Feed Management on Livestock Farms
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Summary

Agriculture, and in particular ruminant livestock, is responsible for a substantial proportion of the greenhouse gases produced nationally, in particular methane and nitrous oxide. Feed represents a high proportion of the total costs, and improved feeding management has the potential to improve feeding efficiency, fertility and health leading to improved viability of livestock farms and reduced methane and nitrous oxide emissions.

Defra funded research has shown that both the type and proportion of forage can reduce greenhouse gas production, and that this links well with better quality forages and diets where feed conversion can be improved. A number of more minor dietary additions / changes can also have a desirable influence, but some involve a potential compromise to production and results are not always consistent across species. Some *in vitro* studies on plant extracts have shown some promise but require trialling *in vivo* before further consideration.

Reduction of methane and nitrous oxide emissions are low on the list of priorities for livestock farmers, compared to maintaining profitability, and being able to reinvest. But, the greatest contribution to reducing these gases will come directly from producing milk or meat more efficiently, hence leading to increased profitability. Growing crops well, storing them effectively and feeding good quality, balanced diets will generally be preferable to looking for small diet modifications, where a beneficial and profitable result may be less clear.

Methane production decreases per unit product, where milk and meat production is greater relative to maintenance.

N excretion must be primarily controlled by limiting the amount of nitrogen input whether to crops directly or as N (protein) fed to animals. Protein supply to ruminants is closely related to feed intake and the production obtained, with the precise balance being important. Improving N utilization depends heavily on matching energy substrates to the N supply. High sugar grasses and legumes can score well in relation to this and with potentially improved intakes.

The adoption of mitigation measures can therefore work alongside the move to improved production on individual farms. Forage production plays a critical part with both quantity and quality being largely influenced by the season. More importantly, especially with dairy enterprises, is the ability to make consistent forage and maintain constant diets whilst controlling 'costs of production'.

So long as high crop yields are obtained, maize and wholecrop cereals have characteristics beneficial to the reduction of both greenhouse gases.

Eliminating lax feeding management including imprecise feeding and the acceptance of waste, could give considerable benefits to a number of farms with dairy, beef and sheep. Time pressure will often be used as an excuse which needs to be overcome by organization, and the application of knowledge that is readily available. This will hopefully lead on to better planning, monitoring of performance (and intakes) and adjustment where necessary. Much of the vast area of grassland used for stock now has the potential to be monitored to a greater extent, and managed to improve stock performance through better feed utilization.

Beef and sheep farms are generally less likely to know feed intakes or precise liveweight gains, so are in a poorer position to calculate their Feed Conversion Efficiency (FCE). This is potentially a useful parameter, where systems are well monitored, and can relate directly to methane losses. But, reasons for changes in intakes and liveweight gains must be appreciated and at a more basic level the days required to finish stock and carcass details must be used to refine the system of production.

Protein is still commonly over supplied in dairy diets and to stock on spring and autumn grazing. Although dairy farmers in particular are keen to reduce unnecessary N use and expense, they are rightly wary about undersupplying protein. There is a need to continue to promote the case for lower protein diets and how to achieve best N utilization through linking dietary protein with energy supply. Maximizing microbial protein will remain essential, and will influence the wide choice of protein brought in. Although grass mixes may favour higher sugar varieties, there will also be reaction to the high cost of purchased protein, and the potential contribution forages can make will be appreciated. Legumes have gained popularity again, but are often seen as complicating management, despite the potential fertilizer savings.

Best practice guidelines have been drawn up that include a number of familiar recommendations for improving stock performance. Most are relevant for all ruminants, and if followed will also put producers in a better position regarding greenhouse gas emissions.

1. Introduction

In the United Kingdom, agriculture contributes about 0.7% of gross domestic product but is estimated to be responsible for 7% of national greenhouse gas (GHG) emissions. Cattle and sheep contribute over half of these GHG emissions; these occur principally as methane (CH_4), which is a natural product of enteric fermentation, and nitrous oxide (N_2O), which is largely the result of microbial breakdown of undigested feed nitrogen (N), though enhanced through fertilizer N.

Under the Kyoto Protocol, the UK Government is committed to reducing GHG emissions, and has set the national target of an overall 80% reduction in GHG emissions by 2050 (against a baseline of 1990). Within the agricultural sector a Greenhouse Gas Action Plan (GHGAP) has been progressively developed by an industry partnership to deliver an initial reduction of 3Mt CO_2e GHG emissions by 2020.

It is generally accepted that careful feed selection, ration formulation and feed management can affect the amount of enteric CH_4 produced and the amount of N excreted by ruminants. In addition, poor feed utilisation is associated with higher emissions of GHG per unit of livestock product (milk or meat) produced.

2. Background

The main greenhouse gasses of relevance to the UK livestock industry are CH_4 and N_2O. In addition, ammonia (NH_3), although not strictly a GHG, also contributes to N_2O emissions.

- Methane (CH_4): In ruminants, enteric CH_4 is produced under anaerobic conditions in the rumen by methanogenic microorganisms (Archaea). Globally, ruminant livestock produce about 80 million tonnes of CH_4 annually, accounting for about 33% of anthropogenic emissions of CH_4 (Beauchemin et al., 2008). In the UK, CH_4 emissions from livestock account for approximately 40% of UK production (2,087 kilotonnes in 2009); of this approximately 85% was the result of enteric fermentation in beef cattle (48%), dairy cows (28%) and sheep (22%), with the remainder the result of manure management. Between 1990 and 2009, CH_4 emissions from enteric fermentation declined by 18%, mainly as a result of reductions in ruminant livestock numbers and increasing productivity.

  Apart from the undesirable effects that CH_4 emissions have on the environment, the production of CH_4 also represents a loss of productive energy for the animal. Consequently, research has tended to focus on dietary manipulation as a means of altering rumen fermentation, not only to mitigate the effect of CH_4 emissions on the environment but also to improve productivity.

- Nitrous oxide (N_2O) is a potent greenhouse gas. Emissions from the livestock industry (livestock manures and forage area) are the largest source of N_2O in the UK. Emissions from grassland are higher than arable land because of the high rates of fertilisers applied, higher rainfall and more compacted soils - all favourable conditions for N_2O emissions.

Although ruminants may produce some N_2O as a result of the reduction of nitrate in livestock feed to ammonia and ammonium, the actual amounts are very low. Of greater significance is the amount and form of N excreted in manures as a result of inefficient conversion of feed protein into product (milk or meat) protein. It is generally accepted that the conversion efficiency of feed protein is low (typically about 20%) with the unutilised feed protein excreted in faeces and urine. However, the range is considerable, and may vary from 10% to 35%. An objective in a number of Defra-funded research projects has been to identify ways of improving this utilisation efficiency.

N_2O emissions, which currently account for approximately half of total agricultural emissions[1], are produced as a result of natural biological processes in the soil. However, emissions are greatly influenced by a number of agricultural practices and activities, and in particular the amount and type of fertiliser N applied to the soil, and the way in which it is applied. The amount of N returned to the soil in crop residues and other land management practices such as tillage and drainage, can affect the proportion of N taken up by the crop. In the past two decades, the amount of fertiliser applied to grassland has declined substantially, and this has contributed to the overall reduction in N_2O emissions from agriculture. However, the storage and handling of manures can have a significant impact on N_2O emissions, and a number of strategies have been identified to reduce emissions of N_2O related to manure management and storage, but these are not considered in this report.

- Ammonia (NH_3): agriculture is the biggest single source of ammonia in the UK. In 2006, it was estimated that UK production was about 315 x 10^3 t/year, of which 90% (288 x 10^3 t/year) was from agriculture[2]. Almost all of this can be attributed to livestock farming, with 77% coming from livestock manures and slurry. Ammonia is an air pollutant, and ammonia emissions from livestock manures can lead to soil acidification and eutrophication. It is estimated that there has been a reduction in agricultural NH_3 production between 1990 and 2010, largely due to reductions in livestock numbers and the use of nitrogen fertilisers, particularly on grassland.

  Although not a GHG, ammonia is a pollutant that results from the inefficient conversion of feed nitrogen into animal product. Livestock diets often contain more N than the animals require, thereby ensuring that the animals' needs for protein, and for essential amino acids in particular, are met. Nitrogen not incorporated into product (milk, meat) or used for body maintenance is excreted in urine and faeces where further microbial activity releases ammonia into the air during manure decomposition.

[1] Source: Committee on Climate Change "Meeting carbon budgets – ensuring a low-carbon recovery (2008 data)
[2] Air Pollution Information System, Nitrous oxide, URL: www.apis.ac.uk/overview/pollutants/overview_N2O.htm. Accessed April 2012

3. Objectives

On most UK ruminant livestock farms, feed costs account for more than half of total input costs. Over the past decade research funded by Defra has demonstrated that improving feed utilisation and feed conversion efficiency on livestock farms can have the dual benefits of improving the economic viability of livestock enterprises and reducing the environmental footprint of milk and meat production. However, concerns have been expressed by farming industry stakeholders that the results of this research have not been widely adopted by livestock farmers or the feed industry. The objectives of this study were therefore to:

- Review the research related to feed use, with particular emphasis on reducing GHG and ammonia emissions;
- Identify the extent to which the results of this research have been adopted by the farming industry, and barriers to uptake of the research;
- Provide 'best practice' guidelines for ruminant livestock farmers and their advisors to improve feed utilisation and reduce GHG and ammonia emissions, and to give these the widest publicity via the main livestock farmer organisations.

4. A Review of Defra-Funded Research

4.1. *Methane*

4.1.1. Feed Ingredients

Considerable effort has been devoted to understanding factors affecting CH_4 emissions and the scope for reducing these through feed and management factors. Earlier reviews of Defra-funded R&D on measurement and control of GHG (CSA4320; CC0259) concluded that diet type could have a significant effect on CH_4 emissions from ruminants. In particular, the relative proportions of concentrates[3] and forages in the diet appeared to have a significant influence, particularly at high levels of nutrition (CC0201). *In vitro* studies showed that increasing the water-soluble carbohydrate content from 0.089 to 0.234 reduced CH_4 emissions by 27.7%, and a subsequent modelling project confirmed that increasing the starch:forage ratio reduced CH_4 emissions per unit of gross energy intake (CC0239). The addition of fumaric acid and a methane oxidiser (*Brevibacillus parabrevis*) were shown to reduce CH_4 emissions by 12.3 and 5.9%, respectively. However, these were short-term studies and need to be confirmed with a wider range of diets over a longer period.

4.1.1.1. Forage Type

There is now a substantial body of evidence to suggest that the inclusion of maize silage in ruminant livestock diets can lead to a reduction in CH_4 production, both per animal and per unit of output. A recently completed study reported that increasing the proportion of maize silage in a ration from 0.25 to 0.75 in a maize silage:grass

[3] In particular starch-based feeds

silage mix resulted in a 13% and 6% reduction in CH_4 production per unit of dry matter intake and per litre of milk output, respectively (AC0209).

In sheep, the inclusion of high sugar grasses showed potential to reduce CH_4 emissions relative to conventional ryegrass (AC0209). Although CH_4 production, measured as litres per day, was not different between herbage types, when expressed per litre of live weight gain, high sugar grasses reduced CH_4 production by about 25% relative to controls.

