
MS0508	Molecular genetics of sex-determination in birds	Roslin Institute	1 April 1994 / 30 June 1997	441,000
MS0510	Molecular genetics of reproductive efficiency in poultry	Roslin Institute	1 April 1994 / 30 June 1997	400,250
LS20:	***Genetic approaches to improving the UK poultry sector***			
LS2002	Candidate genes for reproductive efficiency in broiler breeders	Roslin Institute	1 July 1997 / 30June 2000	386,137
LS2003	Molecular genetics of sex determination and gonadal development in poultry	Roslin Institute	1 July 1997 / 30June 2000	481,743
LS31:	***Improving sustainable production and quality of UK pigs and poultry through genetics***			
LS3106	Precision selection tools to reduce the requirement for food restriction in broiler breeders	Roslin Institute	1 April 2004 / 31 March 2008	613,259
LS33:	***Improving sustainability of UK livestock production through enhanced reproductive performance***			
LS3301	Molecular genetics of sex determination and gonadal development in birds	Roslin Institute	1 July 2000 / 30 June 2003	432,950
LS3311	The molecular biology of sex determination and sexual development in birds	Roslin Institute	1 September 2003 / 31 August 2006	592,213
OC projects:	***Opening Contracting Scheme funded from the budget of Dr David Shannon, Shannon, Chief Scientist***			
OC9423	Manipulation of sex and growth in poultry	Manchester University	1 November 1995 / 31 October 1998	329,721
			Total cost	**3,780,552**

3.6 Red deer research

3.6.1 Artificial Insemination in farmed red deer

Projects: MS0302, MS0304, MS0306, MS0307, MS0310, MS0311

Diversification into red deer was seen as potentially worthwhile for livestock farmers in the mid1990s. The breeding stock being used was only recently derived from wild stock and domestication was needed to reduce seasonality and increase their year-round productivity. Sire referencing could be used to achieve this but there were welfare and disease concerns with moving high quality stags between commercial herds and AI would greatly facilitate the genetic improvement process. The MS03 research programme studied reproduction in red deer but the problems of semen storage and oestrus detection were not solved. Sire referencing has continued by moving stags between herds.

Table 3.6 Reproduction: Red Deer projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS03:	***Lowland deer***			
MS0302	Lowland deer: Ultrasonic scanner studies	ADAS	1 April 1991 / 31 March 1994	150,000
MS0304	Lowland deer: reproductive biology	ADAS	1 April 1991 / 31 March 1993	15,000
MS0306	Red deer: Novel reproductive techniques	ADAS	1 May 1993 / 31 March 1997	126,280
MS0307	Reproductive technology in deer	Institute of Zoology	1 January 1994 / 31 December 1996	137,386
MS0310	Red deer: maternal recognition of pregnancy (ADAS)	ADAS	1 October 1995 / 30 September 1998	71,440
MS0311	Red deer: maternal recognition of pregnancy (University of Nottingham)	University of Nottingham	1 October 1995 / 30 September 1998	48,000
			Total cost	**548,106**

For further project details and publications, see the Defra Science Information System web pages and the following R&D Reviews:

MAFF R&D Review – Genetics and Reproduction: March/April1993

MAFF R&D Review – Reproduction and Genetics: 10 May 1995

MAFF Livestock Science R&D Review – Reproduction: 11 & 2 November 1998

Defra Livestock Science R&D Review – Improving sustainability of UK livestock production through enhanced reproductive performance: 13/14 February 2003

4. Genetic Improvement

4.1 Overview

Genetic improvement has been demonstrated to be the most effective means to improve the efficiency of livestock production, since genetic gain is cumulative, increasing quality and efficiency in each new generation, and does not require the producer to invest in new equipment or infrastructure.

Genetic improvement is a tool rather than an objective, and it was developed within the livestock science research programme to bring about improvements in a number of policy-related areas, including:

- Selection for improved carcass quality
- Reducing the carbon footprint of livestock production
- Control of gender in poultry
- Improving disease resistance

However, the science of genetics developed very rapidly over the course of the programme and much of the research was aimed at making the new technologies applicable to farmed livestock. This included:

- Development of theoretical and applied genetic methodology for application to livestock
- Identification of the genetic basis for muscle accretion, fat deposition, growth, fertility, immunity, and nutrient retention
- Application of genome mapping and genomics to livestock species

The scale of the research needed to map an animal genome, so that genes and control sequences responsible for traits of commercial importance can be identified and used in marker assisted selection programmes, requires multinational consortia. The UK funding contribution for the early development of genetic maps of the genomes of pigs, poultry, cattle and sheep was principally from MAFF, BBSRC and the Wellcome Foundation. Once the appropriate microsatellite markers were identified, the UK research teams were encouraged to involve UK livestock industry in LINK projects to identify the genes and traits of most value the UK producers. This evolution from government support through to industry application is evident in the projects described below.

THEORETICAL GENETICS AND METHODOLOGY

Policy objective:

- To support the development of modern genetics to improve sustainability of the UK livestock sector

Targets:

- Provide tools for livestock breeders to use in the selection for more efficient and sustainable stock

Deliverables:

- Understanding of the principle genetic controls for muscle accretion and quality, fat deposition, and seasonality
- A range of theoretical and applied genetic methodologies now accepted as standard in the UK and international livestock breeding industries

CATTLE

Policy objective:

- Reduction in the size of the UK dairy herd with no reduction in the milk quota, thereby reducing the cost of production and diffuse pollution per litre of milk

Targets:

- Identify and understand the genetic basis for a range of production traits
- Develop selection indices and marker assisted selection techniques for the industry to breed more efficient dairy cows

Deliverables:

- Selection indices for dairy cows, including PIN, ITEM, £PLI and additional indices for fertility and lifetime performance
- A partial understanding of the genetics controlling milk composition, udder health, and fertility
- Genetic markers for QTLs (quantitative trait loci) and candidate genes associated with milk yield and composition, disease resistance, and fertility, now being taken up by the cattle breeding industry

SHEEP

Policy objective:

- Reduction in the number of hill sheep not meeting market specification, thereby reducing the size of the UK flock needed to meet market demand

- Targets:
- Improvement in carcass quality of hill sheep
- Demonstration that these improvements pass down through the stratified system to lowland finishing lambs

Deliverables:

- Genetic selection indices within hill sheep breeds that allow more efficient growth, better health and welfare, and a more consistent carcass quality that better meets market specification
- A range of genetic markers for traits of commercial importance
- Development of computed X-ray tomography (CT scanning) to identify rams with superior carcass conformation for use in sire referencing breeding programmes
- The first demonstration that livestock can be cloned using nuclear transfer from adult cells (Dolly)

PIGS

Policy objective:

- Improvement in pig carcass conformation and meat quality to reduce wastage of carcasses that do not meet market specification.

Targets:

- Understanding the genetics of growth, muscle accretion and fat deposition
- Developing techniques to select for improved qualities in breeding programmes

Deliverables:
- The pig genome map, now used by all major pig breeding companies to select for higher quality pigs
- A blood test to allow selection of pig breeding stock having a better innate immunity to disease
- Demonstration of neonatal piglet survival as a selectable genetic trait

POULTRY

Policy objectives:
- Improvement in poultry production efficiency
- Improved welfare resulting from a reduction in the need to destroy male layer chicks
- Improved welfare in broiler breeder hens by restoring normal fertility without the need to reduce their dietary intake

Targets:
- Developing tools for marker assisted selection in poultry breeding
- Identifying the genetic control of gender in birds in an attempt to reduce the numbers of male chicks hatched in layer breeder flocks
- Identifying alternatives to food reduction in broiler breeder hens to manage their fertility

Deliverables:
- A fully mapped poultry genome and marker assisted selection tools for the UK poultry industry it global market position
- Understanding of the genetic basis for sex determination in birds, which is different from that in mammals, and its application to the selection of eggs carrying female chicks in layer breeder flocks to reduce wastage and improve welfare in the system.
- Separation of the genetics of growth from reproductive performance in broiler breeders, which is expected to lead to new ways to improve broiler breeder efficiency without having to control excessive growth by resorting to starvation

The research that was commissioned to address these targets is covered in the remainder of this chapter

4.2 Theoretical genetics and methodology

Over the past 20 years MAFF, and to a lesser extent Defra, was the major funder for livestock genetics in the UK. Much of the early development of selection indices for dairy cattle and Estimated Breeding Values for farmed livestock species was supported by MAFF.

With the introduction of DNA sequencing and the development of the science of genomics, AFRC/BBSRC became more involved and the fundamental research was supported by them, allowing MAFF/Defra to apply the technology to the identification of genomic markers, Quantitative Trait Loci and Single Nucleotide Polymorphisms related to livestock traits that conferred economic, welfare and environmental benefits for the industry to take up.

4.2.1 Development of theoretical genetics for livestock:

Projects: DS0601, DS0602, DS0607, MS0601, MS0603, LS0601, LS0602, LS3201

This research laid the foundation for most of the breeding programme methodologies in use by the livestock industry. Most of the work was conducted at the Roslin Institute in Edinburgh, supported by the world class department for genetics at Edinburgh University. It helped to make the UK the world leader in poultry and pig breeding industries.

4.2.2 Understanding the genetic basis for traits of importance to UK livestock industry:

Projects: MS1001, MS1002, MS1003, MS1004, MS1005, MS1006, MS1007, MS1008, MS1009, OC9316/OC9316B, OC9604,

During the 1990s, it was believed that the future approach to farm animal breeding would be by identifying the genes responsible for growth, muscle accretion, fat deposition and bone development and by selecting for variations within these genes that confer benefits. Although that approach has been overtaken recently by the development of genome wide selection, in which DNA sequence variations across the whole genome can be readily compared between different individual animals and markers identified for important traits without knowing much about the genes involved, the earlier work gave significant insights into the genetic control governing carcass and meat production. This information was used by the pig and poultry breeding companies in developing their modern lines. An attempt was made to understand the genetic basis for variation in rare breeds, without great success.

4.2.3 Development of new technologies:

Projects: MS1201, MS1202, LS1202, LS1203, LS1208, LS3102

The MS12 and LS12 programmes were concerned with cloning and resulted in Dolly, the first animal to be born following transfer of a nucleus from an adult cell to an oocyte. The work originated out of a need to understand why oversized offspring were sometimes produced following embryo transfer in cattle and sheep. There were obviously differences between the programming of the genes required for development when a sperm fertilised an egg cell in the fallopian tubes of the animal and the fertilised embryo was nurtured in the uterus compared to when this was conducted in the laboratory and then transferred back to a surrogate mother. The early work studied how genes were programmed, switching off the genes that were required to produce an egg cell or a sperm and switching on those needed to develop an embryo that would develop to a healthy animal. The question:- can the egg cell switch off adult genes when a nucleus is injected into it – eventually led to Dolly. The findings caused great controversy and public disquiet, comparable to GM, and MAFF decided that if consumers would not accept meat, milk and eggs from cloned livestock then it was not sensible to continue to support the research and the programme ended.

The research in LS3102 was an attempt to develop rapid screening methods to identify genetic variation of interest in rare breeds. Rare breeds are considered to be a genetic resource that we may wish to use in future livestock farming but no methods exist to identify the genetic sequences that make one breed different from another and which may confer advantages to that breed. This project looked for sequences that were conserved within a breed but not across breeds, using different breeds of pig. The research demonstrated that this could be done but the technology has only recently been available to do this in a cost effective way, in the form of genome wide selection using micro-arrays.

Table 4.2 Genetics: Theoretical genetics and methodology projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
DS06:	***Theoretical genetics of dairy cows***			
DS0601	To determine the physiological components of genetic variation	Roslin Institute	1 April 1991 / 31 March 1996	580,000
DS0602	To develop mathematical techniques to aid in the efficient identification of trait genes (QTL)	Roslin Institute	1 April 1991 / 31 March 1996	246,000
DS0607	Statistical methods for the detection and utilisation of trait genes in livestock	Roslin Institute	1 April 1996 / 31 March 1999	186,476
MS06:	***Theoretical genetics of livestock***			
MS0601	New animal breeding theory in modelling and simulation studies	Roslin Institute	1 April 1991 / 30 June 1997	348,250
MS0603	To test genetic theories and techniques through selection experiments	Roslin Institute	1 April 1991 / 31 March 1997	726,000
MS10:	***Molecular, cellular and genetic analysis of growth***			
MS1001	Genes responsible for the control of muscle cell proliferation and differentiation	Roslin Institute	1 April 1991 / 31 March 1995	197,000
MS1002	Molecular mechanisms controlling the expression of transforming growth factor β gene expression	Roslin Institute	1 April 1991 / 31 March 1994	157,000
MS1003	Biochemical and endocrine mechanisms controlling nutrient partitioning between lean and adipose tissue growth	Roslin Institute	1 April 1991 / 31 March 1996	414,000
MS1004	Regulation of adipocyte development by growth factors	Roslin Institute	1 April 1991 / 31 March 1996	602,000
MS1005	Regulation of adipocyte development by growth factors	Roslin Institute	1 April 1991 / 31 March 1994	246,000
MS1006	The role of bone morphogenetic proteins in the regulation of chondrocyte differentiation	Roslin Institute	1 April 1991 / 31 March 1994	175,000
MS1007	Genes responsible for the control of muscle cell proliferation and differentiation	Roslin Institute	1 April 1994 / 31 March 1997	122,000
MS1008	Identification and mapping of 'candidate genes' for growth	Roslin Institute	1 April 1994 / 31 March 1997	113,000
MS1009	The role of bone morphogenetic proteins in the regulation of chondrocyte differentiation	Roslin Institute	1 April 1994 / 31 March 1997	170,599
MS12:	***Gene identification and gene transfer in farm animals***			
MS1201	Nuclear transfer: the effects of cell cycle and the method of activation	Roslin Institute	1 April 1991 / 31 March 1995	453,000
MS1202	Control of development and differentiation in early embryos	Roslin Institute	1 April 1991 / 31 March 1995	453,000
LS06:	***Theoretical and molecular genetics of livestock***			

LS0601	Estimation of dominance variance in livestock	Roslin Institute	1 October 1995 / 30 September 1998	157,516
LS0602	Sampling-assisted methods for QTL detection and genetic evaluation	Roslin Institute	1 April 1997 / 31 March 2000	208,466
LS12:	***Improving the genetic merit of UK livestock***			
LS1202	Development potential of quiescent cells derived from sheep embryos, sheep foetuses or adult cells	Roslin Institute	1 April 1995 / 31 March 1997	490,676
LS1203	Development after nuclear transfer from quiescent bovine cells	Roslin Institute	1 November 1995 / 31 October 1996	100,675
LS1208	Reconstruction of ovine embryos by nuclear transfer from cultured cell populations	Roslin Institute	1 April 1997 / 31 March 1999	245,467
LS31:	***Improving sustainable production and quality of UK pigs and poultry through genetics***			
LS3102	Identifying genes from rare breeds for sustainable agriculture	Roslin Institute	1 January 2001 / 31 December 2002	16,586
LS32:	***Improving efficiency and quality of UK dairy cattle through genetics***			
LS3201	Integrating QTLs into breeding programmes	Roslin Institute	1 July 2000 / 31 May 2001	55,578
OC projects:	***Opening Contracting Scheme funded from the budget of Dr David Shannon, Shannon, Chief Scientist***			
OC9316 / OC9316B	Genetic divergence in common and rare breeds of cattle and sheep (and continuation)	Institute of Zoology	1 October 1994 / 31 November 1999	221,219 62,878
OC9604	Identifying seasonality genes in livestock	Manchester University	1 June 1997 / 30 November 1999	228,906
			Total cost	**6,977,292**

4.3 Dairy cow research

4.3.1 Selection indices

Projects: DS0603, DS0604, DS0605, DS0606, LS0603

Selection indices provide information about the heritability of traits of commercial interest, and predict what the sire will pass down to his daughters. These indices evolved over the period 1991-2006 with support from the Livestock Science R&D Programme. The indices started with PIN (Profitability Index) which was concerned with just milk yield, protein and butterfat content, followed by ITEM (Index of Total Economic Merit) in the mid 1990s which introduced somatic cell counts and started to consider longevity. The most recent index is £PLI (Profitable Lifetime Index) which has built on the longevity and a number of other traits which are less involved with yield, quality and profitability and more with health, fertility and sustainability.

4.3.2 Embryo transfer

Projects: MS1207, MS1213, LS1204, LS1207

Aspects of the Large Offspring Syndrome (LOS) were covered in the Reproduction Research section of this report. The research in this section is concerned with understanding the cause of LOS, both in terms of what triggers it and how it is expressed. The research clearly showed that incubation of early embryos in laboratory medium after *in vitro* fertilisation results in incorrect imprinting of the genes involved in embryo and foetal growth. Imprinting is required to prevent both sets of genes from each parent from being expressed and switches off expression from one of the chromosomes. This was being interfered with by cultivation in the laboratory and a range of alternative media were tested. Currently, there is no guaranteed way to prevent the inappropriate imprinting during embryo transfer but embryos can now be tested in the laboratory and only those where the imprinting is correct can be transferred to surrogate dams for continued gestation.

4.3.3 Genetic control of commercial traits

Products: DS0608, LS0604, LS3203, LS3204, LK0657

The main trait investigated in this programme was dairy cow fertility. As covered in the Reproduction Research chapter of this report, the different types and causes of infertility were becoming clearer but it was anticipated that fertility was a heritable trait that could be selected for. Demonstration that the heritability of fertility was relatively low, with genetics accounting for only around 20% of the cause, had earlier ruled out using genetic selection as a worthwhile tool but with the introduction of better genetic approaches, allowing genes directly involved with fertility to be identified, the approach was re-adopted. The work in this programme led to the SLP LINK project LK0639 in which a fertility index was derived in close collaboration with the industry, described in the Reproduction Research chapter. This selection index is now in commercial use.

Project LK0657 was also concerned with fertility but took the approach that a contributory factor was the selection for high milk yield for the past 25 years had selected cattle that channelled their nutrients into milk production at the expense of their body condition. The Robust Cow project derived selection parameters for cattle who maintained their body condition during peak lactation, maintaining their fertility and lifetime performance, without making any significant changes to their behaviour or welfare.

4.3.4 Genome mapping

Projects: LS1201, LS3205, LS3206, LK0602, LK0618, LK0630

The earlier project LS1201 was a short project aimed at starting up the Roslin Bovine Genome project, and getting sufficient industry support to be able to run a 10-year RoBoGen LINK project. The support was found and the programme started with LK0604, setting up a bovine resource herd by crossing Holstein cows to Charolais bulls, allowing the segregation of beef and dairy traits to be mapped. This continued through LK0618 but at the end of that project the MDC pulled out of the consortium as the research was not delivering messages and benefits for their levy payers. LK0630 continued the programme but focussed only on beef traits. Separate funding was sourced to allow completion of the dairy traits and this was conducted in LS3205 and LS3208. A wide range of QTLs and markers were identified and are now being rolled out by the cattle breeding industry.

Table 4.3 Genetics: Dairy cattle projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
DS06:	***Theoretical genetics of dairy cows***			
DS0603	National profit indices for dairy cattle	SAC	1 April 1992 / 31 March 1996	147,669
DS0604	The relationship between clinical and sub-clinical mastitis, somatic cell count and other cow characteristics affecting susceptibility to mastitis	ADAS	1 April 1993 / 31 March 1996	41,000
DS0605	Evaluation of sire effect on somatic cell count and incidence of clinical mastitis	ADAS	1 March 1995 / 31 March 1995	10,000
DS0606	Sustainable breeding goals: genetic and economic aspects of selection for yield, reproduction & body tissue utilisation	SAC	1 April 1996 / 31 March 1999	159,816
DS0608	To quantify genetic variation in endocrine pathways for improved economic efficiency in dairy cattle	Roslin Institute	1 April 1996 / 31 March 1999	494,548
MS12:	***Gene identification and gene transfer in farm animals***			
MS1207	Synthetic culture media for the improvement of in vitro maturation of oocytes and embryos (Eureka Syncultmed - bovine oocyte culture)	Genus	1 September 1994 / 31 August 1996	214,346
MS1213	Improvement in cattle embryo transfer technologies	University of York	26 February 1996 / 31 December 1997	119,143
LS06:	***Theoretical and molecular genetics of livestock***			
LS0603	Modelling variance-covariance structures for improving predictions in dairy management and breeding	Roslin Institute	1 April 1999 / 30 June 2000	219,901
LS0604	Reproductive function in high-yielding dairy cows: nutritional and genetic interactions	Roslin Institute	1 April 1999 / 31 December 2000	162,316
LS12:	***Improving the genetic merit of UK livestock***			
LS1201	Bovine genome mapping and QTL localisation	Roslin Institute	1 October 1995 / 31 March 1996	77,927
LS1204	Molecular and developmental investigations into the involvement of genetic imprinting in the large calf syndrome	Babraham Institute	1 April 1997 / 3 March 2000	232,484
LS1207	Identification of factors and mechanisms in embryo culture associated with the large offspring syndrome	Roslin Institute	1 April 1997 / 30 September 2000	642,271
LS32:	***Improving efficiency and quality of UK dairy cattle through genetics***			
LS3203	Genetics of dairy cow fertility	University of Nottingham	1 August 2000 / 31 December 2000	25,019

LS3204	Prepubertal selection of daughter fertility in dairy bulls	University of Nottingham / University of Liverpool	1 September 2002 / 31 December 2005	197,807
LS3205	Identification of Dairy Associated QTL in a cattle resource herd	Roslin Institute	1 April 2001 / 31 March 2002	229,505
LS3206	Identification of Dairy Associated QTL in a cattle resource herd	Roslin Institute	1 April 2002 / 31 March 2006	415,000
LK06:	***LINK Sustainable Livestock Production***			
LK0602	Development of a bovine resource herd and identification of economically important traits	Roslin Institute	1 April 1996 / 31 March 1998	246,000
LK0618	Bovine mapping: a themed approach	Roslin Institute	1 April 1998 / 31 March 2001	900,002
LK0630	Roslin bovine genome mapping	Roslin Institute	1 April 2001 / 31 March 2005	476,264
LK0657	Identifying and characterising robust dairy cows	SAC	1 February 2004 / 31 January 2007	622,751
			Total cost	**5,633,769**

4.4 Beef cattle research

(see also 4.3.4 Genome mapping)

4.4.1 Suckler beef improvement

Project: LK0629

The project looked the use of beef breed crosses as alternatives to the use of surplus dairy heifers to provide replacement heifers to the suckler beef industry. It generated the BREEDS (Beef Replacement Enterprise Evaluation Decisions Support) software, allowing beef producers to explore the merits of new breeds and systems for herd replacement.

Table 4.4 Genetics: Beef cattle projects

LK06:	***LINK Sustainable Livestock Production***			
LK0629	Developing effective suckler cow replacement strategies	SAC	1 October 1999 / 30 September 2003	84,011

4.5 Sheep research

4.5.1 Genetic improvement of hill sheep

Projects: MS0201, MS0202, MS0203, MS0204, MS0205, LS0201, LS0203, LS1003, LS2202, LS2203, LS2204, LS2206, LS3004, LS3005

Hill sheep are a key component at the top of the stratified sheep industry in the UK, being able to survive on the hills and uplands with low input. Their key merits are hardiness and maternal traits but their carcass composition makes them unsuitable for the UK meat retail market. The main thrust of this programme was to develop selection indices that could be applied to sire referencing schemes for hill breeds,

promoting better carcass conformation without losing their hardiness and good maternal behaviour. The programme moved on to include selection indices for crossing sires, such as the longwool breeds used to create mules and cross-bred sheep, and to demonstrate that the improved carcass conformation seen in the mules was retained after crossing the mule ewes with terminal sires. All of this was successful and is now in use in the industry.
Carcass quality is difficult to select for as the true quality could only be measured in the slaughtered animal. Computed X-ray Tomography (CT) was used to identify crossing sires with the best musculature for use in the final stages of the programme and this has demonstrated significant financial benefit for the producers.

4.5.2 Sheep genomics

Projects: LS2205, LS2207, LS3001, LK0628, LK0656
Mapping the sheep genome was not considered by MAFF to be a high priority as the UK sheep industry was thought to be too dispersed to facilitate uptake of the findings. The breed societies started to act as a consortium in the mid 1990s and this promoted meetings in 1997 and 1998 to set limited and focused objectives for a sheep genomics programme. The first LINK project, co-funded by the sheep industry, was initiated in 1999 and followed by a second project in 2004, with some additional work outside the LINK programme. The result is that sheep farmers in the UK are now actively engaged in marker assisted selection for a range of carcass traits as well as actively using sire referencing schemes to in crease the quality of their flocks.

4.5.3 Genetic diversity

Projects: LS3002, LS3003
When the National Scrapie Plan was introduced to the UK, it was apparent that small populations of rare breeds of sheep would not be eligible for breeding if they lacked the required genotypes. To avoid losing these breeds, the blood samples used to assess genotype were stored so that their DNA could be sequenced at a later date if that was shown to be valuable. This eventually proved to be unnecessary as germ banks for sheep breeds to store semen and embryos.

Table 4.5 Genetics: Sheep projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS02:	***Improvement of hill sheep***			
MS0201	Scottish Blackface ewe improvement utilising intra-uterine artificial insemination and embryo transfer	ADAS	1 April 1991 / 31 March 1996	622,000
MS0202	Welsh Mountain ewe improvement utilising intra-uterine artificial insemination and embryo transfer	ADAS	1 April 1991 / 31 March 1994	397,000
MS0203	Intra-uterine artificial insemination in hill sheep	ADAS / University of Nottingham	1 April 1991 / 31 March 1996	243,000
MS0204	Genetic improvement of Scottish Blackface sheep utilising artificial insemination and embryo transfer	ADAS	1 April 1996 / 31 March 1998	322,088
MS0205	Genetic improvement of hill sheep (development of multiple ovulation and embryo transfer for use in less prolific breeds)	ADAS / University of Wales	1 April 1996 / 31 March 1998	139,161

LS02:	***Reproductive technologies in livestock***			
LS0201	Genetic improvement of hill sheep utilising AI and ET	ADAS	1 April 1998 / 31 March 2001	460,942
LS0203	Development of MOET for use in less prolific hill breeds	ADAS	1 April 1998 / 31 March 2001	179,449
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1003	Genetic and nutritional control of fat deposition in ruminants	IGER/ University of Nottingham	1 April 1996 / 31 March 1999	371,821
LS22:	***To underpin the genetic improvement of sheep***			
LS2202	Development of multi-trait selection indices for longwool sheep to breed half-bred ewes of superior economic performance	University of Wales / SAC / ADAS	1 July 1997 / 31 December 2006	958,743
LS2203	Development of a new prolificacy strategy for UK sheep	Roslin Institute	1 April 1997 / 31 March 2000	316,625
LS2204	Genetic control of resistance to gastrointestinal parasites in hill sheep	Roslin Institute	1 April 1997 / 31 March 2000	93,887
LS2205	Meeting to discuss setting up UK sheep genome project	Roslin Institute	1 October 1997 / 31 December 1997	7,247
LS2206	Development of multi-trait selection index in hill sheep	Roslin Institute	1 January 1998 / 31 December 2000	59,295
LS2207	LS2207: Initiating a UK sheep Genome programme	Roslin Institute	1 October 1998 / 31 march 1999	44,767
LS30:	***Genetic approaches to improving efficiency and quality of UK beef cattle and sheep***			
LS3001	Identifying genetic markers for carcass and meat quality traits in sheep	Roslin Institute	1 April 2000 / 31 March 2004	687,715
LS3002	Storage of blood samples from rare sheep breeds (LGC)	Laboratory of the Government Chemist	25 February 2002 / 24 February 2003	10,000
LS3003	Storage of blood samples from rare sheep breeds (Cellmark)	Cellmark / Orchid	25 February 2002 / 24 February 2003	13,500
LS3004	To demonstrate the value of a selection index incorporating CT scans to improve carcass conformation in sheep - production of CT scans	ADAS	1 September 2002 / 31 August 2004	65,930
LS3005	Demonstration of genetic improvement in crossbred progeny from Swaledale progeny	ADAS	1 January 2004 / 31 March 2007	33,046
LK06:	***LINK Sustainable Livestock Production***			
LK0628	QTL identification and utilisation in sheep sire referencing schemes	Roslin Institute	1 July 1999 / 30 September 2003	154,056

LK0656	Marker assisted selection in commercial sheep	Roslin Institute	1 June 2004 / 31 May 2007	121,603
			Total cost	**5,301,875**

4.6 Pig research

4.6.1 Genetics of lean growth

Projects: MS0701, MS0702, MS0703, MS0705, MS0706, LS0701, LS0702, LS0703, LK0611

The MS07 and LS07 research programmes established several lines of pigs different in their growth responses to nutrients. The founder pigs, both Large White and Landrace stock, were donated by breeding companies and the information from the projects was shared with them, informing their ongoing breeding programmes. The findings clearly demonstrated that genetic selection could derive pig lines that were more efficient at producing muscle from limited rations and at no loss of health. Although the pigs in each line were not genotyped, some limited DNA analysis was conducted by restriction fragment length polymorphism. Having established that the genetics controlling feed intake and growth were linked in these lines, the LINK project LK0611 attempted to predict dietary requirements based on growth parameters. This was partly, but not fully, successful.