A diet high in starch may also be effective at reducing emissions from beef cattle at the national level (-5%) (CC0239). However, this modelling exercise suggested that diets high in water-soluble carbohydrates (WSC) could be counter-productive and actually increased national methane emission estimates slightly.

4.1.1.2. Fats and Oils

Although fats are a rich source of energy, they are used cautiously in ruminant diets because of their potentially adverse effects on rumen fermentation, feed digestibility and dry matter intake when used inappropriately. However, certain saturated medium chain fatty acids (MCFA) and oils rich in these free fatty acids have been shown to suppress methanogenesis whilst having lesser influences on dry matter intake and animal performance. Previous studies have reported reductions in CH_4 emissions as a result of including linseed in the diet of ruminants (Ueda et al., 2003; Martin et al., 2006, 2008). Although a number of *in vivo* studies have reported negative effects on rumen fermentation and feed intake when linseed has been included in the diet at levels >5%, negative effects were not observed when linseed oil was included (at 4% of the diet DM) in a chopped hay-based diet fed to sheep (AC0209), and in this study CH_4 emissions were reduced by 22% (24 and 31 l/kg DMI for the linseed and control diets, respectively).

Although it is not uncommon to add fats and oils directly to ruminant rations, the total amount of oil in a ration may be increased by the addition of high-fat feeds, and in particular oilseeds – either directly or after oil extraction. Studies in North America have reported that increasing the level of dietary fat by feeding a diet of crushed oilseeds (sunflower seed, canola seed or flaxseed) or dried maize distillers grains can reduce the energy lost as methane by up to 20%. Research is currently in progress in the UK[4] to examine the effects of feeding dried distillers grains with solubles (DDGS) – which may contain up to 8.5% oil in the DM – on CH_4 emissions by dairy cows.

The origin of the supplementary lipid appears to be an important factor influencing CH_4 emissions. In a study with lactating dairy cows, increasing dietary lipid content by about 3% (DM basis) reduced methane production relative to intake and milk yield by 2.5% and 7%, respectively (LS3656). In this study there was also an interaction with feeding frequency; CH_4 production was 517 and 544 l/day from cows on the rapeseed diet fed in one or two meals per day, respectively.

[4] Defra LINK Project 'Environmental and nutritional benefits of bioethanol co-products' (ENBBIO)

Naked oats can contain up to 12% oil in the DM, and when they were included in the ration of dairy cows the amount of CH_4 excreted and the amount of CH_4 produced per unit feed consumed or milk produced were reduced (10 and 12 % reductions, respectively) (AC0209). Although this response has frequently been attributed to the fat content of the naked oats, there may be other components of naked oats that contributed to the reductions in CH_4 excretion observed, since both neutral detergent fibre (NDF) and water-soluble carbohydrate intakes were reduced when naked oats were fed.

The inclusion of naked oats in the diets of sheep and beef cattle also reduced methane emissions by approximately 33% and 10%, respectively. It was not clear from this study if these differences represent difference between sheep and cattle, since the variety of naked oats used in both trials differed. A whole-farm modelling exercise undertaken as part of this study suggested that inclusion of naked oats had a low cost per tonne of CO_2e mitigated (AC0209).

High oil naked oats (with up to 16% oil) are currently being developed by IBERS (formerly IGER before the merger with Aberystwyth University) as part of the Sustainable Arable OatLINK project (LK0954).

As pointed out elsewhere, however, little research has been conducted on whether or not CH_4 mitigation strategies, which alter the enteric fermentation of the animal, are prone to a compensatory higher CH_4 release from the manure during storage, as the amount of residual fermentable organic matter available may be higher (DairyCo, 2009).

In a modelling exercise, the second most effective mitigation strategy associated with diet manipulation was a high fat diet, which was predicted to provide a 14% saving in CH_4 emissions (CC0270).

4.1.1.3. Feed Additives

It has been known for many years that fumaric acid can be an effective means of decreasing methanogenesis (López et al. 1999; Bayaru et al., 2001). This was confirmed using *in vitro* rumen simulation (Rusitec) in which the addition of fumaric acid reduced CH_4 production by 12% (CSA4320). These studies were only of short-term duration, and need to be confirmed in longer *in vivo* studies. However, it was concluded that the amount of fumaric acid required to achieve a significant reduction in CH_4 emissions would make the ration uneconomic, and may also lead to digestive upsets.

4.1.1.4. Plant Extracts

Numerous plant extracts have been studied for their potential to alter rumen fermentation and reduce CH_4 emissions. Garlic oil is well known to have antimicrobial activity against a wide spectrum of gram-positive and gram-negative bacteria and *in vitro* rumen fluid studies showed that garlic oil altered rumen fermentation and decreased methane production (Busquet et al., 2006). The addition of a commercially available aqueous extract from garlic - allicin – to a rumen simulating fermentor (Rusitec) had no effect on general rumen fermentation but resulted in a reduction in the number of CH_4 producing Archaea in the rumen and a 94% decrease in CH_4 production (AC0209). However, as with many additives, there is evidence that the methanogenic effects of garlic may be short lived as the rumen microorganisms adapt to the new nutrients. There was also evidence that cows fed diets that included the garlic extract produced milk with a strong milk taint. Preliminary studies suggested that this could be removed by appropriate milk processing, but unless this can be achieved economically this will remain a barrier to the use of garlic extract as a means of reducing CH_4 emissions. Many plant extracts have also been examined for their potential to reduce CH_4 emissions. Bodas et al. (2008) screened over 400 plant extracts for their ability to reduce CH_4 emissions using *in vitro* cultures of rumen fluids. Of these, 35 decreased CH_4 production by more than 15%, but longer term *in vivo* studies are required to quantify their full potential to reduce CH_4 emissions.

4.1.2. Increasing Feed Conversion Efficiency

Increasing dry matter intake is usually associated with higher CH_4 emissions per animal, but reduced emissions per unit feed consumed. This is due to the fact that an increasing proportion of feed energy is being used for productive purposes as intake increases, thereby spreading the emissions associated with maintenance over a higher level of output. Thus this relationship tends to favour intensive production systems aimed at maximizing production per animal, at least as far as direct emissions per unit of product are concerned.

A number of mathematical models have been developed which have identified improvements in feed conversion efficiency (FCE) as potentially one of the most effective means of reducing enteric CH_4 production by ruminant livestock. These estimates have been based on the principle that CH_4 production is largely a function of feed intake, and it follows that if productivity can be increased for the same amount of feed consumed, or productivity maintained but with lower feed intakes, then the amount of CH_4 produced *per unit of product* will decrease.

For many years, measurements of CH_4 production were made using animals housed in fixed respiration chambers and the costs associated with these measurements precluded extensive examinations of the effects of different diets on FCE and associated CH_4 emissions. In the last decade, however, techniques have been developed which allow measurements to be made with individual animals while they remain in their normal environment, including grazing.

These are new techniques, and to date there have been no Defra-funded research projects which have examined specifically the relationship between enteric CH_4 production and FCE on a herd basis. However, data gathered for individual cows fed a range of diets show that feed intake accounts for most of the variation observed between animals (AC0219). On this basis, it is not unreasonable to estimate the effects of changes in feed intake – relative to production – on CH_4 production.

A report has recently been published which illustrates the likely current FCE by dairy cows in the UK, and the potential improvement in FCE as a result of improved feed ration management (Colman et al., 2011). Data collected on 3,075 farms (386,000 cows or 20% of the national herd) in the UK suggest that the average FCE for milking cows in UK dairy herds is approximately 1.17 litres of energy corrected milk (ECM) per kg feed DM fed, but that many herds in the UK have the capability to produce, on an annual basis, in excess of 1.4 - 1.5 litres ECM/kg feed DM, indicating a significant loss of the potential of feed to produce milk. Adoption of total mixed rations (TMR) and a controlled nutrition programme[5] resulted in a significant ($P<0.001$) increase in FCE. The scale of the increase noted in the UK varied between 0.07 and 0.09, depending on the year. The increase in FCE was achieved by both a small (non significant) reduction in feed intake and increased ($P<0.001$) milk yield. On the basis of this improvement in FCE, it is estimated that it would be possible to produce the same amount of energy corrected milk (ECM) from 16% less feed DM, with a 20% improvement in annual FCE and only 17% of the feed required for non-milk producing purposes (i.e. dry cows and replacement heifers).

In addition to reducing CH_4 emissions, improvements in FCE are reflected in higher margins. Colman et al. (2011) found a positive relationship between FCE and margin for over 1000 farms described, with a net margin gain of ~£0.45 per 0.1FCE gain per cow per day.

It should be noted that the changes in CH_4 production as a result of improving FCE are a 'one-off' effect, assuming that the feed and nutrition management remain optimal. Indeed, the improvement in FCE – and hence reduction in CH_4 emissions – might be expected to occur within the first few months of implementing the change in feeding regime, with the study of Colman *et al* indicating at least 70% of the gain achieved within 90 days of system adoption.

These calculations assume a fixed level of CH_4 produced per kg of feed consumed. One of the objectives of the total mixed ration (TMR) approach to dairy cow feeding described above is to ensure that feed is available to cows on a continuous basis, thus maintaining a steady intake throughout the day and minimising the fluctuations in rumen conditions associated with once or twice daily feeding which is the practice on many dairy farms. However, it has been shown that when lactating dairy cows are fed TMRs once daily, CH_4 emissions (l/cow/day) were reduced by 6% compared to twice daily feeding, and by 8% relative to milk yield (LS3656). There were no differences in FCE between cows fed once and twice daily (1.87 vs. 1.86 kg 3.5% FCM/kg DMI, respectively), suggesting that the pattern of feeding may have an impact on CH_4 production. While these results do not invalidate the general conclusions above regarding the potential reduction in CH_4 production as a result of

[5] "Performance Acceleration and Control Enhancement" (PACE): Richard Keenan and Co

improving FCE, they do suggest that further research is warranted on the effect of feeding strategy on CH_4 production, and reinforces the need for caution in adopting a single CH_4 emissions factor for ruminants.

4.2. *Nitrogen Excretion - Ammonia and Nitrous Oxide*

As discussed above, nitrogen excreted in livestock manures is a major contributor to ammonia and nitrous oxide production, while N excreted in faeces and urine also represents an inefficient use of feed protein. Some of the strategies identified to improve efficiency of feed N utilisation and N excretion, and recent research undertaken to develop these, are summarised below.

4.2.1. Forage Type

4.2.1.1. High-sugar Grasses

The efficiency of conversion of feed N into milk (20-30%) or meat (10-20%) by ruminants is often well below potential (>40%), and is particularly low with diets based on poor grass silages or grazed herbage. One of the principle causes of the inefficiency of conversion of feed N into product N is the failure of the microorganisms to 'capture' rumen degraded feed protein N. The reasons for this are likely to be many and complex, but it has been suggested that it is due, in part at least, to a deficiency in the supply of energy to the rumen microorganisms, and it was this hypothesis that underpinned the development of high-sugar grasses. Feeding such forages significantly increases the capture of N into microbial protein in the rumen (Moorby et al, 2006) and as such might be expected to decrease ammonia and N_2O emissions resulting from livestock manures.