4.6.2 Genomics and marker assisted selection

Projects: MS1204, MS1205, MS1206, MS1208, LS1001, LS1006, LS1205, LS3105, LK0603

The highly integrated and focussed nature of the pig breeding industry in the UK led to an early uptake of new genetic technologies. The UK was a partner in the Pig Genome Mapping (PiGMaP) international project and MAFF supported work on the uptake of this technology in the UK with a range of projects to provide unpinning knowhow that could be taken up by the industry. Industry co-funding was made available for the SLP LINK project LK0603, which ended in 1993. After this, the pig breeding companies had the expertise needed to continue using genomics in their breeding programme and no further support was needed from government.

4.6.3 Health

Projects: LS3103, LK0623, LK0649

Although the Animal Health divisions of MAFF and Defra are responsible for disease control in livestock, they have not covered neonatal survival or innate immunity, both of which have major genetic component and can be selected for in breeding programmes.

Innate immunity is the ability of an animal to resist infection without the need to switch on an antibody or cellular immune response, both of which take up to 5 days to become effective, so it is much faster. LK0623 and LK0649 projects in the SLP LINK programme measured blood parameters of a large number of pigs kept under normal commercial conditions and compared the differences between pigs that stayed healthy and those that were less able to cope with the pathogen load in the environment. This led to a test for those pigs having a better innate immunity and this is now used in commercial breeding programmes.

Table 4.6 Genetics: Pig projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS07:	***Genetic relationships between food intake, growth and carcass quality***			
MS0701	Intake, growth and carcass quality in pigs	Roslin Institute	1 April 1991 / 31 March 1995	515,228
MS0702	Genetics of lean growth in pigs	Wye College, London	1 April 1991 / 30 April 1994	291,793
MS0703	Genetics of lean growth in pigs (continued)	Wye College, London	1 April 1994 / 30 September 1994	57,343
MS0705	Relationships between selection strategies for components of efficient lean growth rate and nutrition	Roslin Institute	1 April 1995 / 31 March 1996	243,664
MS0706	Genetic relationships between growth, carcass quality and feed intake in pigs – extension	Roslin Institute	1 October 1994 / 31 March 1995	77,660
MS12:	***Gene identification and gene transfer in farm animals***			
MS1204	Identify molecular markers for the production of a genetic map of the pig genome	Roslin Institute	1 April 1991 / 31 March 1994	497,000
MS1205	Analyse the gene causing porcine stress syndrome and identify its action at the genetic level	Roslin Institute	1 April 1991 / 31 March 1994	218,000
MS1206	Marker assisted selection in pigs	Roslin Institute	1 October 1993 / 30 September 1997	47,787
MS1208	Identify molecular markers for the production of a genetic map of the pig genome	Roslin Institute	1 April 1994 / 30 June 1997	1,164,000
LS07:	***Genetic relationships between food intake, growth, reproductive performance and carcass quality***			
LS0701	Genotype with nutrition interaction for reproduction and behaviour of sows selected for lean growth rate	Royal Veterinary College	1 November 1995 / 31 October 1998	109,136
LS0702	Genotype with nutrition interaction for meat and eating quality in pigs selected for lean growth rate	Roslin Institute	1 April 1996 / 31 March 1998	541,714
LS0703	Genetic control of nutrient requirements in pigs	Roslin Institute	1 June 1998 / 31 May 2001	913,924
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1001	Isolation and characterisation of porcine myosin heavy chain genes: a molecular approach to manipulating muscle mass and quality in pigs	Roslin Institute	1 January 1995 / 30 April 1998	323,401
LS1006	Improving pig quality by selection on the porcine myosin heavy chain genes	Roslin Institute	1 July 1998 / 30 September 1999	101,489

LS12:	***Improving the genetic merit of UK livestock***			
LS1205	Exploiting QTL in pig breeding	Roslin Institute	1 July 1997 / 30 June 2001	843,876
LS31:	***Improving sustainable production and quality of UK pigs and poultry through genetics***			
LS3103	Genetic selection for improved pre-weaning survival of piglets	University of Newcastle	1 October 2003 / 30 September 2007	231,81
LS3105	Physical map of the pig genome as a launch pad for finding genes of economic importance	Roslin Institute	1 April 2003 / 31 March 2004	150,000
LK06:	***LINK Sustainable Livestock Production***			
LK0603	Pig QTL mapping consortium	Roslin Institute	1 May 1996 / 31 April 1999	179,880
LK0611	Model for the prediction of carcass composition from genetics and feed intake	Roslin Institute	1 July 2007 / 31 December 1999	52,400
LK0623	Quantifying generalised immunity in genetically diverse pigs	Roslin Institute	1 December 1998 / 30 November 2000	78,701
LK0649	Using Generalised Innate Immunity to Enhance Pig Health and Welfare	Roslin Institute	1 January 2002 / 31 December 2004	146,127
			Total cost	**6,553,123**

4.7 Poultry research

4.7.1 Genomics and marker assisted selection

Projects: LS1002, LS2001, LS2002, LS2003, LS2004, LS3101, LS3106, LK0625, OC9315

Research in this area had three sets of objectives: providing tools for poultry breeders to use genomics to improve carcass quality and performance, to separate growth from reproduction in order to breed broiler lines where the breeder hens do not need to have feed restriction to make them fertile, and identifying the basis for gender determination in birds to reduce the numbers of male chicks destroyed at hatch in layer hen breeder lines. The second and third of these were dealt with earlier in the Reproduction Research chapter of this report (see page 24).

The provision of genomics tools for the UK poultry industry was very successful and was readily taken up. Early work on mapping the chicken genome used a resource flock generated by crossing White Leghorn chickens with red junglefowl, their undomesticated ancestor. These extreme crosses give the easiest segregation of traits to detect but raise the concern that insufficient genetic diversity exists in commercial flocks to allow QTL selection. This was tested in the LINK project LK0625 and showed that there is still sufficient genetic diversity in the in-bred commercial lines to allow for segregation of traits for marker assisted selection.

4.7.2 *In vitro* cultivation

Projects: MS1203, MS1211, LS1206, LS1211

Interest in genetic manipulation and the generation of transgenic livestock in the early 1990s prompted researchers at Roslin Institute to look at ways of achieving this with poultry. The fertilised egg needs to be genetically modified before cell division starts and this is readily achieved in vitro with mammals as the embryo can be transplanted back into a surrogate mother. This research developed an artificial egg that would support the growth of the chick embryo through to a free-living chick. Although agricultural interest in transgenic livestock has diminished, the artificial egg technology is now being used for the creation of transgenic chickens that generate valuable human health products in their eggs.

4.7.3 Environmental impact

Projects: LS3104

The efficiency with which dietary nutrients such as nitrogen and phosphorus are retained by an animal is likely to be under genetic control and, therefore, amenable to selection for increased efficiency. This has never been demonstrated. This project was commissioned to measure it, using different genetic lines of broiler chickens and their ability to incorporate dietary N and P into tissue. The results confirmed that genetic differences occur, allowing for selection of lines that have lower environmental footprints.

Table 4.7 Genetics: Poultry projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS12:	***Gene identification and gene transfer in farm animals***			
MS1203	In vitro culture systems for genetic manipulation of poultry	Roslin Institute	1 April 1991 / 31 March 1995	453,000
MS1211	In vitro culture systems for genetic manipulation of poultry	Roslin Institute	1 April 1994 / 30 June 1997	426,500
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1002	Identification of QTL for fatness and feed efficiency in broiler chickens	Roslin Institute	1 April 1996 / 31 March 1999	264,863
LS12:	***Improving the genetic merit of UK livestock***			
LS1206	In vitro culture systems for poultry eggs	Roslin Institute	1 July 1997 / 31 March 1998	115,500
LS1211	In vitro culture systems for genetic manipulation of poultry	Roslin Institute	1 April 1994 / 30 June 1997	380,231
LS20:	***Genetic approaches to improving the UK poultry sector***			
LS2001	Poultry QTL mapping consortium	Roslin Institute	1 July 1997 / 30June 2000	137,003
LS2002	Candidate genes for reproductive efficiency in broiler breeders	Roslin Institute	1 July 1997 / 30June 2000	386,137
LS2003	Molecular genetics of sex determination and gonadal development in poultry	Roslin Institute	1 July 1997 / 30June 2000	481,743

LS2004	Genetic control of poultry meat quality	Roslin Institute	1 October 1997 / 30 September 2001	463,598
LS31:	***Improving sustainable production and quality of UK pigs and poultry through genetics***			
LS3101	Marker assisted selection for improved reproductive performance in broiler breeders	Roslin Institute	1 July 2000 / 30 June 2003	449,890
LS3104	Reducing nitrogen and phosphorus pollution by poultry – determining the potential for genetic methods	Roslin Institute	1 October 2003 / 30 September 2006	712,568
LS3106	Precision selection tools to reduce the requirement for food restriction in broiler breeders	Roslin Institute	1 April 2004 / 31 March 2008	613,259
LK06:	***LINK Sustainable Livestock Production***			
LK0625	Developing methods for identifying QTL segregating in commercial broiler populations	Roslin Institute	1 April 2000 / 3 March 2003	240,582
OC projects:	***Opening Contracting Scheme funded from the budget of Dr David Shannon, Shannon, Chief Scientist***			
OC9315	Developing strategies for mapping quantitative traits in poultry.	Roslin Institute	1 June 1994 / 31 May 1997	221,877
			Total cost	**5,346,751**

For further project details and publications, see the Defra Science Information System web pages and the following R&D Reviews:
MAFF R&D Review – Genetics and Reproduction: March/April1993
MAFF R&D Review – Reproduction and Genetics: 10 May 1995
MAFF Livestock Science R&D Review – Genetics: 12 & 13 October 1998
Defra Livestock Science R&D Review – Genetics: 24 & 25 October 2001
Defra Livestock Genetics R&D Review: 27/28 October 2004

5. Product Quality

5.1 Overview

The main drivers for MAFF and Defra support for research into product quality were to strengthen the home and overseas markets for UK-produced livestock products and to reduce the environmental footprint of livestock production by reducing the waste caused by disposal of carcasses, meat, milk and eggs not meeting market specifications.

MILK

Policy objective:

- Helping the UK dairy industry to meet regulatory and consumer requirements

Targets:

- Finding ways to ensure the required quality for milk to meet the Drinking Milk Regulations
- Investigating the feasibility of producing milk that helps to meet "Health of the Nation" guidelines

Deliverables:

- Production protocols that ensure milk meets the required regulations
- Alternative management regimes whereby cows produce milk low in saturated fat and high in the essential long chain polyunsaturated fatty of the omega-3 (n-3) series and in conjugated linoleic acid (CLA)

BEEF

Policy objective:

- Helping the UK beef industry to produce meat that meets consumer requirements
- Improving the welfare of bull calves from the dairy herd

Targets:

- Providing knowledge to underpin consistent improvements in beef eating quality
- Investigating the feasibility of producing beef that helps to meet "Health of the Nation" guidelines
- Finding alternatives to veal crates for producing meat from Holstein bull calves

Deliverables:

- Production protocols to improve the tenderness, flavour and fatty acid composition of beef
- Recommendations for the production of 'rosy beef' from young Holstein bull calves without resorting to veal crates and a milk only diet

SHEEP MEAT

Policy objective:

- Reducing wastage from the national sheep flock by animals that didn't reach market specification
- Improving the market value of lamb

Targets:

- Providing sheep breeders with knowledge to allow them to breed sheep that have lower carcass fat and higher musculature

- Improving the eating quality of lamb

Deliverables:
- Demonstration of the value of Computed X-ray Tomography for selection of rams with superior carcass characteristics
- Selection indices for breeders to improve the conformation of their lambs
- Demonstration that the desirable flavour of lamb raised on grass-based diets is correlated with the presence of the essential long chain polyunsaturated fatty acids important for consumer health

PIG MEAT

Policy objective:
- Support for the UK pig industry to produce pork that meets consumer requirements

Targets:
- Better eating quality for UK pork

Deliverables:
- Methods to produce lean pigs that have good intramuscular fat
- Knowledge of the role of different myosin fibre compositions in pork eating quality

POULTRY AND EGGS

Policy objective:
- Support for the UK poultry industry to produce chicken meat that meets consumer demands
- To demonstrate the safety to the consumer of using feedstuffs containing genetically modified (GM) plants

Targets:
- Production protocols that result in high quality chicken meat
- Chicken meat that has a stronger desirable flavour
- Detection of recombinant DNA derived from dietary components in meat from broilers fed GM feed

Deliverables:
- Recommendations to broiler breeders and producers of procedures to improve chicken meat
- Demonstration of the absence of recombinant DNA sequences, derived from GM rations, capable of encoding foreign proteins in meat and organs of chickens entering the food chain

5.2 Milk research

5.2.1 Controlling milk quality

Projects: DS1001, DS1002, DS1003, MS0109

The early work in this programme was in support of the Drinking Milk Regulations, generating evidence and recommendations for dairy farmers to meet the requirements for microbiology, somatic cell counts, and minimum levels of butterfat and protein. The findings from this and other work commissioned by organisations such as the Milk Marketing Board set the standards for the procedures in use today