This hypothesis was confirmed in a series of studies with lactating dairy cows (LK0615, LK0638). The first of these studies (LK0615) clearly demonstrated an improvement in feed N utilisation – by almost 33% - when fed high sugar grass were compared to conventional rye-grass. This resulted in a reduction – by almost 30% - of N excreted (Figure 1). Furthermore, there was a shift away from excretion in urine, which might have environmental benefits since lower urea content in urine is likely to lead to lower ammonia losses to the environment. This study also confirmed that live weight gain in lambs and feed intakes by steers were higher in animals consuming the high-sugar grass.

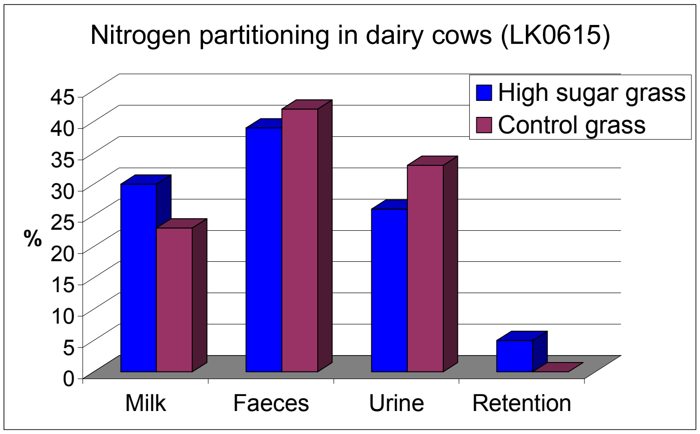

Figure 1: Nitrogen partitioning in dairy cows

Improvements in feed N utilisation were also indicated in a subsequent study with growing lambs (AC0209). Nitrogen retention of 5.2 g/day was recorded in lambs fed on the high sugar grasses, compared to 3.2 g/day for lambs fed the conventional grasses, and was further enhanced – to 8.4 g/day – when a mixture of high-sugar grasses and white clover was fed, although these differences were not statistically significant.

LS3638 examined the effects of plant attributes on proteolysis and microbial protein synthesis in the rumen, since these are key determinants of the efficiency of conversion of feed nitrogen into products and pollutants. This work will identify current opportunities and future goals in developing new strategies for forage breeding, forage management and livestock feeding that will increase the efficiency of utilisation of feed protein by ruminants, thereby reducing pollutants.

4.2.1.2. Forage Legumes

There is considerable interest in the use of forage legumes as feeds for ruminant livestock. This interest has arisen as a result of a number of attributes, and in particular their ability to fix atmospheric nitrogen (fertiliser sparing), higher feed intakes and improved N and energy utilisation relative to conventional ryegrasses. The reasons for the improvements in protein and energy utilisation have been attributed to an increased intake of food and passage rate of digesta compared with ryegrass alone (Dewhurst et al., 2003). White clover (*Trifolium repens L.*) and red clover (*T. pratense L.)* are the most important legumes of temperate pastures (Abberton and Marshall, 2005).

Studies with red clover showed that substituting grass silage with a mixture of red clover and maize silages in the diet of lactating dairy cows resulted in a large increase in milk yield (LS3640). The proportion of feed N in milk was similar for both the grass silage and 40:60 red clover/maize diets (0.251 and 0.242, respectively) - despite the 36% higher N intakes for the mixed silage diet. However, N utilisation efficiency for red clover containing diets was increased significantly (0.287, $P<0.001$)

when the proportion of red clover in the clover/maize silage diet was reduced to 25%. Feed N utilization was also increased (0.277), by reducing N intake, either by restricting the intake of the red clover/maize diet or by including the red clover at 25% rather than 40%.

In the subsequent experiment in this project, red clover or mixtures of red clover with whole crop oat silage were fed. Increases in dry matter intake and milk production were seen relative to ryegrass silage, but the magnitude was not as great as with maize silage. Feed N utilisation was not significantly improved when red clover silage replaced grass silage made from a high-sugar grass variety (0.197 and 0.188 g milk N/g feed N) but was significantly improved when grass silage was partially replaced by mixtures of red clover and whole crop oat silage (0.266 g milk N/g feed N) or red clover and maize silage (0.254 g milk N/g feed N). Feed N utilisation was further improved (0.276 g milk N/g feed N) when the red clover/whole crop silage (0.40:0.60) mix was fed with a low protein compound.

These studies demonstrate that replacing grass silage with red clover silage mixed with either whole crop oat or maize silage can result in reduced urine and faecal N excretion and increased N use efficiency (feed N/milk N) by up to 33% (LS3640).

The plant enzyme polyphenol oxidase (PPO) has been demonstrated to reduce proteolysis in red clover, and a study was undertaken to explore the potential for exploiting this beneficial trait to improve N use efficiency (LS3654). In a study in which dairy cows were fed ryegrass or red clover, N intake was significantly higher on the red clover diets than the grass and this resulted in higher levels of N in milk, urine and faeces. Proportion of N in milk and urine were not significantly different across diets with a trend towards a proportionally higher N output in the faeces of animals offered grass. These results are surprising and contradict earlier studies (Dewhurst et al., 2003; Broderick et al.,2001) which both found a greater portioning of dietary N into product (milk and retained) when red clover was fed instead of grass.

4.2.1.3. Maize Silage

Substituting maize silage for grass silage may provide an opportunity to reduce the overall dietary protein content. Changing the relative proportions of maize silage and grass silage from 25:75 to 75:25, respectively, while maintaining the same overall dietary protein content (140, 160 or 180 g CP/kg DM) actually reduced the efficiency of feed N retained in milk (AC0209).

4.2.2. Feed Supplements

The protein in silage is very rapidly degraded to amino acids and ammonia in the rumen, and research has been undertaken to identify substances which, when added to the diet, would reduce the rate of degradation and so increase the amount of dietary protein available for direct absorption in the small intestine, thereby reducing N losses. Tannins are natural plant products that have been shown to render plant proteins more slowly degradable during ensilage and in the rumen and one study sought to identify the potential for naturally occurring non-toxic tannins to reduce the rate of N degradation during ensiling and in the rumen and improve N utilisation (LS3653). Thirteen commercially available tannins were evaluated and all reduced NH_3-N concentrations in the grass silage by a mean of 12% relative to the negative control, i.e. from 2.13 to 1.88 g NH_3-N/kg DM. When two of the most effective tannins – mimosa and chestnut - were evaluated *in vivo* using sheep, there was no significant effect of tannins on N retention (i.e. difference between N intake and total N losses in urine and faeces) in mature wether sheep, although there was a change in the relative proportions of N excreted. Tannins caused a shift in N excretion from urine to faeces, which might be relevant in terms of pollution from ruminants since lower urea content in urine is likely to lead to lower volatile N losses to the environment.

4.2.3.Feed Selection and Reducing Dietary Protein Content

Although a number of factors influence the amount of N excreted by dairy cows, the one having the greatest effect is the amount of feed N consumed. Many feeding studies have demonstrated the close correlation between N excreted in manure and N consumed, and this relationship is illustrated in the figure below, which combines data from 25 studies in Europe and North America involving dairy cows fed a range of diets (Cottrill, unpublished).

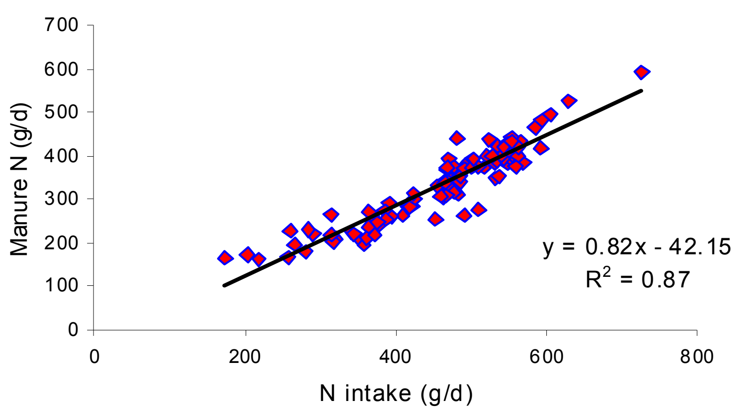

Figure 2. The relationship between N excreted in manure and N consumed by dairy cows

A wide range of feeds are used to formulate ruminant diets, and their selection can have a significant impact on the efficiency of feed N utilisation and N excretion. The Defra LINK project 'Feed into Milk' (FiM) provided new estimates of both the protein requirements of dairy cows and the supply of metabolisable protein from feeds, and the feeding recommendations from that project are now widely used to formulate rations for UK dairy cows. It is generally accepted that the adoption of these standards has led to a reduction in the overall level of protein in dairy cow rations. A subsequent review of the protein requirements of beef cattle and sheep highlighted uncertainties with respect to the protein requirements of these animals, and in particular for pregnant ewes and growing cattle (WQ0133).

A number of studies have demonstrated that changes in the feeds used and levels of protein in the diet can result in an increase in the proportion of feed N retained in milk and a reduction in N excreted (LS3640, LS3656, AC0209).

In AC0223 (completed 2010), the effect of extending dairy cow lactations (~450 days) at a constant total annual milk output were associated with fewer followers and calves (by 28%) and increased GHGE per year (by 13%). The lower milk output in the latter months of an extended lactation was more than offset by GHG emissions per cow remaining relatively constant throughout the period. As a result, extending to a ~405 day lactation does not improve feed utilisation or GHG emissions.

Although there may be scope for reducing dietary protein content, this should not be undertaken at the expense of production, or of herd health and fertility. The N content of diets can vary markedly, due largely to the variable N content of forages, but to date there are no simple and reliable measures available to livestock producers to identify when protein intake is in excess of requirements.

Milk urea N has been promoted as a monitor of protein supply, or protein:energy balance in dairy diets. Although the figures are felt to reflect blood urea levels, and are therefore a simpler determination, most samples monitored are bulk herd samples. These may reflect more than one diet being fed and are therefore not always easy to interpret.

4.2.4. Increasing Productivity and Feed Conversion Efficiency

In the UK, feed costs for cattle and sheep typically account for 40-70% of the variable costs of milk or meat production, and increasing the amount of milk or meat produced per unit of feed consumed should be a natural objective on ruminant livestock farms, especially at a time of increasing feed costs. FCE is a key profitability indicator on most pig and poultry farms, but this is not the case for many ruminant livestock enterprises where the main barrier to quantifying FCE is the absence of a reliable measure of feed consumed. This is particularly the case for grazing livestock. Tools are available to estimate amount of grass available in the UK; plate meters (either mechanical or electronic) are available and allow estimates to be made of both height and density of the sward, although it is not clear how widely these are used. Some farms use sward sticks and plate meters if they are part of a project and may then continue, however they are not commonly used.

For livestock fed silages, equations have been developed to estimate the density of the silage based on the silo dimensions and the dry matter content of the silage, and these can be used to provide an estimate of the amount of silage available. On many dairy, and increasingly beef farms, cattle are fed using TMR mixer wagons, and these provide the opportunity to record in some detail the amount of feed given. The reductions in CH_4 emissions as a result of improving FCE described above (Section

4.1.2) were attributed to the adoption of the controlled nutrition programme used in association with this particular feeding system. It must be recognised, however, that TMR diets are not appropriate for all dairy or beef farms.