5.2.2 Manipulating unsaturated fatty acid composition

Projects: MS1805, LS1803, LS3503, LS3507, LS3508, LS3509, LS3517

The Government White Paper 'The Health of the Nation', first introduced in 1992, recommended that UK consumers should increase their dietary intake of essential long-chain polyunsaturated fatty acids, with particular emphasis on those in the omega-3 series. As milk and dairy products are major sources of fat for many consumers, research was initiated to assess the feasibility of reducing saturated fats in milk and replacing them with the omega-3 (later known as n-3) polyunsaturated fatty acids alpha-linolenic acid (C18), eicosapentaenoic acid (EPA, C20) and docosahexaenoic acid (DHA, C22). Including fish oil in rations was successful but could impart off flavours. Other natural plant sources were investigated. The research demonstrated that this could be partially achieved by feeding dairy cows on oil seed rations. The reduction in saturated fat and increase in unsaturated fat had the additional benefit that butter made from this milk would spread 'straight from the fridge'. More recently, the health benefits of conjugated linoleic acid (CLA) as a natural anti-cancer agent have been promoted in milk. There was some uptake of this technology but the additional cost of production coupled with the difficulty of labelling milk and other dairy products with appropriate health claims backed by the Department of Health have slowed down its commercial exploitation

Table 5.2 Product Quality: Milk projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
DS10:	***Pathogens in milk and diary products***			
DS1001	To develop rapid specific methods to detect pathogens in milk and dairy products	CSL	1 April 1991 / 31 March 1994	440,000
DS1002	To develop rapid specific methods to detect pathogens in milk and dairy products	CSL	1 April 1994 / 31 March 1996	177,000
DS1003	To develop a management strategy for somatic cell count compliance	ADAS	1 April 1995 / 31 March 1997	85,000
MS01:	***Improvement of beef suckler cows***			
MS0109	Development of livestock farming techniques for altering the protein:fat ratio in the natural composition of milk	ADAS	1 December 1994 / 31 March 1995	35,000
MS18:	***Livestock research to improve the Health of the Nation***			
MS1805	Feeding strategies to regulate the fatty acid composition of milk	ADAS Bridgets	1 April 1995 / 31 March 1997	200,000
LS18:	***Livestock research to improve the***			

	health of the nation			
LS1803	To enhance the role of milk: achieving the Health of the Nation objectives	ADAS Bridgets	1 October 1997 / 31 March 2001	601,966
LS35:	***Improving the quality and marketable value of meat and milk***			
LS3503	Conjugated linoleic acid – a literature review	ADAS	1 April 2000 / 30 June 2000	14,500
LS3507	Vitamin E requirements for sustainable milk production	ADAS	1 June 2001 / 30 September 2004	77,688
LS3508	Dietary strategies for increasing docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) content in milk – a review	ADAS	1June 2000 / 31 August 2000	14,500
LS3509	The effect of duration of feeding whole oilseeds on the level of saturated and unsaturated fatty acids in bovine milk	ADAS	01 February 2001 / 31 July 2002	118,531
LS3517	Nutritional, hormonal and genetic influences on milk fat composition in dairy cows	University of Nottingham	1January 2002 / 31 December 2005	217,306
			Total cost	**1,981,491**

5.3 Beef research

5.3.1 Eating quality

Projects: MS0110, MS0111, LS1003, LS1901, LS1902, LS3511, LS3515, LS3522, LK0644, LK0653, LK0669

Beef eating quality is considered to be inconsistent and a number of approaches have been used to address this:

5.3.1.1 Tenderisation processes: MS0110, MS0111, LK0669

The use of salt solutions to accelerate the tenderisation process was investigated. Although it was successful, public opinion turned against chemical treatment of food and there was limited uptake by the industry. Shortening the cooling process by injection of iced water was found to be feasible but a number of obstacles are needed to be overcome before it can be used commercially

5.3.1.2 Flavour enhancement: LS1901, LS3515, LK0644

Taste panels had shown that UK consumers preferred the flavour of beef and lamb produced from animals fed grass and forage, rather than that from stock fed intensive cereal based diets. This research successfully identified ways to achieve that flavour in beef cattle reared intensively.

5.3.1.3 Toughness and juiciness: LS1003, LS1902, LS3511, LS3522, LK0653

Genetic approaches to reducing toughness have had limited success to date because of the genetic complexity of muscle quality. The LINK project to study the impact of the myostatin deletion responsible for double muscling in domestic breeds showed that while the mutation did not reduce tenderness, the background genetics of the animal influenced whether or not the myostatin deletion was expressed, making it unreliable for marker assisted selection. Most success was achieved by the use of management systems that promoted a steady growth and finishing of the beef animals, rather than rapid finishing.

5.3.2 Polyunsaturated fatty acid content

Projects: MS0106, MS1802, MS1803, LS1801, LS1804, LS3523

The feeding systems used in dairy cows to increase polyunsaturated fatty acid content were applied to beef animals with success. The level of DHA present in beef muscle is significantly higher than that in milk as it is located in cell membranes.

5.3.3 Veal

Projects: MS1901, MS1902, MS1903, LS1903, LK0632

Legislation to ban veal crates in the UK and public concern about live exports stimulated interest in what the UK industry could do with Holstein male calves from dairy herds. Several alternative systems were tested for their ability to produce welfare-friendly veal but none of them were suitable for commercial uptake.

Table 5.3 Product Quality: Beef projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS01:	***Improvement of beef suckler cows***			
MS0106	Polyunsaturated fatty acids and beef quality	University of Bristol	1 October 1994 / 31 March 1995	18,096
MS0110	Interactions of calcium and sodium salts in meat systems	University of Bristol	1 March 1995 / 31 March 1995	14,000
MS0111	Influence of calcium chloride on the rapid tenderization and flavour of cold-boned forequarter beef muscle	University of Bristol	1 July 1995 / 31 October 1995	28,050
MS18:	***Livestock research to improve the Health of the Nation***			
MS1802	Optimising the fatty acid composition of beef muscle	University of Bristol	1 August 1995 / 31 July 1998	193,390
MS1803	The Effects of dietary vitamin E on meat quality in grass-fed beef cattle	University of Bristol	1 April 1995 / 31 January 1996	74,990
MS19:	***R&D to support live exports***			
MS1901	Literature survey on meat quality aspects of beef derived from dairy calves	University of Bristol	14 February 1995 / 31 March 1995	4,000
MS1902	Demonstration of best veal production practice	ADAS	1 May 1995 / 30 April 1996	28,957
MS1903	Iron levels for veal calves – a literature review	ADAS	1 September 1995 / 31 November 1995	5,000
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1003	Genetic and nutritional control of fat deposition in ruminants	IGER/ University of Nottingham	1 April 1996 / 31 March 1999	371,821
LS18:	***Livestock research to improve the health of the nation***			
LS1801	The use of dietary vitamin E to extend the shelf life of fresh beef and beef mince	University of Bristol	1 April 1996 / 31 March 1998	134,784
LS1804	Deposition of n-3 poly-unsaturated fatty acids in cattle and sheep and the effects on meat quality	University of Bristol	1 April 1998 / 31 March 2001	410,820

LS19:	***Meat marketing initiatives***			
LS1901	The effects of nutrients and diets on meat flavour	University of Bristol	1 January 1996 / 31 March 1996	4,850
LS1902	Technologies for increasing the quality and value of beef forequarter muscles	University of Bristol	1 April 1996 / 31 March 1999	293,896
LS1903	Demonstration of best veal production practice	ADAS	1 May 1996 / 30 April 1998	69,434
LS35:	***Improving the quality and marketable value of meat and milk***			
LS3511	Producing low-fat healthy ruminant products	University of Bristol	1July 2001/ 31 March 2005	463,424
LS3515	Optimising the eating quality of beef produced on sustainable forage systems	IGER	1 July 2001 / 28 February 2007	1,297,565
LS3522	Effect of lifetime nutrition on ruminant carcass and meat quality	University of Nottingham	1April 2004 / 31 March 2006	180,748
LS3523	Healthiness and quality of beef produced from traditional and modern breeds reared in species-rich, unimproved grasslands	University of Bristol	1November 2004 / 31 October 2008	834,478
LK06:	***LINK Sustainable Livestock Production***			
LK0632	Producing lean mince from Holstein bulls	SAC	1 March 1999 / 31 December 1999	9,900
LK0644	Control of flavour in British beef	University of Bristol / University of Reading / IGER	1 June 2000 / 31 May 2005	221,500
LK0653	The effect of the double muscling gene in cattle on production efficiency and meat quality	Roslin Institute	1 January 2003 / 31 December 2005	79,649
LK0669	Vascular perfusion chilling (VPC) for red meat carcasses – feasibility assessment	University of Bristol	1 April 2006 / 31 December 2006	84,656
			Total cost	**4,824,008**

5.4 Sheepmeat research

5.4.1 Carcass quality

Projects: LS0202, LS1003, LS3001, LS3004, LS3514, LS3516, LS3519, LK0670

The main concern of consumers with lamb is the high saturated fat content. Breeding programmes were set up to select sheep lines that had more musculature and less carcass fat. These were successful and the overall quality of UK lamb has improved markedly. The introduction of Computed X-ray Tomography (CT) allowed rams from the hill and terminal sire breeds to be selected for body conformation while they were still alive and able to pass their genes to further generations.

5.4.2 Eating quality

Projects: LS1904, LS3510, LS3511, LK0607

The breeding programmes to reduce carcass fat were linked to the eating quality of the meat produced. Eating quality was shown to be related to muscle density and this was incorporated into the CT selection procedures used to select superior rams. Meat flavour from grass-fed animals was shown to be preferred by UK consumers, helping to differentiate home produced meat.

5.4.3 Polyunsaturated fatty acid content

Projects: MS1801, LS1804

Most sheep in the UK are reared on grass and forages, which leads to high levels of the long chain n-3 polyunsaturated fatty acids in the meat. Not only does this confer positive flavour values but also promotes healthy eating, helping to strengthen the position of UK lamb in the market.

Table 5.4 Product Quality: Sheepmeat projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS18:	***Livestock research to improve the Health of the Nation***			
MS1801	Dietary and genetic influences on fat deposition and fatty acid composition of sheepmeat	University of Bristol	1 August 1995 / 31 July 1998	385,036
LS02:	***Reproductive technologies in livestock***			
LS0202	To investigate the use of X-ray CT in the prediction of carcass conformation in live animals	ADAS	1 October 1997 / 31 March 2002	199,606
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1003	Genetic and nutritional control of fat deposition in ruminants	IGER/ University of Nottingham	1 April 1996 / 31 March 1999	371,821
LS18:	***Livestock research to improve the health of the nation***			
LS1804	Deposition of n-3 poly-unsaturated fatty acids in cattle and sheep and the effects on meat quality	University of Bristol	1 April 1998 / 31 March 2001	410,820
LS19:	***Meat marketing initiatives***			
LS1904	An investigation of flavour in meat from sheep grown slowly or quickly on grass diets	University of Bristol	1 November 1996 / 31 March 1997	15,080
LS30:	***Genetic approaches to improving efficiency and quality of UK beef cattle and sheep***			
LS3001	Identifying genetic markers for carcass and meat quality traits in sheep	Roslin Institute	1 April 2000 / 31 March 2004	687,715
LS3004	To demonstrate the value of a selection index incorporating CT scans to improve carcass conformation in sheep - production of CT scans	ADAS	1 September 2002 / 31 August 2004	65,930
LS35:	***Improving the quality and marketable value of meat and milk***			

LS3510	Meat quality – carcass shape and eating quality in sheep	SAC	1February 2002 / 31 March 2006	1,393,245
LS3511	Producing low-fat healthy ruminant products	University of Bristol	1July 2001/ 31 March 2005	463,424
LS3514	The role of Sire Referencing Schemes in terminal sire sheep to improve the carcass quality of crossbred lambs	SAC	1June 2000 / 31 May 2005	43,667
LS3516	Continuing to improve through genetic selection, utilising MOET, carcass confirmation of hill sheep	ADAS	1 April 2001 / 31 March 2004	587,000
LS3519	Improving carcass quality of UK hill sheep using Computed Tomography	SAC / Roslin Institute	1April 2003 / 31 March 2007	1,399,430
LK06:	***LINK Sustainable Livestock Production***			
LK0607	Incorporating X-ray computed tomography into selection programmes to improve the quality of sheep meat	SAC	1 June 1997 / 15 April 2001	259,115
LK0670	The effect of TM-QTL and other QTLs on lean meat yield and meat quality in sheep and its evaluation using VISA	SAC	1 October 2006 / 30 September 2010	712,569
			Total cost	**6,994,458**

5.5 Pigmeat research

5.5.1 Carcass quality

Projects: MS1601, LS3521, LK0611

Pig breeding in the early 1990s had selected for lean growth, at the expense of fat deposition. This resulted in pigmeat that many considered too dry. Subsequent research examined ways to restore intramuscular fat without increasing carcass fat.

5.5.2 Eating quality

Projects: MS0707, MS1603, LS1001, LS1006, LS1802, LS3518, LK0626

As above, the focus of research during the 1990s was on restoring eating quality of pig meat in the new, rapidly growing, efficient genetic lines. Boar taint became a problem when castration of male pigs was stopped. Muscle fibre differences were demonstrated between Large White and Duroc pig lines, with the Duroc providing better eating quality. These genetic differences were used by breeders to select pig lines with improved eating quality.

5.5.3 Polyunsaturated fatty acid content

Projects: MS1604, MS1606, MS1804

The lower levels of saturated fat and higher polyunsaturated fats (PUFA) in pig meat made pigmeat a healthy eating option. The long chain n-3 PUFA content could be readily increased by feeding fish oils but this reduced the shelf life of the product unless vitamin E levels were also increased.