Many of the studies reviewed here have reported dietary effects on feed utilisation:

- FCE in dairy cows fed *ad libitum* on diets in which the forage consisted of mixtures of red clover and maize silage (0.40:0.60 or 0.25:0.75, respectively) were not different to the control (grass silage) treatment, despite the fact that silage intake was significantly higher on the red clover/maize silage diets (+53% and +46%, respectively) than the grass silage diet. However, restricting intake of the 0.40:0.60 red clover:maize silage diet to approximately that achieved in the control diet increased FCE from 1.32 to 1.48 kg milk/kg feed DM (LS3640)
- Dairy cows fed high-sugar grass (zero-grazed) had higher feed digestibility (72%) compared to perennial rye grass (67%) and although DMI was not increased as a result of this, milk yield was increased by more than 20% (LK0605)
- Relative to control grass, LWG in lambs was approximately 20% higher in lambs where ewes and lambs were grazing paddocks of high-sugar grasses (LK0605)
- For dairy cattle, an increase in milk yield per cow (by 30% in the modelled scenario), coupled with a reduction in dairy cow numbers, i.e. maintaining current national milk production levels, resulted in the largest reduction (-24%) in CH_4 emissions at the national level (CC0270)
- Feeding high-sugar grasses can lead to (LK0615):
    - Increased dry matter digestibility in dairy cows
    - Increased milk production in dairy cows
    - Increased live weight gain in sheep
    - Increased absorption of non-ammonia nitrogen from the small intestine

4.2.5. Implications of on-farm Non-dietary Mitigation Measures on Methane and N Excretion

Although a number of mitigation measures have been identified that reduce CH_4 and N excretion by ruminant livestock, there is a need to understand the likely effect of these when applied to whole-farm systems. A modelling exercise was undertaken to assess the implications of farm-scale CH_4 mitigation measures for long-term national methane emissions (CC0270). This project concluded that an increase in milk yield by dairy cows, coupled with a reduction in dairy cow numbers to maintain national milk output at current levels, would result in the largest reduction in CH_4 emissions[6]. The effect of increasing milk yield per cow as a means of decreasing CH_4 emissions was also accompanied by a similar increase in nitrogen excretion (as reflected in emissions of ammonia, nitrous oxide and nitrate leaching).

[6] A 30% increase in milk yield/cow was predicted to result in a 27% reduction in methane emissions in this scenario.

5. Adoption of Mitigation Measures on Farms: Dairy

Changes in feeding management made on many dairy farms are mainly directed at improving profitability and managing forage supply through fluctuating seasons. In general, dairy farmers are not actively looking to decrease CH_4 emissions, but are interested in improving feed utilization and reducing dietary nitrogen excess.

With particularly low milk prices in recent years there has often been a desire to increase output to improve profitability. This has not always resulted, and the additional costs, together with the need for more forage has restricted output and financial performance. A number of seasons where grazing or the production of conserved forage has been unpredictable in various locations, has added to this concern.

More recently a number of dairy farmers have developed a more focussed dairy system. Milk price had increased, but has now decreased dramatically and there is renewed enthusiasm for improving efficiency of milk production. This has been in a variety of ways, but mainly as clearer targets in milk production whether as calving success, milk output or herd fertility parameters. These are supported by greater precision in feeding of diets, better forage production and increased expectation from forage, and improved fertility management. Improved knowledge transfer and better technology have contributed considerably to this, whilst dairy labour remains a constant challenge. Achieving the quality and quantity of forage sought appears to have become more difficult in many cases. This is especially as herd size has increased, and possibly as forage required for anaerobic digestion is increasing.

The recent DairyCo report (Profiting from efficient milk production, 2012) highlights that it is the ability to reduce the 'costs of production' rather than a high milk price that is essential to improve net margin. Feed and forage costs feature substantially in influencing the margin.

Milk yield/cow continues to increase, and although cow numbers on individual farms do not decrease, the national dairy herd continues to decline. This increase in milk yield/cow itself will reduce methane emissions per litre of milk.

5.1 Methane Reduction

Methane production in the dairy cow is a result of rumen microbe activity and the ruminant's ability to utilize forage feeds. Hydrogen gas is produced which is taken up by bacteria that produce methane. The better the cow's diet and the better the forage digestibility, the less CH_4 is produced, and the more efficient milk production can become. It is however, the ability to utilize forage of varying quality that makes the ruminant particularly valuable to us, especially in grazing less productive land.

As indicated, a good option for the reduction in CH_4 at farm level, would appear to be increasing the milk yield/cow and reducing the number of cows.

Decreasing CH_4 emissions is low on the list of priorities for the dairy farmer, mainly because there are many other issues that are of greater importance in dictating profitability.

Research work has for long made it clear that CH_4 production represents a loss of energy, but to a large extent it has been regarded as an inevitable loss. Where dairy farmers have appreciated the potential loss of energy to the cow, any action initiated must be seen as both practical and economic.

5.1.1. Feeding Forage Maize

Maize has been appreciated on dairy farms for many years. In most cases it has provided forage with greater consistency at a comparable cost/tonne of dry matter to grass silage. Developments in both the earliness of varieties and management of the growing crop (including plastic mulching) mean that the area over which maize can be grown has increased. However, the increases in acreage year on year are now relatively small, and the resultant quantity available to dairy cows may not be very different (Figure 3). (Source: Defra statistics).

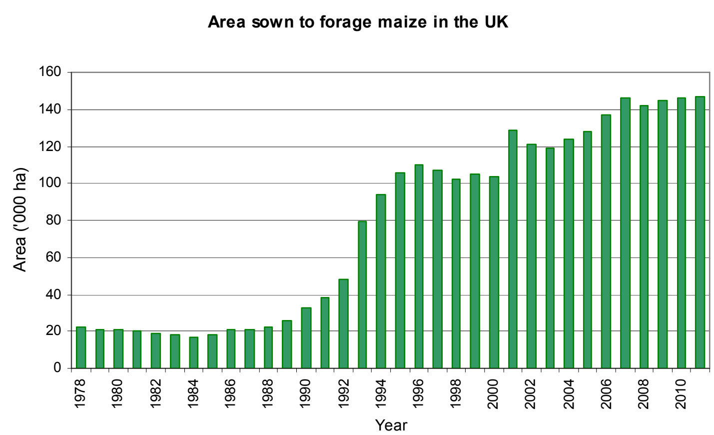

Figure 3: **Area sown to forage maize in the UK**

A proportion of the crop goes to beef cattle and a limited amount to growing dairy heifers, but an increasing amount is used in anaerobic digestion.

Occasional inconsistency of maize crop yields and a harvest late in the growing season may be reasons for farmers ceasing to grow maize. High input costs, and the perceived additional costs of protein supplementation are also factors influencing growers.

The proportion of forage that maize accounts for in dairy diets varies substantially. Although many will have 40 – 50% maize, those with over 70% will be more limited. Again, there are several reasons for this, but it must be accepted that grass traditionally grows well in the UK and if managed well may involve less inputs. Project AC0209 indicated that it was necessary to change from a 75:25 grass silage: maize silage ration to a 25:75 ration, to achieve 13% and 6% reduction in CH_4 per unit of dry matter intake and per litre of milk output respectively. The higher maize inclusion will have raised the starch:ADF ratio, which will directly decrease CH_4 production. Whether the maize itself conveys further advantage remains debateable.

The key target in growing maize has been a good grain proportion and a high starch percentage. With many varieties now able to achieve 30%+ starch, there is increased interest in the digestibility of the plant and total energy content. Increased digestibility could potentially be advantageous in allowing more milk production to come from forage, but maintaining a beneficial effect on CH_4 emissions.

It should be accepted that for many farms forage maize is not the crop of choice, being in 'marginal' areas of the country. If it is grown, more often than not the crop does not mature fully and it loses its beneficial qualities as a second forage and probably its ability to decrease CH_4 emissions. Maize crops are very saleable, and some dairy farmers will have maize grown for them on more favourable land locally.

Wholecrop cereals will in many cases provide a better alternative for many on marginal land. The success of this will depend heavily on what crop is grown, the proportion of grain and how well the crop is ensiled and fed. How successful wholecrop cereals are in reducing CH_4 emissions is unclear, and again the proportions fed will vary widely.

As part of the greater attention being paid to the diet fed, more dairy farmers that are wanting a consistent trough diet, are succeeding in making sufficient maize (or maize + wholecrop cereal) to cover the full 12 months.

Growing maize will possibly have an indirect effect on the quality of grass silage made. The need to cut less acres of grass for 1st and 2nd cuts, can reduce the risk in making grass silage.

Some forage maize acres are diverted to crimped maize or grain maize. This may be used on the originating farm, or sold to those with predominantly but not exclusively grass silage systems. This is likely to replace other 'concentrate' supplementation and not benefit CH_4 emissions.

5.1.2.High Fat Diets

Although the inclusion of fats and oils can be shown to reduce CH_4 emissions, they are not used with this in mind. Nutritionists and farmers are aware of the risk of upsetting rumen function and also the often high cost of 'protected' fats. Much of the fat used is 'protected' and inclusion rates remain low (<5% of diet dry matter), for both the above reasons. The principle source of oils that are included in UK dairy diets at present are:- 1. blended vegetable oils added to compound feeds, 2. palm fatty acid supplements 'protected against rumen degradation' through the manufacturing process, 3. processed (extruded) linseed (or linseed combined with protected palm fatty acids). There is some use of 'expeller' protein sources (soya and rapeseed), with more oil than 'extracted' products, though this is largely on organic farms. There has in the past been use of whole oilseeds (particularly cotton), though this does not have a place at present despite being used in the US.

Additional oil in the diet is seen as a way to increase energy density, especially where forage is of lower digestibility or cow body condition needs to improve. Protected fats (either as calcium salts or as selected fatty acids) have been the approach of choice. Because ‘protected’ fats are intentionally ‘rumen inert’, fibre digestion is largely unaffected and they are unlikely to reduce methane production. There is an acceptance that with some calcium salts a reduction in milk protein % may occur in early lactation, possibly reflecting reduced intake. With high feed costs, and where forage quality and availability are good, there is an opportunity to remove supplementary fats from the diet and reduce cost/litre.

The processed linseed products (Lintec and Flaxpro) have stimulated some interest recently through claims of omega-3 benefiting production and fertility, together with implied reduction in CH_4 emissions. The validation of these products is yet to be confirmed by widespread use.

New sources of distiller’s grains are anticipated in the UK. In general distiller’s grains from ethanol manufacture do not have the level of oil that has been seen in imported maize distiller grains in the past. Nevertheless this could prove a desirable diet ingredient in future, and any contribution to decreasing CH_4 emissions is potentially desirable.

Whilst cereals remain a key feed in dairy diets, high oil ‘naked oats’ are unlikely to find a place unless they can come closer to competing in agronomy with wheat and barley.

Overall, the possible mitigation of CH_4 production using oils must be balanced against reductions in diet digestibility.

5.1.3. Feed Additives

For an additive to be effective in reducing methane, it is likely to need to maintain a concentration in the rumen. This may be difficult in some dairy systems, unless a release system is developed.

There are currently no additives being used in dairy diets that have caused a significant decrease in CH_4 emissions. Section 4.1.1.3 (feed additives) indicates that although fumaric acid has the potential to decrease CH_4 emissions, it is impractical, unless an effective slow release mechanism is identified.

Yeast products are being used to increase rumen performance, and it has been suggested that they might reduce CH_4 production. Studies do not appear in agreement over this, and this might be partly a reflection of the different products being used.