Table 5.5 Product Quality: Pigmeat projects

AU:	***AU* – Project Title**	**Contractor**	**Start / End**	**MAFF/Defra**

project			dates	Cost (£)
MS07	***Genetic relationship between food intake, growth and carcase quality***			
MS0707	Levels and relevance of tainting compounds in British pigmeat	University of Bristol	1 April 1995 / 31 March 1996	40,000
MS16:	***Physiology of reproduction and nutrition in pigs***			
MS1601	Regulation of fat deposition in pigs	University of Nottingham	1 November 1991 / 31 October 1994	220,020
MS1603	Control of protein deposition and the efficient production of lean but juicy pigmeat	University of Bristol	1 November 1991 / 31 March 1995	244,000
MS1604	The polyunsaturated fatty acid composition of red meats	University of Bristol	1 January 1994 / 31 March 1994	82,140
MS1606	Regulation of fat deposition in pigs (continued)	University of Nottingham	1 November 1994 / 31 March 1995	28,558
MS18:	***Livestock research to improve the Health of the Nation***			
MS1804	Optimising essential fatty acid content of pig meat – implications for keeping and eating quality in the light of nutritional recommendations	University of Nottingham	1 October 1995 / 31 December 1997	98,456
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1001	Isolation and characterisation of porcine myosin heavy chain genes: a molecular approach to manipulating muscle mass and quality in pigs	Roslin Institute	1 January 1995 / 30 April 1998	323,401
LS1006	Improving pig quality by selection on the porcine myosin heavy chain genes	Roslin Institute	1 July 1998 / 30 September 1999	101,489
LS18:	***Livestock research to improve the health of the nation***			
LS1802	Short-term nutritional control of pigmeat quality	University of Bristol	1 April 1998 / 31 March 2001	336,428
LS35:	***Improving the quality and marketable value of meat and milk***			
LS3518	Improving succulence in British pork	University of Bristol	1January 2002 / 31 December 2004	507,319
LS3521	EU approval of the Autofom for pig carcass classification and updating prediction equations for current techniques	Meat & Livestock Commission	1January 2003 / 30 June 2003	24,750
LK06:	***LINK Sustainable Livestock Production***			
LK0611	Model for the prediction of carcass composition from genetics and feed intake	Roslin Institute	1 July 2007 / 31 December 1999	52,400
LK0626	Genetic control of meat quality	Roslin Institute	1 October 1999 / 30 September 2001	214,701

			Total cost	**2,273,662**

5.6 Poultry research

5.6.1 Carcass quality

Project: LS1002

The poultry breeding industry had been very successful in selecting broiler lines that were efficient feed converters. This project introduced newer genomic approaches to that traditional breeding procedure.

5.6.2 Meat eating quality

Projects: LS2004, LS3501, LS3520

Meat from broilers has little natural flavour, making it ideal for a wide range of prepared meals. For birds where the flavour was important to the consumer, the influence of genetics and production systems were studied. The integration of free range chickens in woodland was assessed and shown to have some limited welfare and meat quality benefits.

5.6.3 Egg quality

Project: LS3524

MAFF and Defra supported very little research on egg quality, but consumer preference for brown shelled eggs and the unexplained production of white shells in free range systems were of concern. The research did not identify the cause of this although it was suggested that pigmentation in the skin of the hen exposed to sunlight might divert pigment away from the shell.

5.6.4 Food safety:

Project: CS0119

The debate about the safety and acceptability of meat and milk from livestock fed on rations containing genetically modified plant material prompted this research. GM maize and soya were fed to broilers from hatch until slaughter and recombinant DNA sequences and their gene products were tested for in all organs of the bird. No plant DNA sequences capable of encoding recombinant proteins were detected in any organ or carcass component that enters the human food chain.

Table 5.6 Product Quality: Poultry projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
CS01:	***Chemical safety of food***			
CS0119	Digestion and absorption of feed components in broilers	ADAS Drayton	1 May 2001 / 31 October 2002	230,798
LS10:	***Molecular, cellular and genetic analysis of growth in farm animals***			
LS1002	Identification of QTL for fatness and feed efficiency in broiler chickens	Roslin Institute	1 April 1996 / 31 March 1999	264,863
LS20:	***Genetic approaches to improving the UK poultry sector***			

LS2004	Genetic control of poultry meat quality	Roslin Institute	1 October 1997 / 30 September 2001	463,598
LS35:	***Improving the quality and marketable value of meat and milk***			
LS3501	Desk study – optimising poultry meat quality including eating quality in extensive poultry systems	ADAS	1 February 2000 / 31 March 2001	29,363
LS3520	The Integration of extensively reared table chicken into newly planted commercial woodland	Oxford University	1 October 2002 / 30 September 2004	201,205
LS3524	Investigation of the white egg shell problem in free range laying flocks	ADAS	1April 2005 / 31 March 2006	57,115
			Total cost	**1,246,942**

For further project details and publications, see the Defra Science Information System web pages and the following R&D Reviews:

MAFF R&D Review – Dietary manipulation of the fatty acid composition of meat and milk: 20 October 1997

MAFF Livestock Science R&D Review – Product Quality: 19 March 1999

Defra Meat, Milk & Egg Quality Programme R&D Review: 4 October 2005

6. Grasslands

6.1 Overview

The UK climate favours grasslands while being less than ideal for high energy crops. The value of grasslands for ruminant farming was recognised as an advantage for the UK that should be exploited and a programme of research was conducted at IGER over the duration of the Livestock Science R&D programme. To ensure that the research was translated into benefits to producers, an agreement was signed with British Seed Houses, which became part of Germinal Holdings, for the company to have first option on all new varieties of grass and clover developed at IGER and for them to take new varieties to the market. This has operated well, with several new varieties being made available to grassland farmers every year. Over the period of the research, the following new varieties have entered the national lists:

Forage Grasses:	Forage legumes:
Hybrid ryegrass 6	Small leaf size white clover 4
Italian Ryegrass 3	Medium Leaf size white clover 5
Early heading date perennial Ryegrass 1	Large leaf size white clover 1
Intermediate perennial ryegrass 8	Red clover 2
Late perennial ryegrass 3	
Cocksfoot 1	

Research into red clover was stopped at the end of the 1980s with the focus being applied exclusively to white clover varieties. This decision was based on the principle that white clover was an important component of grazed swards as it fixed nitrogen, reducing the need for added fertiliser, and could persist in mixed swards. However, with the renewed interest in home grown proteins in the mid-1990s, red clover research was restarted and has given rise to several new varieties which are valuable crops, particularly for feeding beef cattle.

The research programme was an excellent example of synergy between MAFF/Defra funding and AFRC/BBSRC support. The research council support was used to understand the biology and genome organisation of the grasses and clovers, which was then applied to the selection of varieties for commercial and environmental value with Departmental and industry funding.

GRASS BREEDING

Policy objective:

- Maximising the value of grass in UK agriculture

Targets:

- Development of new varieties of grass to meet the business and environmental needs of UK ruminant farmers
- Addition of these varieties onto the NIAB national lists and their commercialisation by British Seed Houses

Deliverables:

- Many new varieties of ryegrass and fescue/ryegrass crosses with improved characteristics, including better pest resistance, lower soil nutrient requirements, better drought tolerance, higher nutritional value, and greater persistence in diverse swards.

LEGUME BREEDING

Policy objective:

- Maximising the value of legumes in UK agriculture

Targets:

- Developing new varieties of white clover, red clover, and *Lotus* to meet the business and environmental needs of UK ruminant farmers
- Addition of these varieties onto the NIAB national lists and their commercialisation by British Seed Houses

Deliverables:

- New varieties of white clover with increased persistence under grazing conditions and in mixed swards with grass, better disease resistance, more efficient N capture and usage, higher quality as a forage for ruminant livestock.
- New varieties of red clover that are more persistent, better suited to combining and ensiling, and rich in polyphenol oxidase (PPO) resulting in their protein being used more efficiently by cattle and sheep.
- Selection of new varieties of lotus (bird's-foot trefoil) better suited to low fertility swards in UK upands

GRAZING STUDIES RESEARCH

Policy objective:

- Maximising the value of grass in Uk agriculture

Targets:

- Understanding the dietary selection of plant species in mixed swards by grazing cattle and sheep
- Understanding the interactions within plant species and between plants and animals under grazing conditions

Deliverables:

- Demonstration of the different sward characteristics preferred by cattle and sheep.
- Demonstration of the 70:30 dietary preference for clover:grass by grazing cattle
- Data on the suitability of new varieties of grass and clover for grazing and their environmental impact

6.2 Grass breeding research

6.2.1 Agronomy

Projects: MS1401, MS1402, MS1403, MS1404, MS1411, MS1412, LS1403, LS1404, LS1406, LS1407, LS3620, LS3621, LS3647, LS3650

The main driver for grass breeding research in the MS14 programme in the early 1990s was development of new varieties that would persist under grazing conditions and in mixed swards with other varieties. This laid the foundations for the perennial and hybrid ryegrass varieties that followed. The emphasis then changed in the LS14 programme to take more consideration of the value of ryegrass as a forage crop for ruminants by closer collaboration between the plant breeders and the livestock nutritionists at IGER.

6.2.2 Feeding value

Projects: LS1401, LS1402, LS3616, LS3617, LS3619, LS3649

Selection for higher dry matter, digestibility, protein content and water-soluble carbohydrate produced a number of varieties that have become established as the grasses of choice for livestock farmers re-seeding their pastures. The development of varieties with higher water-soluble carbohydrates led to the new Sugar Grass varieties, which have a higher nutritional value and improve the capture and utilisation of dietary nitrogen by ruminants

6.2.3 Pest & disease resistance

Projects: MS1406, MS1407, MS1408, LS1405, LS3618

To avoid the use of chemical pesticides, breeding for resistance to disease and pests is in line with Departmental policy. The disease that was studied, and in which progress was made to increase natural resistance, was crown rust. This disease, which reduces the nutritional value of the grass, is likely to become increasingly prevalent during the hotter drier summers forecast as a result of climate change. Nematode infestation can destroy large areas of grassland. Newer varieties of ryegrass are more resistant to attack and the use of carabid beetles to attack slugs and nematodes was shown to be a viable alternative.

Table 6.2 Grasslands: Grass breeding projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS14:	***Exploit genetic variability in forage grasses***			
MS1401	Develop and use multitrait selection to enhance perennial ryegrass germplasm	IGER	1 April 1991 / 30 June 1997	622,000
MS1402	Hybridise Italian and perennial ryegrasses to increase grassland adaptability	IGER	1 April 1991 / 30 June 1997	719,250
MS1403	Sexual reproduction in forage grasses	IGER	1 April 1991 / 30 June 1997	471,000
MS1404	Exploit genetic variability to improve vegetative growth and nitrogen use efficiency of perennial ryegrass	IGER	1 April 1991 / 30 June 1997	716,000
MS1406	Nematode pests of forage grasses	IGER	1 April 1993 / 30 June 1997	255,500
MS1407	Diseases of forage grasses	IGER	1 April 1993 / 30 June 1997	327,500
MS1408	Enhancing the role of carabid beetles in controlling grassland pests	IGER	1 April 1993 / 30 June 1997	152,500
MS1411	Intergeneric hybridisation to increase grassland reliability	IGER	1 April 1994 / 30 June 1997	177,000
MS1412	The importance and potential of endophytic fungi in grassland in England and Wales	IGER	1 April 1995 / 30 June 1997	139,750
LS14:	***To exploit genetic variability in forage grasses***			
LS1401	Improve the ruminant feeding value of perennial ryegrass using multitrait selection	IGER	1 July 1997 / 30 June 2000	343,350

LS1402	Improve the consistency and persistency of yield and quality of ryegrass used for conserved winter feed	IGER	1 July 1997 / 30 June 2000	374,957
LS1403	Maintaining reproductive growth in germplasm developed for improved efficiency of ruminant production	IGER	1 July 1997 / 30 June 2000	156,878
LS1404	Produce perennial ryegrass with higher quality and nitrogen-use efficiency under frequent harvesting	IGER	1 July 1997 / 30 June 2000	499,952
LS1405	To identify novel resistance to crown rust in perennial ryegrass	IGER	1 July 1997 / 30 June 2000	163,691
LS1406	Increase the adaptive range of ryegrasses through intergeneric hybridisation	IGER	1 July 1997 / 30 June 2000	157,145
LS1407	Development of endophyte for tolerance of abiotic stress in ryegrass	IGER	1 July 1997 / 31 December 2001	135,053
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3616	Develop marker-assisted selection criteria to improve the value and utilisation of grasses in livestock production	IGER	1 July 2000 / 30 June 2005	540,700
LS3617	Identify genetic mechanisms controlling variations in nitrogen use efficiency and protein production in grass	IGER	1 July 2000 / 30 June 2005	287,489
LS3618	Identify markers associated with crown rust resistance in ryegrass	IGER	1 July 2000 / 30 June 2005	223,145
LS3619	Improve the nutritional value and agronomic performance of perennial ryegrass	IGER	1 July 2000 / 30 June 2005	571,615
LS3620	Improve the persistency and stress tolerance of Italian and hybrid ryegrass	IGER	1 July 2000 / 30 June 2005	411,372
LS3621	Agronomic and nutritional qualities of grazed grass varieties: development of breeding tools	IGER	1 April 2000 / 30 June 2004	468,880
LS3647	Genetic analysis and selection of grass traits using DNA marker technology for sustainable grassland improvement	IGER	1 July 2003 / 30 June 2007	836,322
LS3649	Identify new genes for nutritional quality and disease resistance in grass populations to enhance the sustainability of UK grassland	IGER	1 July 2003 / 30 June 2007	612,518
LS3650	Utilise genetic variation within and between improved grass populations to increase the sustainability of UK grassland	IGER	1 July 2003 / 30 June 2007	1,319,746
			Total cost	**10,683,313**

6.3 Legume breeding research

6.3.1 Agronomy

Projects: MS1301, MS1302, MS1303, MS1307, LS1301, LS1302, LS1303, LS1305, LS1307, LS3613, LS3614, LS3515, LS3645

White clover had long been recognised as a valuable component of swards for grazing, bringing a good source of protein and reduced requirements for N fertiliser. It fell out of favour as it was rapidly lost in pastures sue to competition by more aggressive grasses and by grazing and trampling by stock. The research programme was aimed at improving the germplasm to generate new varieties that were better able to persist under grazing. This was successful and several new varieties entered the NIAB National Lists and have been used successfully.

Red clover was not researched until the requirement for home-grown proteins identified it as an opportunity. New varieties have been developed that are grown as a monoculture, for combine harvesting and ensiling for beef cattle, and ongoing research is selecting cultivars that will succeed in biodiverse pastures.

6.3.2 Pest & disease resistance

Projects: MS1304, MS1305, MS1306, MS1308, LS1304, LS1306

One of the reasons why early varieties of white clover lacked persistency was their susceptibility to pests and diseases. New varieties have been selected for increased resistance and this has increased their uptake by livestock producers.