5.1.4. Plant Extracts

Whilst plant extracts have been widely studied for benefit on CH_4 emissions, there are no products actively used in dairy feeding now. Garlic extract (allicin) is included in a particular silage additive – aimed at controlling mould and yeast activity leading to aerobic spoilage. Although garlic extract has seen some development in relation to CH_4 emissions in sheep, it has not been beneficial or practical in dairy diets.

Tannins may have the ability to decrease CH_4 emissions, but it appears principally for the plant breeder to look how the tannin content of forages can be increased.

Essential oils have been promoted to farmers for a long time, though it has been to modify rumen flora and improve rumen efficiency, rather than directly to reduce methane.

5.1.5.Increasing Feed Utilisation Efficiency

Feed utilization can be improved in a number of ways that can lead to greater energy being directed to milk production. Improving feeding not only increases milk production, but also gives better fertility, so giving potential to reduce the number of replacements required. Overcoming other (health, management, or environmental) factors that impede or restrict milk may be equally important.

There is increased precision in rationing and feeding management across dairy farms, whether as predominantly grazing, parlour feeding, Total Mixed Rations (TMR) or Automated Milking Systems (AMS). Systems of feeding have become more detailed, and there is a greater appreciation of how to manage the rumen, the need for effective transition diets, and how to balance nutrient supply. These are essential for better milk production that in turn improves the efficiency of feeding. Knowing how the rumen will react has generally been predicted. It is now becoming possible to monitor rumen pH, so optimizing the diet and potentially minimizing energy lost as CH_4.

For spring grazing herds with very low purchased feed inputs, targets may be rather different. Extending grazing so that the minimum period is spent on conserved forage, may minimize the costs of production. Whether this represents the best utilization of feed is debateable.

Moving from the current typical mix of forage plus concentrates to a more intensive diet will be beneficial in stimulating more milk and less CH_4 emissions/litre, but it is likely that cows may risk poorer health and the cost of milk production may increase. Most farmers are seeking to increase herd milk output, largely through feeding more and better quality forage. Including or increasing the proportion of forage maize may contribute to this. Utilizing more digestible forage will still be a positive way to reduce the overall carbon footprint, and the starch:ADF ratio of diets has potential to indicate CH_4 production. So long as a high starch and energy density is maintained, CH_4 production/litre milk will decrease.

The need for constancy in feeding dairy cows is now far more accepted. This has been helped by the use of maize and wholecrop providing more constant forage. In addition, greater control of mixer wagon operation (ingredient quantity and the extent of mixing), means that daily output to groups of cows can be more constant, and consistent. This has provided the potential for a significant improvement, especially where different staff may be involved in feeding the cows.

Section 4.1.2 gives the case for higher Feed Conversion Efficiency (FCE) being a useful target where reduced CH_4 emissions/litre is sought. Although valuable in this context, many dairy farms are working against physical and management factors that limit feed intake. Some of this is the result of modern cows still being housed in older/smaller buildings, and a compromise on space requirements. Although dairy farms do not in general have particular welfare issues, health status may also be below that desired. This arises from metabolic problems arising at calving, lameness, mastitis and other sub-clinical disease levels for which vaccination may be necessary.

So, whilst seeking the best FCE, it is important to be reasonably confident that performance is not restricted. Keenan Nutrition have heavily promoted the desirability of high FCE. More recently BOCM Pauls have introduced F2M to track progression to a target. The extent of its take up is difficult to estimate, but with more automation in the feeding of dairy cows the figure will be more common, though its validity may remain in question in some cases.

Current figures[7] show a National FCE of 1.2, a PACE[8] National average of 1.3 and the top 25% in the UK at 1.5. The difference between average and top 25% is considerable, and does show the potential for improved margins as well as contributing to reduction of CH_4 emissions. It should be borne in mind that the range around the averages will also be very wide.

FCE is calculated from the kg FCM produced/kg DM eaten. Certain points must be accepted:-

- An accurate estimate of the feed actually eaten is required rather than that which is offered. Accurate forage dry matter in particular is necessary
- FCE will vary with the yield potential of the herd. Higher yielding herds have higher feed conversions – more production / less maintenance, and a higher energy density
- The composition of the DM eaten can be very different between 2 herds, especially in terms of energy density, reflecting forage type and proportions plus fat or mineral inclusion
- Stage of lactation will influence FCE. Cows in early lactation will have a higher FCE due to the milk yield exceeding the expectation from the diet
- FCE will also vary between breeds and where there are marked condition score changes

With improving FCE (less feed use for the same milk yield) CH_4 production is shown to decrease in individuals, but needs to be quantified on a herd basis. Where savings

[7] Keenan Mech fibre community
[8] Performance Acceleration and Control Enhancement

of 0.075 FCE were possible as suggested, intake is reduced by 1 kg DMI, reducing daily CH_4 emission by 5%.

The physical form of the diet has been much discussed in relation to dry matter intake and rumen health. Correct and constant processing of the diet ingredients is a key feature of modern mixer wagons. This is so that the physical mix restricts 'sorting' by cows and provides the rumen with a diet that can be well digested. Whilst fine processing of forages can be shown to benefit intake and potentially reducing methane production, it is often costly, and may fail to maintain good rumen health where concentrates are included.

Use of straw in milking diets has been widely promoted. Part of the reason has been to achieve improved rumen health, probably reflecting the concentrate loading of the diet together with the particle size of the forage. For others it is considered that the presence of straw (typically up to 1kg/cow) gives a more appealing diet to the cow, and is allowing better utilization of the diet, potentially improving FCE. These are no doubt linked and the straw inclusion is found beneficial on a number of farms. High cost of straw and restricted availability is causing some farms to question the inclusion. A greater proportion of the diet as grass or maize silage and less concentrate may be more practical and more productive.

5.2. *Reducing Nitrogen Excretion*

There has been an appreciation of the desirability of reducing nitrogen excretion in dairy diets for longer than concerns over methane. Thoughts about nitrogen excretion will also probably be linked to the use of manure and slurry, for the productive crop growth. But, capture of excreted nitrogen is generally poor, and any way that excretion can be reduced, needs consideration.

Oversupplying nitrogen in dairy diets has become appreciated as undesirable mainly for reasons of cost, and greater difficulty in managing slurry. It also requires more of the cow's energy to excrete an excess, and may jeopardise cow fertility as well as increasing potential pollution. At the same time, the use of increased dietary protein to apparently stimulate an increase in milk production has been important, and remains a challenge of education on some farms.

The move towards lower dietary protein levels has been steady, with many farms reluctant to move to lower levels. Farmers require a gradual acclimatisation to lower protein diets, so that they can gain confidence that milk yield is not being constrained.

The availability of milk urea nitrogen (MUN) values has helped highlight where dietary nitrogen is excessive, or possibly energy or suitable substrates inadequate. Guidelines originally were 250 – 350 mg urea/l, though it is now appreciated that values considerably lower (certainly 150mg/l) can equate to excellent milk production and fertility. The values are certainly not used to the full as scepticism remains over some results. Considerable fluctuations on some farms discourage use, but overall even in these cases, the trends are of greater relevance.

5.2.1. Reducing Dietary Protein Content

Inevitably this topic is referred to in several parts of 5.2.

Initially progressive farms, but now many more farms encouraged by nutritionists and feed advisers, are moving milking cow diets to considerably lower protein levels. Diets originally 18% + are now often 16 – 17%. Better diet formulation and the agreed Feed into milk (FIM) project have given a sound base from which to work. FIM has encouraged the targeting of Metabolisable protein (MP), though crude protein % itself will not always be lower. In general, working to the MP targets has been satisfactory, and there does appear to be reasonable consensus across the industry.

The protein content of grass silages would appear to have declined, largely through the use of less nitrogen fertiliser but possibly also with lower protein grass species. This, together with the use of maize and cereal wholecrop has been valuable in decreasing the dietary protein supply without necessarily setting out to feed lower protein supplements. Maize and wholecrop are discussed further in 5.2.4 below.

There has been recent promotion of feeding lower amounts of protein (and total supplement) to cows in the first month of lactation specifically. This recommendation has been intended to reduce initial milk yields and milk fat content, so reducing the period of negative energy and potentially improving fertility.

5.2.2. Feeding High-sugar Grasses

Maximising rumen microbial protein synthesis must be the fundamental objective in feeding the ruminant, and manipulating diet balance and quality to achieve this is the key. With grass as the principal feed to all ruminants, the ability to increase the amount of sugar present has the potential to increase the utilization of nitrogen.

Higher sugar grasses have been available for some time in grass mixes, and have been adopted reasonably well. Dairy farmers seek specific seed mixes for a number of reasons, with yield, persistency and perceived digestibility/acceptability being key in addition to price. Higher sugar content will be desirable, but this may compromise the grass protein level, which in some cases may be of added benefit. Where a substantial proportion of maize or cereal wholecrop are fed, the loss of protein may definitely be undesirable. Actual sugar content, digestibility and protein content of grass variety mixes are not known.

In grazed swards higher sugar content is of direct benefit. The LINK project[9] (2005) showed that approximately 5% units increase in sugars was required to give a significant response in performance. Grass mixes would need very careful selection of the 'high –sugar' varieties to achieve this, that may be considered restrictive.

[9] LINK High-sugar ryegrasses for improved production efficiency of ruminant livestock and reduced environmental N-pollution (2005).

Higher sugar grasses are also beneficial in grass to be ensiled, making a good fermentation easier to achieve, and it is implied that the higher sugar content is maintained in the silage. This aspect will almost certainly depend on the efficiency of fermentation, and may need further confirmation.

5.2.3. Feeding Forage Legumes

The potentially desirable properties of legumes (clover and lucerne) have been known for some time, and those in relation to N utilization are given in section 4.2.1.2. White clover in grass mixes has long been popular, but largely for reasons of weed control it is too often considered difficult to maintain, and hence is deleted or omitted. Many farms now sow a ley without clover, and then reintroduce clover once the new ley is established.

Red clover has attracted increased interest, and there is renewed enthusiasm for lucerne on lighter land. Both are predominantly used as forages for conservation, and they are not generally suited to grazing. In some cases red clover/Italian ryegrass mixes are considered easier to manage and ensile, than pure red clover. Being dependent on a solely cutting regime, is at times restrictive and careful grazing is possible.

Improved silage making techniques (speed of work and effective wilting) means that crops can generally be ensiled at the high dry matters necessary for success, 35%+. In this respect, baled silage as opposed to clamp has been popular, despite potentially increased cost. The analysis of these crops specifically, has not received the attention due and often digestibility and energy (ME) values appear low. Protein % in red clover silage often appears lower than anticipated, but is possibly reflecting the stage of harvest. These factors do make potential users wary, but these forages become accepted when crops come to be grown and fed.

Those growing these crops are generally pleased with the saving in fertiliser, and their contribution to the diet. However, for others there remains a suspicion that management will be more complex, persistency uncertain and costs may be increased compared to perennial/Italian ryegrass leys.

5.2.4. Maize Silage and Cereal Wholecrop

Maize silage has gained its present position in livestock diets for reasons of good yields and consistency rather more than its ability to reduce N excretion.

The benefits in the diet can be seen in terms of improved milk yields and quality, and savings in bought in feed. Although a crop often dependent on contractors, a single harvest (despite often late in the year) is attractive. The land used for maize has also proved a receptive and beneficial site for farm produced manure and slurry. Its low protein and high starch content has meant that in many diets where good grass silage has been fed, the excess dietary N is substantially reduced. The use of maize could be extended further, leading to lower protein diets, but for some it remains a management complication and others are on marginal land where mature crops are difficult to achieve.

Cereal wholecrop should be regarded as having the potential to fulfil a similar role to maize in lowering dietary protein, and indeed can substitute well. Success with this crop often depends on achieving a good grain crop to ensile, and ensiling it well. These more marginal maize farms may not have as good an arable approach, and a high grain crop will remain a challenge. Storage of wholecrop can be as a lower dry matter fermented product, a high dry matter product 'stabilized' against yeast and mould activity, or 'preserved' as 'Alkalage'. This latter process adds a urea based product which releases ammonia. In this case the protein content will increase from some 9% to 16 – 18%. Although lower amounts of this product may be fed, it adds nitrogen rather than dilutes it.

Even with the reduced target protein levels in diets, farmers have generally come away from the highest proportions of maize silage being fed. Although this may be partly avoiding over reliance on a single forage, it is also an appreciation of the additional dietary protein requirement. Trial work quoted (Section 4.2.1.3) indicated that at any given protein level, high maize proportion did not improve the efficiency of N retention.

Fresh maize is not utilized well in most seasons. When maize grains are mature they not only require processing well (better than is often the case), but the silage also needs to be left for a minimum of 4 to 6 weeks before feeding to improve carbohydrate degradability. This is an ongoing challenge to achieve in practice, but it will allow the cow to utilize the maize with greater efficiency.

5.2.5. Feed Supplements

For many farms, the main supplement is a compounded feed which has a major influence on the diet protein %. Inadequate understanding and lack of analysis of the forages fed, mean that the ideal supplement is not always chosen and changes are not made as often as desirable. Feed manufacturers themselves are not always good at providing low protein products that maintain a high energy content. To some extent this may reflect that farmers still judge compound feed by protein content (rather than energy), and expect a more favourable price. It also reflects the lack of an agreed approach to declaration of energy content or digestibility. Declarations of feed ingredients by categories (e.g., oilseeds), remains too vague to be useful.

Rapidly increasing price of protein feeds (led by soya bean meal) will be an important factor in milk producers questioning the amount and type of protein fed, especially with declining milk price. With time and a better understanding of the case for lower protein inclusion, there will be tighter control on protein feeding. Greater volatility in the milk price will mean that this will be more important if margins are to be maintained. Rape and soya remain the principal proteins, with a limited number of other vegetable proteins available and 'non protein nitrogen' also available in various forms. Slow release forms of urea are promoted in higher starch diets as giving comparable levels of production to rape or soya, but achieving a greater contribution from forage. Whilst this is desirable if an increased margin is achieved, the efficiency of nitrogen use is unchanged unless less nitrogen can be fed in the diet. Most non protein nitrogen sources will increase in price if energy prices increase.

The protection of soya and rapeseed in particular, typically through heat or chemical treatment has been available for some time and a number of commercial products are available. Although generating a higher undegradable protein content, it is not necessarily financially advantageous in the final diet. Nitrogen excretion is only likely to be reduced if a lower protein input is possible.

Nitrogen from grass silage is considered more difficult to utilise because of the considerable degradation of the protein. Different approaches have been proposed to try to reduce this degradation. Additives are used to improve the efficiency of fermentation, and where this occurs grass protein breakdown is reduced to some extent. This does not feature very highly in farmer's reasons to choose an additive, and it is considered to be a relatively variable benefit.

Although the rumen provides an excellent source of microbial protein, the extent of degradation of protein is often greater than desirable. Despite the interest in tannins being able to influence the use of nitrogen, there are no commercial products currently available.

Essential oils[10] (CRINA) have been claimed to reduce protein degradability and there is some support that this action is occurring through inhibition of some rumen microbes. This does not appear to be widely used in the UK.

Synthetic lysine and methionine have long been promoted to benefit milk production, but quantifying the response to added amino acids has been difficult, and it is not currently seen as a route to reducing nitrogen excretion.

5.2.6. Increasing Feed Utilisation Efficiency

Measuring FCE has been slow in adoption, for a variety of reasons referred to in Section 5.1.5, making it less useful than for non-ruminants.

Many farms do not record forage intakes (conserved or fresh), and are unlikely to start, ensuring primarily that intake is not restricted. Those farmers who are enthusiastic about increasing production from grazed grass can now quantify the grass available, mainly using a plate meter. This has proved a valuable education in managing grazing and increasing milk production from it whatever the production level of the herd. The principles and practice of this approach are available through the Grass+ manual[11] (DairyCo).

Although well understood, zero grazing of fresh grass with known amounts being fed, is unlikely to become widespread, since it is costly in time, machinery, slurry storage

[10] CRINA – DSM Nutritional Products Ltd 2012
[11] DairyCo – Grassland Management Improvement Programme

and spreading. Public perception is little different to stock housed on conserved forage diets.

A Total Mixed Ration (TMR) is a desirable way of providing nutrients to the dairy cow, combining energy and protein substrates for effective use and avoiding fluctuations in rumen fermentation. However, the ruminant is very adaptable, and recycling of urea can mean that this approach is not necessarily always advantageous.

Where more precise TMR feeding systems are matched by careful management, with detailed forage analyses and accurate feed refusals, reliable estimates of FCE can be obtained. This more detailed knowledge encourages dietary change to improve utilization of nutrients and with it reduced N excretion and some farmers are using this approach.

There is considerable scope to improve feeding efficiency on most dairy farms, whether a simple or complex feeding system, by more accurate record keeping, taking forage quality into account and monitoring feeding against milk production.

It remains important to accept that other management factors (stocking rates, welfare, feed storage, trough management, lameness and cow comfort) can have substantial effects on how the diet is utilized. It is also important to accept that the requirements for milk production cannot be separated from the requirements for good health and fertility.

6. Adoption of Mitigation Measures on Farms: Beef

6.1 *Systems of Beef Production*

UK beef production systems cover a wide range of farm types and management systems, from hill land with poor grazing value to lowland which is intensively managed. UK cattle production is highly integrated with an important exchange of stock between beef and dairy herds. The dairy herd produces animals for beef production in the form of pure-bred Holstein/Friesian males and beef-cross males and females. Some of the crossbred females are used as suckler cows. Pedigree suckler herds mainly produce bulls, some of which are sold to bull studs from where the semen is sold into dairy herds. The keeping of pedigree beef bulls for natural service is also common in dairy herds.

Beef production is very diverse which is in marked contrast to the dairy industry where there are relatively few distinct production systems and dairy breeds. The main factors that result in diversity within the beef industry are:

1. Farm type: Hill farms with relatively poor grazing are suitable only for grazing, and the beef systems here mainly involve suckler herds with calves sold at weaning for finishing on better land. Some hill farms have improved some of their pastures to the extent that they are more versatile and are able to both rear and finish livestock. Lowland farms may have suckler herds and finish home grown stock or they may buy in and finish store cattle. Most beef cattle that originate from the dairy herd are grown and finished on lowland farms.
2. Breed: There are well over 30 breeds of beef cattle in the UK. It has been found that the magnitude of the difference in performance between breeds is such that breed substitution is a far quicker way of changing the level of performance than selection within a breed.
3. Production system: Systems that involve cattle that are housed throughout their lives are generally based on cattle born in the dairy herd. The aim is to achieve a consistently high growth rate and slaughter at 11-14 months of age. Cereals, grass silage, maize silage and by-product feeds are the staple ration ingredients. However, most beef cattle produced in the UK spend a period at grass and the incorporation of a grazing period tends to introduce a considerable amount of unpredictability into the system with age at slaughter ranging from 18 to over 30 months.
4. Age at slaughter: This can range from 11 to over 30 months. Feed conversion efficiency deteriorates markedly as animals get older. In terms of converting barley into live weight gain it is likely to be around 6:1 at 11 months and 20:1 at 30 months.
5. Finishing system: There is a wide range of breeds and crosses used and a wide range of management and feeding practices adopted.

6.2 *Obstacles to Progress in Reducing GHG emissions by Better Cattle Performance*

6.2.1 Farmer Attitude

The priority for most farmers is to make a profit, not to reduce GHG emissions. It is therefore important to get farmers to understand that reducing GHG emissions often results in better performance and profit. For example improving fertility, health, longevity and reducing mortality will reduce the number of animals needed and the number of replacements kept, overall reducing emissions. Best practice manure management such as covering slurry stores and injecting slurry into the soil will reduce emissions and have financial benefits to farmers.

6.2.2 Measuring Live Weight Gain

Measurement of cattle live weight gain does not occur on many beef farms and if carried out the information is often not used effectively. It is the lack of understanding of how this can improve performance and profit that is often responsible for the lack of interest in applying precision to the formulation of cattle rations. This is in contrast to dairying where a measurement of performance in terms of milk yield is readily available and rations can be adjusted accordingly.

6.2.3 Feeding Levels

Beef farmers are generally broadly aware of quantities of forage required to keep stock over winter. However, some have little grasp of daily appetite and how to adjust forage: concentrate ratios to deliver desired LWG. Estimates of the amount of grass available for grazing is mostly done by comparing year on year production and their experience of the seasons. Sward sticks and plate meters are used by top performing farmers but are rarely used by the majority. The main barriers to uptake of grass measuring techniques (sward sticks and plate meters) are time constraints and lack of knowledge to apply the information.

6.3 Technical Areas Most Likely to Bring Improvements

One Eblex publication[12], shows that improving efficiency in beef cattle by 5% genetic improvement and 5% improvement in feed quality will result in a GWP_{100} saving (kg CO_2 eq/kg meat) of 0.30 and 0.31 respectively.

6.3.1 Cattle Genetics

To achieve better feed efficiency in beef cattle there is a need to focus on breeding, feeding and management.

A feed efficiency project hinging on the Stabiliser breed has recently been awarded a grant of £1.2 million by the Technology Strategy Board. This project is designed to help producers drive down production costs; it will also look at options for reducing

12 'Change in the Air' (2009)

GHGs. Cattle are individually fed and weighed which will enable the first EBV for Net Feed Efficiency (NFE) in the UK to be calculated.

6.3.2 Grazing Management

Few producers measure grass height (<5%) and prefer to assess grass availability by eye. Most beef farmers would underestimate grass height, usually by 2-3 cm which leads to later spring turnout for many cattle than could be achieved. Grass utilization and quality is then compromised. The concept of turning just part of the herd out onto grass and leaving the rest inside for longer is a concept that is not adopted by enough farmers. It could have considerable application if early turn out fields are chosen wisely and younger, lighter stock are turned out first at low stocking rates limiting damage to wet spring pastures.

Any apparent superiority of rotational grazing is due largely to the built-in discipline which leads to efficient defoliation. It is now established that continuous grazing with the same N fertiliser and stocking rate results in performance similar to that of rotational grazing in carefully controlled trial work. Most producers will continue to set stock and graze continuously for ease of management. Those disciplined to manage rotational grazing will typically have better performance.