6.3.3 Biodiversity

Projects: LS3643, LS3644, LS3646

The changing emphasis of the livestock science R&D programme in the late 1990s towards environmental issues opened the possibility of using red clover, white clover and lotus in areas of improved grasslands in the uplands. Inclusion of these legumes would reduce the need for fertilisers and would bring biodiversity to the swards supporting a wider range of invertebrates and thus birds. A range of clovers and bird's-foot trefoil from hill areas in Europe were compared and those that showed advantages in the uplands site at IGER Bronydd Mawr were selected for further development.

Table 6.3 Grasslands: Legume breeding projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS13:	***Develop techniques and exploit genetic variation to improve forage legumes***			
MS1301	To develop techniques and to exploit genetic variation to improve forage legumes	IGER	1 April 1991 / 30 June 1997	1,269,500
MS1302	Improve white clover germplasm	IGER	1 April 1991 / 30 June 1997	983,750
MS1303	Develop methods to enhance symbiotic nitrogen fixation and make better use of nitrogen from legumes	IGER	1 April 1991 / 30 June 1997	1,125,750
MS1304	Fungal and viral diseases of forage legumes	IGER	1 April 1994 / 30 June 1997	461,500
MS1305	Nematode pests of forage legumes	IGER	1 April 1994 / 30 June 1997	139,750

MS1306	Review of damage by pests and diseases to white clover in England and Wales	IGER	1 April 1994 / 30 June 1997	52,000
MS1307	Literature review "Clover and other grazed legumes in UK pasture land"	IGER	1 January 1994 / 31 March 1994	8,233
MS1308	Reduction of damage by *Sitona* weevils to clover seedlings	IGER	1 April 1995 / 30 June 1997	100,250
LS13:	***To understand and exploit forage legume characteristics***			
LS1301	Design of reliable white clover for sustainable agriculture	IGER	1 July 1997 / 30 June 2000	562,212
LS1302	Exploitation of genetic variation to produce reliable, well adapted white clover varieties	IGER	1 July 1997 / 30 June 2000	717,774
LS1303	Identify genetic mechanisms controlling variations in N-flux and N-use efficiency in grass and clover	IGER	1 July 1997 / 30 June 2000	249,588
LS1304	Development of white clover germplasm resistant to nematodes	IGER	1 July 1997 / 30 June 2000	187,166
LS1305	Breeding productive and persistent red clover cultivars for sustainable livestock systems	IGER	1 July 1997 / 30 June 2000	155,000
LS1306	Control of pests and diseases of newly-sown white clover	IGER	1 July 1997 / 30 June 2000	61,147
LS1307	Research to explore the potential of lotus	IGER	1 April 1998 / 30 September 2004	189,149
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3613	Utilisation of selection criteria in white clover to produce varieties suitable for grass/clover swards	IGER	1 July 2000 / 30 June 2005	795,590
LS3614	Breeding productive and persistent red clover cultivars for sustainable livestock systems	IGER	1 July 2000 / 30 June 2005	318,361
LS3615	The basis of variation in yield and persistency of white and red clover in upland environments	IGER	1 July 2000 / 30 June 2005	349,655
LS3643	Developing selection criteria for forage legumes that balance production, biodiversity and reduced environmental pollution	IGER	1 July 2003 / 30 June 2007	957,488
LS3644	Utilisation of selection criteria in white clover to produce varieties that balance production, biodiversity and reduced environmental impact	IGER	1 July 2003 / 30 June 2007	1,209,766
LS3645	Developing productive and persistent red clover varieties for sustainable livestock systems	IGER	1 July 2003 / 30 June 2007	576,623
LS3646	Developing approaches to the use of forage legumes in upland environments to enhance biodiversity and produce balanced quality ruminant feed	IGER	1 July 2003 / 30 June 2007	544,121
			Total cost	**11,014,373**

6.4 Grazing studies

6.4.1 Dietary selection

Projects: MS1101, MS1102, MS1103, MS1104

In the early 1990s it was considered to be important to understand the ways that ruminants grazed pastures and much of the research in this programme used mechanisms strapped to the animal to record its grazing behaviour. This information was interesting but probably contributed little to future ruminant management systems.

6.4.2 Livestock production

Projects: MS1105, MS1107, MS1108, MS1111, LS3611, LS3612, LS3648

These animal production studies not only tested out new varieties of grass and legumes for grazing cattle and sheep but also established new management systems for getting the highest value from mixed grass / clover swards.

6.4.3 Agronomy

Projects: MS1106, MS1109, MS1110

As described above, early varieties of clover were unable to compete with aggressive grass growth and animal grazing and trampling. This research identified the issues that needed to be addressed and allowed the plant breeders to select for more appropriate varieties in the legume breeding research described above.

Table 6.4 Grasslands: Grazing research projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS11:	***Sward/animal interactions - sheep***			
MS1101	To understand behavioural and mechanical factors controlling grazing time and intake by grazing herbivores	IGER	1 April 1991 / 31 March 1997	407,000
MS1102	To develop techniques for determining dietary choices, searching and handling times and energy expenditure for grazing sheep	IGER	1 April 1991 / 31 March 1997	417,000
MS1103	To understand factors determining dietary preference in grazing ruminants	IGER	1 April 1991 / 31 March 1997	963,000
MS1104	To understand spatial adaptation of plant species to grazing, its role in selection by grazers and in sward stability	IGER	1 April 1991 / 31 March 1997	660,000
MS1105	To evaluate for lowland lamb production novel white clovers with improved winter hardiness and spring growth potential	IGER	1 April 1991 / 31 March 1994	152,000
MS1106	Mechanisms regulating clover persistency in grazed swards	IGER	1 April 1991 / 31 March 1997	889,000
MS1107	To explore the potential of winter annuals to improve seasonal production from grass-clover swards	IGER	1 April 1991 / 31 March 1994	166,000

MS1108	To explore the potential of *Lotus* spp. as low-input grazing legumes for conditions of low fertility	IGER	1 April 1991 / 31 March 1997	197,000
MS1109	Establishment and growth of a sequence of crops in a permanent legume base	IGER	1 April 1991 / 31 March 1992	47,000
MS1110	Interactions between plants and animals in pastoral systems	IGER	1 April 1991 / 31 March 1997	431,000
MS1111	An evaluation of the potential for extending the grazing season in England and Wales	ADAS	1 December 1995 / 31 March 1996	15,000
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3611	Improving the efficiency of utilisation of grass and legumes by grazing cattle and sheep	IGER	1 July 2000 / 30 June 2005	856,344
LS3612	Develop selection criteria for balanced grass/legume swards and ruminant diets	IGER	1 July 2000 / 30 June 2005	604,259
LS3648	Identification, genetic control and evaluation of traits enhancing environmental quality and bioremediation in multifunctional grassland	IGER	1 July 2003 / 30 June 2007	450,819
			Total cost	**6,255,422**

For further project details and publications, see the Defra Science Information System web pages and the following R&D Reviews:

MAFF R&D Review – Grasslands and Forages: 21 February 1995

MAFF Livestock Science R&D Review – Grasslands and Uplands: 12 & 13 October 1999

Defra Livestock Science R&D Review – Improving sustainability of UK livestock production through optimal nutrition: 18 & 19 February 2004

7. Less Favoured Areas (LFA)

7.1 Overview

The majority of land classified as LFA in Britain is in the hills and uplands, and accounts for over 60% of the agricultural area. It is widely used for grazing hill sheep and suckler beef cattle. During the 1990s, headage and other payments from the EU Common Agricultural Policy encouraged UK farmers to stock the uplands with large numbers of cattle and sheep, and the research supported by MAFF was intended to improve the performance of these animals. The primary focus was on improving grassland and managing it to achieve maximum performance of the stock grazing it. The relatively low level of nutrition that was achieved for hill sheep caused high rates of post-natal mortality, and pressure from the National Farmers Union to improve lamb survival resulted in research aimed at improving welfare.

The stocking levels were such that this caused severe degradation of the environment in many parts of upland Britain, with losses of dwarf shrubs such as heather. This was recognised late in the 1990s and led to a change in the direction of the upland livestock science programme to reflect the higher prioritisation of environmental protection. Grazing with sheep and cattle was shown to be important for the establishment and management of heather moorland but the number of animals and the times of the year when they were allowed on uplands were crucial. The results of the research helped to define the prescriptions for hill farming allowances.

LIVESTOCK PRODUCTION

Policy objective:

- To promote the sustainability of upland farming

Targets:

- To identify best practice for sheep and cattle management in upland LFAs
- To reduce mortality in young lambs born on the hills and uplands

Deliverables:

- Demonstration of the suitability of new varieties of grass and clover for reseeding improved pasture in the uplands
- Management practices based on sheep and cattle numbers and movements that maximise the performance of upland livestock production systems
- Improvement in hill lamb survival by increasing dietary levels of vitamin E for pregnant ewes

BIODIVERSITY

Policy objective:

- To reduce the loss of biodiversity in farmed upland areas caused by overgrazing

Targets:

- To identify management practices that permit sheep farming in the uplands but allow heather and other dwarf shrubs to persist

Deliverables:

- Prescriptions for environmental stewardship schemes that reduce cattle and sheep numbers and their movement

- Management practices that allow heather seedlings to re-establish in previously over-grazed upland farms

7.2 Livestock research

7.2.1 Improved grassland

Projects: MS1501, MS1502, LS1501, LS1506

The nutritional quality of swards in upland rough grazing is poor and many producers chose to replace areas of rough grazing with improved grassland. The grass and clover breeding research programmes at IGER generated new varieties that were more suited to upland cultivation, and these were tested out at the IGER Bronydd Mawr upland farm site. The improvement in productivity and profitability that this brought to Bronydd Mawr became the basis for a set of recommendations that were widely taken up across Britain

7.2.2 Production

Projects: MS1503, MS1504, MS1507, LS1502, LS1503, LS1505, LS1511, LS3402, LS3404, LS3405, LS3407, LS3408

Coupled with the generation of improved grasslands, system studies were inaugurated to determine the effect on livestock productivity of stocking density, time and duration of exposure of the swards to sheep and cattle, and the impact of grazing with only sheep or cattle or with both, either together or sequentially. The most efficient system was shown to be round the year grazing with sheep with additional summer grazing with beef cattle. The cattle removed the rank grasses such as purple moor grass (*Molinia)* that sheep would not eat and which, if left, would overgrow the grass species preferred by sheep.

MS1504 was a one-off project aimed at assessing the feasibility of producing camelids, such as llamas and guanacos, in upland farms. The higher costs of production and the lack of CAP support made camelid production less profitable than sheep and cattle and the industry never gained momentum.

In 2002, Defra considered refining the basis for the Hill Farm Allowance, introduced in 2001, by using a better definition of the differences between hill farms around Britain, at different elevations and with different terrains. This project provided a range of different levels of hardship between farms and was used to inform the support payments for hill farmers following CAP reform.

7.2.3 Livestock welfare

Projects: MS1505, MS1509, MS1511, LS1507, LS1508, LS1512, LS3401

Hill ewes can lose 25% of their lambs within days of their birth, mainly due to exposure and lack of maternal attention. Apart from the welfare concerns, this reduces profitability and launched a campaign by sheep farmers for MAFF to identify ways to reduce post-natal mortality. Research funded by Animal Welfare Division focused on genetic selection for maternal traits. The Livestock Science programme identified low levels of dietary vitamin E as a factor in lamb survival and demonstrated that increasing maternal levels of dietary vitamin E increased the vigour of lambs at birth and their ability to follow the ewe, allowing her to suckle them.

Table 7.2 Less Favoured Areas: Livestock research projects

AU: **Project** ***MS15:***	***AU* – Project Title** ***Upland resource use: Grassland management, animal production and land use options for less favoured areas***	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS1501	Exploitation of new grasses and legumes in upland environments	IGER	1 April 1991 / 30 June 1997	1,064,250
MS1502	Development of low input sheep grazing systems based on white clover	IGER	1 April 1991 / 30 June 1997	824,250
MS1503	To study effect of management on sheep and cattle performance	IGER	1 April 1991 / 30 June 1997	701,750
MS1504	Development of fine fibre production from South American camelids	IGER	1 April 1991 / 31 July 1997	267,000
MS1505	Vitamin E deficiency in lambs	ADAS	1 October 1995 / 31 March 1996	17,500
MS1507	Implication of extensive land management for sheep production in Britain	Wye College, London	30 October 1996 / 30 April 1997	25,140
MS1509	`Epidemiological studies to evaluate risk factors associated with elevated mortality rates in sheep, notably in lambs`	VLA	13 February 1995 / 1 April 1995	9,970
MS1511	Ewe prolificacy, barrenness and lamb mortality	ADAS	1 December 1995 / 31 March 1996	10,800
LS15:	***Upland resource use and land use options for less favoured areas***			
LS1501	Exploitation of new grasses and legumes in upland environments	IGER	1 July 1997 / 30 June 2000	347,966
LS1502	Development of efficient, biologically sustainable and economically viable upland sheep systems.	IGER	1 July 1997 / 30 June 2000	351,606
LS1503	Combined use of cattle and sheep for effective sward utilisation and animal performance	IGER	1 July 1997 / 30 June 1998	114,000
LS1505	A comparison of management systems for wintering hill ewes removed from areas of semi natural rough grazing in winter	ADAS	1 October 1996 / 30 September 1999	95,842
LS1506	Transfer of technology for improving the reliability of upland improved pastures to farmers	IGER	2 December 1996 / 31 March 1997	12,119
LS1507	The effects of implementing best practice and supplementing ewes with Vitamin E on reducing lamb mortality	ADAS	3 January 1997 / 31 December 1999	136,992
LS1508	The effects of supplementing ewes with cobalt and iodine before mating and throughout pregnancy	ADAS	1 October 1997 / 31 March 2000	61,310
LS1511	Development of efficient, biologically sustainable and economically viable upland beef systems.	IGER	1 July 1998 / 31 March 2004	722,787

LS1512	Develop and quantify effectiveness of Vitamin E rumen bolus given to extensively managed ewes in reducing lamb mortality	ADAS	1 February 1999 / 31 December 2000	53,519
LS34:	***Management of livestock production to sustain and enhance the environment in less favoured areas***			
LS3401	An epidemiological survey of vitamin E deficiency in UK sheep flocks	University of Reading	1 March 2000 / 31 December 2000	39,486
LS3402	Optimal grazing management systems for sheep and beef cattle in the hills and uplands	IGER	1 July 2000 / 31 March 2004	559,289
LS3404	Adaptation of the n-alkane technique for use with extensively managed cattle and sheep grazing studies	ADAS	25 September 2000 / 25 March 2001	24,986
LS3405	Classification of hill land	University of Reading	1 April 2002 / 31 October 2002	49,452
LS3407	Optimal grazing management systems for sheep and cattle in the hills and uplands	IGER	1 April 2004 / 31 March 2009	1,452,307
LS3408	A comparison of mainstream and at risk cattle breeds for the management of the hills and uplands	IGER	1 April 2004 / 31 March 2009	275,929
			Total cost	**7,218,250**

7.3 Biodiversity

Projects: MS1506, MS1508, MS1510, LS1504, LS1509, LS1510, BD1228, OC9418

All the projects in this programme were aimed at deriving prescriptions for upland management systems that prevented the loss of dwarf shrubs while allowing sheep farming. The conclusions from the research were that reducing numbers of sheep would protect heather and increase the availability of grass per animal, improving carcass conformation. However, the loss of headage payments caused by lower numbers of animals were not compensated for by the gains in saleable meat, so there was little incentive for upland farmers to change their management practices except where environmental stewardship scheme subsidies were paid. CAP reform removed the headage payments support and brought about a reduction in hill sheep numbers.

BD1228 demonstrated that heather regeneration requires some physical disruption of the sward to allow heather seedlings to establish, and that this can be achieved by grazing with low numbers of sheep for most of the year together with short duration grazing with cattle to reduce rank grasses and break up the sward.

Table 7.3 Less Favoured Areas: Biodiversity research projects

AU: **project** ***MS15:***	***AU* – Project Title** ***Upland resource use: Grassland management, animal production and land use options for less favoured areas***	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS1506	Effects of extensification of grassland use in the uplands	IGER	1 April 1991 / 30 June 1997	120,500

MS1508	The Economic impact of heather conservation in ESAs	ADAS	1 April 1995 / 31 March 1998	121,208
MS1510	The effects on animal performance and financial returns of reducing sheep numbers to encourage heather recovery	ADAS	1 April 1995 / 31 March 1998	43,892
LS15:	***Upland resource use and land use options for less favoured areas***			
LS1504	Effects of extensification of grassland use in the uplands	IGER	1 July 1997 / 30 June 2000	147,565
LS1509	Economic impact of heather conservation in ESAs: Pwllpeiran research	ADAS	1 April 1998 / 31 March 2001	124,263
LS1510	The effects on sheep physical and financial performance of reducing sheep numbers to encourage heather cover	ADAS	1 April 1998 / 31 March 2001	42,218
BD12:	***Uplands***			
BD1228	Environmentally sustainable & economically viable grazing systems for restoration and maintenance of heather moorland: England & Wales	ADAS	1 January 2002 / 3 March 2007	969,836
OC projects:	***Opening Contracting Scheme funded from the budget of Dr David Shannon, Shannon, Chief Scientist***			
OC9418	Control of Molinia in heather moorland after reduction in sheep grazing	The Heather Trust	1 January 1995 / 31 December 1997	270,012
			Total cost	**1,839,494**

For further project details and publications, see the Defra Science Information System web pages and the following R&D Reviews:

MAFF Livestock Science R&D Review – Grasslands and Uplands: 12 & 13 October 1999

Defra Livestock Science R&D Review – Management of livestock production to sustain and enhance the environment in less favoured areas: 30 May 2002

8. Environmental Protection

8.1 Overview

While many of the other research projects in the Livestock Science research programme had environmental implications, there were several, described below, that were directly targeted at environmental pollution.

DAIRY CATTLE

Policy objective:

- Reduction in the level of diffuse pollution generated per litre of milk produced

Targets:

- Better management and rationing systems to reduce wastage and pollution
- Breeding animals with a lower environmental footprint

Deliverables:

- A model demonstrating the environmental benefits of management systems targeted to animal requirements.
- A comparison of the environmental footprints of different dairy cattle breeds and crosses, which showed no significant environmental benefit over continuing development of the Holstein breed

PIGS

Policy objective:

- Reduction in the level of diffuse pollution generated per kilo of pigmeat produced

Targets:

- Management of aerial pollution in pig houses
- Better management of management and rationing systems to reduce wastage and pollution

Deliverables:

- Engineering solutions for improved designs of pig housing to reduce aerial pollution
- Information on the lack of hazard for either growth or respiratory disease by the levels of ammonia and dust found in UK pig houses
- An integrated management system that monitors pig growth and tailors ration composition and supply to meet requirements on a daily basis
- Design of paddocks and feeding systems for outdoor breeding pigs to reduce their environmental footprint

POULTRY

Policy objective:

- Reduction in the level of diffuse pollution generated per kilo of chicken meat or eggs produced

Targets:

- Management of aerial pollution in poultry houses
- Better management of rationing systems to reduce wastage and pollution
- Breeding animals with a lower environmental footprint

Deliverables:
- Recommendations for poultry house designs and ventilation systems to reduce exposure of stock and staff to aerial ammonia and dust
- An integrated management system that monitors poultry growth and tailors ration composition and supply to meet requirements on a daily basis
- The first demonstration that different genetic lines of poultry have different levels of nutrient capture and usage efficiency, opening the possibility of breeding livestock for lower environmental footprint.

FARMED RED DEER

Policy objective:
- Reduction in the level of diffuse pollution generated per kilo of meat

Targets:
- Assessment of the environmental footprint of farmed red deer

Deliverables:
- Information suggesting that red deer produce more diffuse pollution per kilo of meat than sheep.

8.2 Dairy research

8.2.1 Nutritional management

Projects: IS0102, LK0638

Provision of sufficient nutrients to meet the requirements of milk production, body maintenance and foetal development is key to sustainable dairy farming. Losses of nutrients to the environment can be reduced if the composition and quantity of the rations can be targeted to the need of the animal. The desk-based research in IS0102 assessed the contribution that automated nutritional management can make to reduction of the environmental footprint by increasing milk yield without compromising the health and welfare of the cow. This is based on the premise that increasing milk yield per cow will reduce the carbon and nitrogen footprint per litre as the nutritional requirements and diffuse pollution associated with cow maintenance do not increase with yield.

The industry co-sponsored research in LK0638 demonstrated that inclusion of varieties of ryegrass with higher water soluble carbohydrate content into dairy cow rations resulted in improved partitioning of dietary nitrogen into milk and reduced ammonia production per litre of milk. These varieties have been readily taken up by the seed companies and incorporated into modern ryegrass mixtures.

8.2.2 Breed differences

Project: IS0213

Concern grew in the 1990s that increasing levels of North American Holstein genetics in the UK dairy herd had resulted in reduced fertility, shorter productive lifetimes and, as a result, higher levels of diffuse pollution per litre of milk produced. Crossing with other breeds, such as Jersey, Brown Swiss and Montbéliard, was being adopted by dairy farmers to restore fertility and introduce hybrid vigour but there was no evidence to support these breeding decisions. The desk study in IS0213 compared a number of pure dairy breeds and their crosses. The conclusions drawn were that there was no substantive evidence that diffuse pollution per litre of milk was any lower in breeds other that Holsteins since rumen microbiology is the

main source of methane and the higher yields from Holsteins reduces relative pollution per litre.

8.2.3 Integrated management

Project: IS0214

By defining the desired criteria for sustainability in dairying and using modelling framework involving N and P cycles, biodiversity, landscape, product quality and animal welfare, the research will link with industry to identify feasible and practicable systems for implementation

Table 8.2 Environmental Protection: Dairy research projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
IS01:	***Integrated systems***			
IS0102	Environmental and animal welfare benefits of the integrated management of dairy cows - cost benefit analysis	Silsoe Research Institute	1 January 2003 / 31 August 2003	35,351
IS02:	***Integrated systems***			
IS0213	Longevity and lifetime efficiency of pure and cross-bred dairy cows	IGER	1 December 2002 / 31 November 2003	40,000
IS0214	New integrated dairy production systems: specification, practical feasibility and ways of implementation	IGER	1 April 2004 / 31 March 2007	446,603
LK06:	***LINK Sustainable Livestock Production***			
LK0638	High-sugar ryegrass for sustainable production of ruminant livestock and reduced environmental N-pollution	IGER	1 April 2002 / 31 December 2004	207,297
			Total cost	**729,251**

8.3 Pig research

8.3.1 Aerial pollution

Projects: MS1701, MS1702, LK0619

The early work by ADAS at their Building Research centre was focused on the design of pig housing to reduce the levels of aerial pollution by ammonia and dust. A number of solutions were recommended, including improved ventilation, spraying with water, and coating the pigs in oil. These solutions required building manufacturers to redesign their products and this was not taken up.

The later LINK project revisited the aerial pollution problem from the stand point that it might be possible to reduce levels of dust and ammonia to a point where they are no longer damaging for pig production. The research was unable to show that dust and ammonia introduced into the air in pig rearing houses at a range of concentrations was responsible for either reduced growth rates or increased levels of respiratory disease.

8.3.2 Nutritional management

Projects: LK0614, LK0652

The nutritional requirements of pigs change between weaning through to finishing phases. Producers change the rations based on the age of the pig in a series of steps. This research developed a means of monitoring the size and weight using visual image analysis (VIA) of the pig and varying ration composition to meet their dietary needs on a daily basis. By removing the excesses and deficits inevitably caused by the step changes, nutrient use is optimised and diffuse pollution reduced. The company involved with the research has marketed the equipment and there is slow uptake by the industry.

8.3.3 Integrated management

Project: IS0215

This research aimed to identify and develop practical approaches to the outdoor pig breeding sector to reduce inputs and diffuse pollution while maintaining the perceived benefits of outdoor systems and profitability. Approaches included the design of paddocks and management of feeding systems, and their application on commercial pig farms.

Table 8.3 Environmental Protection: Pig research projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS17:	***Environmental and welfare aspects of pig and poultry production***			
MS1701	Aerial pollution measurements and control in pig housing	ADAS	1 April 1991 / 31 March 1997	338,400
MS1702	Aerial pollutants and livestock welfare	Silsoe Research Institute	1 April 1991 / 31 March 1997	991,500
IS02:	***Integrated systems***			
IS0215	Integrated production systems for outdoor pig breeding herds	Dalehead Foods Ltd, SAC, Newcastle University	1 April 2004 / 31 March 2007	468,927
LK06:	***LINK Sustainable Livestock Production***			
LK0614	Integrated management system for pig nutrition control and pollution reduction	Silsoe Research Institute / University of Edinburgh	1 January 2000 / 31 December 2003	548,501
LK0619	Production and disease response of pigs to aerial pollutants	Silsoe Research Institute	1 August 1998 / 31 December 2002	281,483
LK0652	Sustainable systems for weaner management, package 2: Nutritional management towards sustainable production	SAC and the Universities of Leeds, Newcastle and Nottingham	1 September 2003 / 31 August 2007	644,086
			Total cost	**3,272,987**

8.4 Poultry research

8.4.1 Aerial pollution

Project: MS1703

This research assessed the production of ammonia and dust in poultry houses and, using Computational Fluid Dynamics, the best design for poultry houses to remove it. As with the pig research in MS1701 and MS1702, uptake by the industry was limited and a policy decision was taken that any further research would only be considered for Departmental support if it was conducted in close collaboration with the poultry industry.

8.4.2 Nutritional management

Project: LK0612

As with the pig research project described above, changing ration composition to match the growth stage of the bird on a daily basis will reduce the waste of nutrients to the environment caused by the periods of over- and under-supply implicit in the 2-3 step changes used by the industry. The research developed an automatic weighing procedure to monitor bird growth and development, and linked this to an automated feeding system. Uptake of the equipment has been greater overseas than in the UK, where investment by the poultry industry in lower.

8.4.3 Genetic control

Project: LS3104

There is every reason to believe that the efficiency with which an animal captures dietary nutrients from the ration and partitions them to growth and reproduction, including egg and milk production, will have a genetically variable component. If so, then it should be possible to breed livestock that are intrinsically more efficient and produce less diffuse pollution per unit of product. Measuring carbon, nitrogen and phosphorus flows in a small animal like a chicken is more readily carried out than on larger species of livestock. This project clearly demonstrated that different genetic lines of commercial broiler chickens had different levels of efficiency of nutrient capture and usage. The genetic basis for this variation is now under investigation and, if successful, could lead to marker assisted selection for livestock with reduced environmental footprints

Table 8.4 Environmental Protection: Poultry research projects

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS17:	***Environmental and welfare aspects of pig and poultry production***			
MS1703	Respiratory hazards in poultry housing	Silsoe Research Institute	1 April 1991 / 31 March 1997	738,000
LS31:	***Improving sustainable production and quality of UK pigs and poultry through genetics***			
LS3104	Reducing nitrogen and phosphorus pollution by poultry – determining the potential for genetic methods	Roslin Institute	1 October 2003 / 30 September 2006	712,568
LK06:	***LINK Sustainable Livestock Production***			

LK0612	Integrated management system to enhance efficiency and pollution control in poultry production	Silsoe Research Institute	1 July 1998 / 31 December 2001	494,047
			Total cost	**1,944,615**

8.5 Red deer research

8.5.1 Environmental footprint

Project: IS0202

Red deer farming for venison production offers an alternative for livestock producers previously committed to beef cattle or sheep production. Since the deer has a wider dietary range than the sheep or bovine, the possibility was investigated that it had a higher efficiency of nutrient capture than the cow or the sheep and, therefore, a lower carbon footprint. The desk study highlighted the relatively small amount of information on this topic but those studies that had addressed it showed that the deer was no more efficient. The sheep has a lower emission of methane than the red deer per kilo of carcass, perhaps due to higher maintenance requirements of the red deer due to its larger size and its lack of thermal insulation.

Table 8.5 Environmental Protection: Red deer research project

AU: **Project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
IS02:	***Integrated systems***			
IS0202	Desk study to review literature on carbon and nitrogen efficiencies in venison production	ADAS	1 January 2003 / 30 June 2003	22,711
			Total cost	**22,711**

9. Automation

9.1 Overview

As part of the government support to improve the competitive position of UK agriculture in world markets, MAFF supported the development of automated systems for use in livestock management to improve efficiency, reduce labour costs, and improve the health and welfare of stock. Development of robotic milking systems has been commercialised, at least one system using the developments accruing from the MAFF research at Silsoe Research Institute. Environmental control systems have become more common although, at the time when the research was being supported, the UK agricultural buildings industry was at too low a level to meet the investment costs. The rapid development of microprocessors and memory has reduced costs to the point where they become available to UK building engineers.