The concept of balancing grass supply with herd demand is not well appreciated. A plate meter reading can be used to assess kgDM/ha and then this can be linked to appetite (assumed to be 2% of animal liveweight) as kgDM/head/day. Again the main barriers to uptake of this approach are time constraints and lack of knowledge to apply the information.

As far as conserved forage is concerned, few farmers think of grass in terms of amount of dry matter required - it is usually thought of in terms of acres mown, number of bales or quantity of silage in the clamp. There is a need to drive forward the concept of calculating the amount of grass dry matter of a certain energy and protein level needed for individual beef production systems on farms. Most beef producers appreciate differences in forage quality and match it to the system – e.g. top quality silage for finishing cattle and mediocre forage for suckler cows.

6.3.3 Pasture Improvement

Pasture improvement also offers lots of scope to increase production, particularly on lowland farms. High-sugar ryegrasses (HSG) will improve output and stock carrying capacity of land and are currently included in most seeds mixtures. However, all those labeled as HSG have the Aber prefix. HSG is therefore a brand. Other grasses which are not labeled as HSG may have a high sugar content (e.g. Calibra). It should always be remembered that grass varieties (whether high sugar or not) vary with regard to a range of attributes such as persistency, density of sward, rate of establishment etc and choice of variety should be based on the needs of the production system in question. A system that hinges on clover and grass is more energy efficient (MJ/kg meat) when no fertiliser is used.

The main barriers to improving grassland by reseeding are: –

1. An establishment cost of about £400/ha (less if direct drilled)
2. Disappointing results because of deficiencies in soil nutrients (phosphate and potash) and pH not at the optimum level
3. Poor understanding of the financial value of good quality grass
4. Difficulty in managing fast growing grass – especially on grazing systems
5. In practice poor grassland management (resulting in overgrown relatively indigestible grass) leads to the concept that grass is unreliable as far as quality is concerned. The concept that a ME of 12.0 + MJ/kg DM can be maintained in grass all season is not generally appreciated. Concentrate feed is perceived as being much more reliable.
6. Growing more grass is often not seen as a priority since keeping more cattle is not an option due to limited building space. For many farmers improving the quality of the grass that is already being grown would be of more value than increasing the quantity grown.

6.3.4 Better Diet Formulation

Improvements in feeding can deliver a relatively rapid improvement in efficiency. There are many opportunities for producers to make better quality forage and utilize more of the forage that they grow and conserve.

Eblex Business Pointers[13] show that in extensive beef systems, top third beef producers have winter feeding periods that are 10% shorter than bottom third producers and produce carcasses of similar weight. In intensive beef production top third performers finish their cattle in 25% fewer days and the carcasses are 7% heavier. Since FCE naturally reduces with age for all types of cattle, this underlines the opportunity immediately available for both financial and environmental improvement when performance is improved.

6.3.5 Supplementing Grazed Grass with Cereal

At the time of writing 1 kg of fertilized grazed grass (2012) is likely to cost about 5.8 p/kgDM (Charlie Morgan 2012 - personal communication). The cost of processed barley is about 22 p/kg DM (13.3 MJ/kgDM, £190/tonne). If grazed moderate quality grass (M.E 10.0 MJ/kg DM) grass is supplemented with barley (substitution rate on a dry matter basis of 1 kg of barley for 0.5 kg grass) then the theoretical extra cost of feeding 1 kg of barley dry matter is 19.1 p/day (i.e. 22p minus 2.9p). The extra live-weight gain achieved by an animal weighing 300 kg and offered a supplement of 1 kg of barley/day is likely to be about 0.20 kg/day (Energy and Protein Requirements of Ruminants 1993)) which would be worth about 35 p/day. Over 100 days the additional liveweight gain achieved from offering the supplementary feed would be 20

[13] Eblex Business Pointers (2011)

kg with an estimated value of £40. The extra feed would cost £19.10 giving a financial benefit over feed of £20.90/animal. The cattle would also reach slaughter condition 15 to 20 days sooner.

6.3.6 Maize Silage

Maize silage provides opportunities for lowland beef systems to improve DLWG. Defra census figures show 146,000 ha of maize grown in UK in 2010. This compares with 1,232,000 ha of temporary grass (< 5 years old) and 9,980,000 ha of grassland over 5 years old. Most forage maize is fed to dairy cows. Obstacles to uptake include location (marginal areas and unsuitable land), limited supplies of manures, does not fit in with the rotation, (especially on grassland farms) and disappointing performance. Growth rates of beef cattle fed forage maize can be disappointing since there is sometimes a lack of understanding of the need to balance forage maize diets with additional protein and trace elements. There are sometimes difficulties in clamp management resulting in large amounts of waste.

6.3.7 Use of Legumes

White clover is used in most grazing seed mixes, however it will die out unless pH, P and K levels are maintained and management is sympathetic to clover growth. The main barrier to uptake is the general lack of grassland improvement carried out, either by full reseed or overseeding. This is sometimes due to cost, lack of knowledge and understanding or the fact that farmers do not have the machinery.

Red clover is becoming increasingly popular due to its high protein content and excellent silage. The main barriers to uptake are concerns over the effect on fertility in cattle and sheep when grazed, some farmers find it difficult to manage and it lacks persistency.

6.4 Measurement of Production from Grazed Swards

Production from an area of grazed grass can be assessed by using a rising plate meter to measure grass availability before and after it has been grazed. The relationship between measured height and field cover is imperfect but provided the same assumptions are made throughout it can be a valuable guide. The tool is accurate between 1200 and 3200 kg DM/ha. Only a small number of beef farmers are using this technique.

6.5 Efficiency of Grass Utilisation by Cattle at Pasture

The Defra (June 2011) census shows the following areas of permanent and temporary grassland in England –

- Permanent grassland (over 5 years old) – 3,239,000 ha
- Temporary grassland (under 5 years old) – 620,000 ha
- Sole right rough grazing - 497,000 ha
- Common rough grazing – 399,000 ha

The table below shows Defra (June 2011) figures for the number of cattle and sheep in England along with calculated estimated Livestock Equivalents. For the sake of this approximate calculation it will is assumed that all cattle use either permanent or temporary grassland and that 85% of breeding ewes use these types of pasture.

TABLE 1 - Cattle and Sheep Populations in England - June 2011 (thousands)

Stock type	Number	Livestock unit equivalent	Number of livestock units	Stock as % of total LU
Dairy cows	**1,129**	**1**	**1,129**	**23.5**
Beef cows	**759**	**O.85**	**645**	**13.5**
Young cattle (mainly < 2 years of age) destined for beef or breeding	**3,500**	**0.55**	**1,925**	**40.0**
Ewes	**5,570 (85% of total)**	**0.2**	**1,114**	**23.0**
TOTAL			**4,813**	**100**

6.5.1. Level of Grass Utilisation

It can be seen from the table that young cattle in England equate to an estimated 1,925,000 livestock units which accounts for 40% of the total for cattle and sheep. If it is assumed that these animals also occupy 40% of the grassland (permanent and temporary) then they take up 1,543,600 ha. A typical average liveweight for young cattle at any one time would be 300 kg and a typical average daily growth rate throughout the year would be 0.75 kg. The metabolisable energy required by each animal to achieve this performance level would be about 65 MJ/day (AFRC 1993).

At a growth rate of 0.75 kg/day the total amount of liveweight produced by the cattle over one year would be 892,000 tonnes[1]. The estimated total amount of grass dry matter produced per annum in England is 16. 4 million tonnes[2] which equates to 4.7 tonnes of dry matter per animal/annum. If the grass has an average energy density of 10.0 MJ/kgDM then the amount of energy available for each animal is 129 MJ/day compared with the 65 MJ needed. This shows therefore that only 50% of the grass grown is utilized.

[1]Total Liveweight gain of cattle over year = 892,500 tonnes (3,500,0000 cattle x 255 kg liveweight gain/ annum)

[2]Quantity of grass dry mater produced = 16,364,598 tonnes (1,543,830 ha x 10.6 tonnes DM/ha)

7 Adoption of Mitigation Measures on Farms: Sheep

The diverse landscape of the UK ranges from the mountains of Scotland and Wales to the lush lowland pastures of the South West of England. The UK has 85 recognised breeds of sheep plus a large number of crossbreeds with particular breed types adapted to specific environments.

Some farms in the UK may be dedicated to sheep production but sheep are often run in conjunction with a beef enterprise in the uplands and hills. In lowland areas, sheep are often part of a farm rotation with other livestock and arable crops.

The combination of the large number of sheep breeds and farm types leads to a wide range of sheep systems.

Sheep graze large areas of the hills and uplands that are not suitable for other cropping. In hill areas, hardy mountain sheep are kept (mostly as pure breeds) as they are well adapted to the environment. A proportion of lambs which are not retained as replacements for the hill flock may be sold as store lambs and transferred to the lowlands to finish. Older hill and mountain ewes are transferred to upland (or lowland) farms and crossed to produce breeding stock (Mules and half-breds).

In lowland areas, sheep are often managed in rotation with beef cattle, dairy cows and arable farming. In these areas, there are diverse sheep enterprises including crossbred ewes mated to terminal sires, purebred flocks, early lambing flocks and specialist store lamb finishing units.

The age of slaughter for lambs can be as young as ten weeks from intensive sheep systems or as much as twelve months (or more) on long keep finishing systems.

Despite the wide range of sheep systems, grass and forage crops supply over 95% of the nutritional needs of sheep. Supplementary feeding and winter housing (1- 3 months on some farms) are only used to protect sheep welfare and optimise productivity. The 2012 Defra Farm Practices Survey reported that sheep and lambs were kept outside for 48 weeks of the year. The emphasis on grazed systems, and relatively low reliance on concentrate feeds, means that mitigation measures for methane and nitrogen must focus on improved utilisation of grassland and forage crops.

In order to help the UK government achieve its targets for GHG reductions the sheep industry will need to improve efficiency of production by 11% in the next ten years. The sheep industry is striving to achieve this through improved feed efficiency (type and quality of feed), improved fertility and flock longevity. Due to the largely extensive nature of sheep farming the industry does not use large amounts of fossil fuels or machinery. Machinery is mainly used to conserve forage for the winter months.

7.1 Methane Reduction

7.1.1 Feeding Forage Maize

Forage maize can be fed successfully to ewes and finishing lambs. However uptake amongst sheep farmers has been relatively low and those that have taken it up are in good maize growing areas and grow it primarily for cattle.

Feeding forage maize is unlikely to be taken up by sheep farmers to primarily reduce methane production. Growing maize is not always a practical option when taking into account crop rotations and availability of manure. Forage maize does not lend itself to ring feeders and outdoor feeding and so is not appropriate for many sheep farmers who are trying to use extensive grazing. It is uneconomic to grow forage maize in many sheep areas, specifically for smaller flocks.

Farmers that use a total mixed ration (TMR) feeding system are more likely to incorporate maize in the diet. The majority of TMR users are cattle farmers although some very large sheep farmers (typically 2,000 breeding ewes or more) may justify the cost of the specialist machinery required.

There are some farmers who have fed maize to sheep but have encountered problems because the ration has not been balanced to take into account the high energy and low protein content of the crop. When maize silage is mixed with grass silage and properly supplemented then excellent results can be achieved with pregnant ewes. A small minority of sheep farmers are taking this approach.