The development of integrated management systems, with automated monitoring of animal performance, reproductive state, and health linked to rationing and management decisions, was a main feature of the research at Silsoe Research Institute over the period of the Livestock Science research programme. Systems for pigs and poultry were successfully developed and commercialised. A system for dairy cows is still under development. Development of tests for ketosis and ammonia using breath was successful. The assessment of body condition score is more difficult in cattle than is was in pigs and is still being developed. Ovulation detection, using cow-side automated detection of progesterone in milk, was taken to the proof or principle stage but further development has been slowed down by the requirement for capital investment.

DAIRY CATTLE

Policy objective:

- Improvement in the competitive position of UK agriculture using modern technologies

Targets:

- Development of automated milking systems
- Development of cow-side progesterone monitoring in milk
- Development of an integrated management system, monitoring cow performance and condition and providing management decision support.

Deliverables:

- A robotic milking machine was developed, and the commercially successful DeLaval Voluntary Milking System incorporated much of the engineering developed at Silsoe Research Institute
- Development of a robotic milk sampling device and ELISA for milk progesterone was completed and has now entered the commercial development stage
- Cow-side tests for ketosis, by detecting acetone in breath, and dietary protein efficiency, by detecting ammonia in breath, were developed. Linking these to body condition score during peak lactation, using visual image analysis, was partially successful but is ongoing.

PIGS

Policy objective:

- Improvement in the sustainability of UK agriculture using modern technologies

Targets:

- Development of integrated management systems
- Development of monitoring systems for aerial pollutants and linkage to ventilation systems

Deliverables:

- An automated system for weight and growth assessment based on visual image analysis, integrated with feed formulation and delivery to optimise nutrient use and animal welfare.
- Sensors for monitoring aerial pollutants and ventilation systems to reduce the levels.

POULTRY

Policy objective:

- Improvement in the competitive position of UK agriculture using modern technologies

Targets:

- Development of integrated management systems
- Development of monitoring systems for aerial pollutants and linkage to ventilation systems

Deliverables:

- An automated system for weight and growth assessment based on electronic perch weighers, integrated with feed formulation and delivery to optimise nutrient use and animal welfare.
- Sensors for monitoring aerial pollutants and ventilation systems to reduce levels.

9.2 Dairy research

9.2.1 Robotic milking

Projects: DS1401, DS1402, DS1403, DS1405, DS1406, DS1408

The main objective of the robotic milking research at Silsoe Research Institute was development of sensors that would allow the cups on the milking machine to seek out the teats and attach them safely. Concerns were expressed about the hygiene aspects if stockmen were not present to clean the teats prior to attachment of the cups, but this was solved by automated sensing and washing protocols. Analysis of the cost benefits of automated milking systems was also undertaken, providing guidelines to dairy farmers on the ratio of cows to machines and the design of parlours to provide the most efficient throughput. The milking machine manufacturer DeLaval was closely associated with the research and although the final design from Silsoe was not used by the company, many of its design features were incorporated into their commercial model.

9.2.2 Ovulation detection

Projects: LS2401

Research at Nottingham University and elsewhere had demonstrated that the reproductive state of the cow could be assessed from the changing pattern of progesterone levels in her milk. The only commercially available assay was not suitable for widespread uptake and use in the parlour. The research at Silsoe Research Institute designed an automated system that would sample the milk and run an automated ELISA assay, feeding back the results into a database and advising the stockman of any action required. The development of the equipment was financed through a spin-off company, WellCow Ltd. The process of bringing the machine to the market is still underway.

9.2.3 Integrated management

Projects: DS1404, DS1407, DS1409, LS3627

Integrated circuit technology allowed new opportunities for making non-invasive measurements of the metabolic state and welfare of cows in the milking parlour. Silsoe Research Institute developed automated methods to assay urea and somatic cell counts in milk, ammonia and acetone in breath, and reproductive hormones in saliva. Uptake of these methodologies has been slow, mainly because of the low profitability of the dairy industry and the high cost of production.

Table 9.2 Automation: Dairy research projects

AU:* project** ***DS14:	***AU* – Project Title** ***Health and welfare aspects of dairy farming***	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
DS1401	Robotics for dairy engineering	Silsoe Research Institute	1 April 1991 / 31 March 1995	385,000
DS1402	`Sensing udder cleanliness, in conjunction with fully automatic milking operations`	Silsoe Research Institute	1 April 1991 / 31 March 1995	117,000
DS1403	Automatic milking systems design methodology	Silsoe Research Institute	1 April 1991 / 31 March 1995	513,000
DS1404	Non-invasive health monitoring of dairy cows	Silsoe Research Institute	1 April 1995 / 31 March 1996	100,000
DS1405	Hygiene systems of dairy cows husbandry	Silsoe Research Institute	1 April 1995 / 31 March 1996	138,000
DS1406	The logistics of automatic milking systems on UK farms	Silsoe Research Institute	1 April 1995 / 31 March 1996	43,000
DS1407	Automatic condition scoring of dairy cows - a feasibility study	Silsoe Research Institute	1 April 1995 / 31 March 1996	14,995
DS1408	Assessment of automatic milking on UK dairy farms	Silsoe Research Institute	1 June 1996 / 31 D71May 1999	145,039
DS1409	Non-invasive monitoring of dairy cow performance, milk quality and health	Silsoe Research Institute	1 April 1996 / 31 March 1999	412,205

LS24:	***Improvement of suckler cows***			
LS2401	Automatic ovulation prediction in dairy cows	Silsoe Research Institute	1 April 1999 / 31 March 2002	329,582
LS36:	***Improving the sustainability of livestock production through optimal nutrition***			
LS3627	A feasibility study on the automatic recording of condition score in dairy cows	SAC	1 April 2001 / 30 April 2002	47,366
			Total cost	**2,245,187**

9.3 Pig research

9.3.1 Integrated management

Projects: MS1704, MS1705, MS1706, LS1701, LK0614

The basis for this work was the development of visual imaging systems that used closed circuit television cameras or webcams to record images of pigs at electronic feeding stalls and convert these to the weight of the animal. This was used to monitor pig growth and development, and specify the composition and quantity of rations required by the animal. The technology was taken up by a UK manufacturer of pig feeding systems.

9.3.2 Environmental control

Project: LS1703

This research assessed the production of ammonia and dust in pig houses and linked this to ventilation systems for reduction in levels. Uptake by the industry was limited because of the low investment in farm building manufacture in the UK and a policy decision was taken that any further research would only be considered for Departmental support if it was conducted in close collaboration with the industry.

Table 9.3 Automation: Pig research projects

***AU:* project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS17:	***Environmental and welfare aspects of pig and poultry production***			
MS1704	Integrated Livestock monitoring Systems	Silsoe Research Institute	1 April 1991 / 31 March 1997	322,000
MS1705	Integrated livestock monitoring	Silsoe Research Institute	1 October 1996 / 31 July 1996	174,000
MS1706	Development of a video imaging system for the continuous monitoring of pigs	Silsoe Research Institute	1 November 1995 / 31 March 1996	15,000
LS17:	***Automated monitoring systems for livestock production***			
LS1701	Development of an integrated monitoring system to produce pigs to a quality and conformation target	Silsoe Research Institute	1 August 1996 / 31 July 1999	335,487

LS1703	Environmental control systems for UK Pig and Poultry production	Silsoe Research Institute	1 April 1997 / 31 March 1998	199,327
LK06:	***LINK Sustainable Livestock Production***			
LK0614	Integrated management system for pig nutrition control and pollution reduction	Silsoe Research Institute / University of Edinburgh	1 January 2000 / 31 December 2003	548,501
			Total cost	**1,594,315**

9.4 Poultry research

9.4.1 Integrated management

Projects: LK0612

This research attempted to use the automated control systems developed for pig houses but applied to poultry. Bird growth was assessed at the flock level using electronic perches that weighed birds as they stepped on them. This data was linked to the Flockman management system already in use by major poultry producers, providing real time measurement of bird growth not otherwise available. Uptake of the new automated system was better overseas than in the UK because of low profit margins in the UK broiler industry.

9.4.2 Environmental control

Project: LS1703

This research assessed the production of ammonia and dust in poultry houses and linked this to ventilation systems for reduction in levels. Uptake by the industry was limited because of the low investment in farm building manufacture in the UK and a policy decision was taken that any further research would only be considered for Departmental support if it was conducted in close collaboration with the industry.

Table 9.4 Automation: Poultry research projects

***AU:* project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
LS17:	***Automated monitoring systems for livestock production***			
LS1703	Environmental control systems for UK Pig and Poultry production	Silsoe Research Institute	1 April 1997 / 31 March 1998	199,327
LK06:	***LINK Sustainable Livestock Production***			
LK0612	Integrated management system to enhance efficiency and pollution control in poultry production	Silsoe Research Institute	1 July 1998 / 31 December 2001	494,047
			Total cost	**693,374**

10. Knowledge transfer

10.1 Overview

Projects: MS1413, LS1602, LS1603, LS1604, LS1604B, LS1605, LS1606, LS1607, LS1608, LS1609, LS1611, LS1612, LS1613, LS1614, LS1615, LS1616, LS1618, LS1619, LS1620, LS1621, LS1622, LS1623, LS1624, LK0647
During the mid 1990s, the privatisation of the national agricultural extension service ADAS removed the well-established conduit for advice on new developments coming from research findings. The LS16 Assessment Unit was set up to support measures to improve the flow of information on research findings out to end users.

The study to assess uptake of grasslands research demonstrated that this had been successful but this could be explained by the fact that all new varieties of grass and clover suitable for livestock grazing developed at IGER were brought to the market by the IPR arrangement with Germinal Holdings, while the British Grasslands Society held regular meetings. These were supplemented with sponsored roadshows, workshops and demonstration farms to ensure that the rapid advances in sustainable grassland agriculture would reach the farming community.

Integration within the pig, poultry and dairy industries ensured that new developments were disseminated and taken up shortly after the findings were released but the extended nature of the sheep industry, particularly in the uplands, posed problems of getting new information taken up. In collaboration with the National Sheep Association, workshops were supported around the UK.

The collaborative research LINK project LK0647 studied the attitudes of livestock farmers to new information and the constraints that influenced whether this was taken up, using the theory of reasoned action. The findings of this research provided valuable information on the best routes to getting change in the farming community and have informed subsequent Defra policy. Farmer-to-farmer networking was identified as successful and was used in Southwest England (LS1609) and Gloucestershire (LS1616). Other knowledge transfer initiatives included support by the Defra Chief Scientific Adviser for the Genesis Faraday Partnership, participation in the national Foresight programme, establishment of a national standard for nutritional requirements in farmed livestock, and evaluation of the success of the Sustainable Livestock Production LINK programme.

Table 10.1 KT projects

AU: **project**	***AU* – Project Title**	**Contractor**	**Start / End dates**	**MAFF/Defra Cost (£)**
MS14:	***Exploit genetic variability in forage grasses***			
MS1413	Study to assess the uptake of results generated from grasslands R&D	ADAS	1 October 1995 / 31 March 1996	14,000
LS16:	***Technology and information transfer initiatives***			
LS1602	Grassland roadshows	MMB	1 April 1996 / 31 march 1997	10,000

LS1603	Demonstration of progressive farming practice for grassland / livestock enterprises	Glas Consultants Ltd	5 January 1998 / 30 September 2001	135,166
LS1604	Evaluation of grasses under grazing	IGER	1 April 1997 / 31 March 2000	337,281
LS1604B	Evaluation of varieties: production with NIAB cutting regimes	IGER	1 September 1997 / 30 June 2000	59,729
LS1605	MAFF/NSA Sheepnights	NSA	1 November 1998 / 31 December 1998	9,578
LS1606	Grassland Technical Workshop	MDC	1 March 1998 / 30 June 1998	1,000
LS1607	Technology transfer aspects of LS2202 (Swaledales)	ADAS	1 July 1999 / 31 December 2003	39,913
LS1608	Technical workshops	MDC	1 October 1998 / 30 June 1999	3,000
LS1609	SWARD: South West Agricultural and Rural Development Project	Prosper West Cornwall	1 April 1999 / 31 October 2000	5,000
LS1611	Sheepnights II	National Sheep Association	1 September 1999 / 31 August 2000	11,892
LS1612	Foresight for the UK agricultural industry	ADAS	17 August 2000 / 17 November 2000	49,687
LS1613	Knowledge transfer in livestock agriculture in support of smaller farm businesses	ADAS	1 October 2000 / 31 March 2002	400,000
LS1614	Agricultural discussion groups: Technology Transfer Technical Mission to Ireland	Thomson Associates Consultancy & Training	17 October 2000 / 16 November 2000	7,643
LS1615	Review of Livestock Nutritional Standards	British Society of Animal Science	1 October 2001 / 31 March 2002	30,965
LS1616	Agricultural Producer Groups in Gloucestershire	Gloucester Business Link	1 April 2002 / 31 March 2004	91,125
LS1618	Farm Animal Genetics and Genomics (Genesis) Faraday Partnership	Roslin Institute	1 October 2002 / 30 September 2008	830,000
LS1619	Strategic review of pig research	Meat & Livestock Commission	1 August 2003 / 31 October 2004	128,851
LS1620	IPPC Model Applications – Pigs	ADAS	1 January 2004 / 31 December 2004	119,271
LS1621	Analysis of England Sheep Farmers Attitudes Towards Sheep Handling Marketing Practices	University of Reading	1 April 2004 / 31 May 2004	6,650

LS1622	Assessing livestock farmers' attitudes towards consequential loss insurance	University of Reading	1 May 2004 / 31 October 2004	49,041
LS1623	Evaluation of the commercial success of the SLP LINK programme	The Technology Partnership	15 July 2004 / 14 October 2004	39,600
LS1624	Forage Legume Network (LEGNET)	Thomson Associates Consultancy & Training	1 October 2004 / 31 March 2005	39,900
LK06:	***LINK Sustainable Livestock Production***			
LK0647	Improving the targeting of knowledge and technology transfer in the livestock sector by understanding farmer attitudes	University of Reading	1 August 2001 / 31 July 2003	10,425
			Total cost	**2,429,717**

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