7.1.2 High Fat Diets

Diets with higher fat content such as those containing high levels of oilseeds, dried distillers grains or naked oats are not commercially common for sheep despite recent research. Omega 3 additives are being used in some compound sheep feeds (25g per head per day) and claim to improve fertility and lamb vigour. The inclusion of these products at these low rates is however unlikely to have any effect on methane production. Likewise rumen protected fats are used in compound feeds for pregnant and lactating ewes but these are unlikely to have any effect on methane emissions.

Naked oats are not readily available at the present time for sheep feeding and are not currently a cost-effective option.

Imported distiller's grains, and in time similar UK produced products, can provide feeds with increased oil levels (4-9%) If available these can be used in concentrate mixes for ewes and finishing lambs. The high copper levels of some distiller's grains (from whisky distilling) limit their use in sheep diets due to risk of copper toxicity.

7.1.3 Feed Additives

A number of commercial feed additives are available and are sold to farmers to improve efficiency e.g. yeast based products to improve rumen stability; however these are not targeted specifically at reducing methane production. In section

4.1.1.3. the potential of fumaric acid to reduce methanogenesis was discussed. However, currently there are no commercially available products for sheep farmers.

7.1.4 Plant Extracts

Limited *in vitro* studies have meant that these have not been taken up to any extent in ewe or lamb diets to give improved feed utilization or contribute to methane reduction.

7.1.5 Increasing Feed Utilisation Efficiency

Improving feed utilisation and live-weight gain presents the best opportunity to mitigate methane production on sheep farms. Many farmers calculate the total amount of purchased feed consumed by the flock over the winter period. Relatively few sheep farmers would formulate feed rations based on forage analysis to meet the nutritional requirements of their sheep. The Defra Farm Practices survey 2012 indicated that only 17% of lowland grazing producers and 10% of LFA producers 'always' use a ration formulation programme or nutritional advice from an expert when planning livestock feeding regimes. In contrast 33% of lowland and 38% of LFA producers stated that they 'never' used a ration programme or specialist nutrition advice. For many if they do approach anyone for advice, it will be their compound feed manufacturer and there are probably as many farmers over-feeding ewes as underfeeding.

Farmers with small flocks are less likely to justify the cost of specialist ration formulation although some pedigree flocks (which are often small) may take advantage of this due to the relatively high value of their stock.

Many sheep producers focus on finishing lambs off grass as quickly as possible. There has been a recent knowledge transfer focus (through levy bodies and others) on efficient grassland utilisation to reduce the reliance on expensive purchased feeds and maximise financial returns. However, farms that creep feed lambs at grass early in the season can take advantage of the superior feed conversion efficiency of younger animals and will have lower total emissions than those that rely on finishing lambs more slowly on grass alone over an extended period.

Due to the small amount of time that sheep are housed per year, the capital investment in feeding equipment such as feeder wagons can rarely be justified. Breeding ewes are housed for short periods of time (4-8 weeks, if housed at all). This limits the opportunity to control diets and the emphasis needs to be on efficient utilisation of grassland, including good seed mixes, use of clover, fertiliser planning and rotational grazing. Barriers to improving grassland have included the cost of reseeding, lack of perceived benefits, and the fact that some environmental schemes restrict grassland improvement programmes. The need for environmental impact assessments before reseeding is also a barrier.

7.1.6 Reducing Nitrogen Excretion

7.1.6.1 Feeding High-sugar Grasses

One of the multiple retailers is encouraging the use of high-sugar grasses (HSG) by farmers in their LambLink (and equivalent beef and dairy) producer groups. This retailer is aiming to reduce CO_2 from producer's cattle and sheep by 186,000 tonnes. To achieve this they have teamed up with British Seed Houses to introduce Aber HSGs and Aber clovers to 13,500 farmers across the UK. The reported aim is to improve the environmental impact but also to reduce purchased feed costs and improve efficiency of production.

The Defra Farm Practices survey 2011 indicated that for LFA grazing livestock 52% of producers had sown some temporary grassland with HSG and 19% had sown at least 80% of their temporary grassland with HSG. On lowland grazing livestock holdings 55% of farmers had sown some temporary grassland with HSG and 21% had sown at least 80% of temporary grassland with HSG.

Many commercially available grass mixes now include HSG. Farmers that have taken up HSG are keen to improve pasture to increase DLWG of their stock rather than to reduce methane directly.

7.1.6.2 Feeding Forage Legumes

Incorporating forage legumes such as red and white clovers in grass leys has proven benefits for nitrogen fixation. The benefits for reducing nitrogen excretion are covered in section 4.2.1.3. This has been widely taken up by sheep farmers who acknowledge the positive attributes that clover offers such as high palatability, improved live-weight gain and reduced fertiliser requirements. White clover is the predominant species present on sheep farms.

The Defra Farm Practices survey 2011 indicated that 76% of LFA grazing livestock farms (with temporary grass) had used some clover in their temporary grass and 36% reported that over 80% of their temporary grassland included clover. On lowland grazing farms 82% had used some clover in reseeds and 44% reported that at least 80% of their temporary grassland is sown with a clover mix.

Some farmers have taken up red clover primarily for high protein silage for cattle and autumn finishing of lambs. We estimate the proportion to be less than 10%. Red clover would be more prevalent in lowland areas and on mixed holdings. A small amount of lucerne is grown nationally providing opportunistic grazing for sheep on largely dairy farms.

A barrier to the uptake of red clover on sheep farms is in part the impact it can have on the fertility of the flock at tupping time. The oestrogenic effects of red clover are known to inhibit ovulation rates. Farms with limited grazing available for tupping are especially restricted.

7.1.6.3 Feed Supplements

Tannins are found naturally in varying quantities in some varieties of legume crops such as clovers, birdsfoot trefoil, lotus, sulla and sainfoin. The potential benefits of feeding tannins have included improved performance, improved tolerance of intestinal worm burdens and reduced worm numbers. The anthelmintic properties are of particular significance in organic systems. Section 4.2.2 highlights the potential for reduced N losses, however currently those few people who do grow these crops are using them as alternative methods of worm control. Problems associated with growing the crops and a lack of persistency and inconsistent yields are all barriers to using tannin rich species. Unless there is an additional benefit over and above reducing nitrogen excretion, and agronomic aspects of the crops improve, farmers are very unlikely to grow them.

Commercially extracted tannins have been used experimentally but there is no evidence of their use in commercially available sheep feeds/supplements.

7.1.6.4 Reducing Dietary Protein Content

At critical times of the year (late pregnancy and early lactation) the diets of many breeding ewes are sub-optimal in protein (both quantity and quality). This has a detrimental effect on milk production and therefore lamb growth rate. Supplementary compound feeds offered to sheep are not generally considered to be very high protein and are fed for a limited period limiting the options for reducing protein content.

High levels of digestible undegradable protein (DUP) post-lambing have a positive effect on reducing the number of worm eggs shed by ewes reducing the burden on growing lambs. Therefore reducing protein at these critical stages would hinder flock profitability. At less critical times of the year when sheep productivity is lower a diet lower in protein would be adequate, but in practice this is achieved on grazed grass. Incorporating forage legumes in grass swards reduces the need to supplement with high protein compound feeds but may provide a diet with protein levels above requirements of breeding ewes at certain times of the year. Focussing the use of higher protein pastures to more productive stock e.g. fast growing lambs could ensure better use of the crop.

8 Organic Production

Whilst efficient feed management is fundamental to organic farming, the objective is the quality rather than the quantity of production. The aim of organic livestock farming is to create an integrated, environmentally sustainable production system where the emphasis is on the effective use of the farm's own resources. Reliance on external inputs is minimised as far as possible.

As such, standard measures of efficiency commonly used in conventional systems of livestock production, although sometimes very good in organic systems, e.g. output/ha, feed conversion, yield, margin over concentrates etc are less applicable.

In addition it is usually inappropriate to consider on its own a single livestock enterprise on an organic farm as it is more important to optimise the whole farm system. For example integration of beef and sheep production is usually critical for parasite control and grassland management. It is the balance of the various enterprises: - livestock, arable rotations and soil fertility building on an organic farm which is the key to success.

An EC Regulation sets out the requirements for producing organic food and includes detailed rules for livestock production. The consequence of the Regulation is that a farmer must be registered with an approved control body, and undergo regular inspections to ensure that they meet strict organic standards.

The standards laid out by each certification body along with the record keeping requirements and regular inspections is essentially a 'code of best practice' which must be adhered to. It encompasses the whole production cycle including the husbandry, housing, welfare, feed inputs, traceability, soils and environment.

Organic ruminant livestock production relies largely on grassland with clover based pastures and shorter term leys in rotations designed also to provide winter feeds and fertility building cycles.

The recommendations given above for best practice and for improving feeding efficiency with conventional forage based livestock systems apply to organic production.

With limited bought in concentrate feeds and the restrictions on ingredients, best practice recommendations on the production, storage and mixing, and pest control are much less relevant. As fertilisers, herbicides, pesticides, feed additives and drugs are absent or severely restricted by derogation on organic farms, health hazards associated with animal feed production and management are of low risk.

9 Guidelines for 'Best Practice' in Livestock Feed Management

A review of best practice for reducing greenhouse gases from agriculture and land management (AC0206) identified increased livestock nutrient use efficiency as a key mitigation method, with the potential for reducing N_2O levels by 6% (120 kt CO_2e) in direct effects and a further 2-6% in secondary and indirect effects. It also identified a reduction of 3-10% in NH_3 production due to secondary and indirect effects. Specific activities identified were

- Improve the diets and feeding regimes of livestock to decrease wastage of feed nutrients (particularly protein and energy-yielding compounds) for productive purposes
- Avoid diets that contain N in excess of the dietary requirement of the animal
- Balance diets for energy and protein to increase the efficiency of N utilisation by the animal
- Target specific livestock nutrient requirements for correct genetic potential (i.e. breed), age, sex and production stage
- Adjust management regimes to allow more efficient production (e.g. 3x daily milking of dairy cows)

9.2 Guidelines of Best Practice in Livestock Feed Management for Farmers and Advisors and their Dissemination

Feed management extends from growing the crop for grazing, forage conservation and supplementation to feeding the diet and utilisation.

Decreasing methane emissions and nitrogen excretion may be primarily associated with the diet in relation to maintenance and production requirements, but achieving good herd/flock health and fertility, with a lower replacement rate may be equally important. All farms with breeding stock should be able to describe herd/flock performance in a manner that these parameters can be expressed.

For successful uptake, the recommendations made must be seen as practical and in line with improving profitability of the enterprise. A marked change of system will only be made for reasons of increased profitability, and it will be within this that emissions of methane and nitrous oxide will need consideration.

Feed management is intimately linked with achieving good fertility and maintaining good health. Poor feed management, especially around calving and lambing, will lead to suboptimal milk production over the whole lactation and for cows in particular, risk poorer fertility. Increased inefficiency will therefore be reflected in immediate and longer term parameters such as the number of lambs reared per ewe or the number of replacements required.

Effective knowledge transfer will remain important in clarifying how methane/N reductions improve dairy efficiency and are compatible with improved profitability.

9.2.1 Dairy Systems

All dairy farms should develop a clear plan of direction and take on board an approach to manage it. DairyCo has indicated that profitability can be high with both low cost and high output systems. It is the cost of production that differentiates the profitable herds from those less profitable, and costs must be in line with the output. Within any herd, maintaining a high level of production relative to maintenance, and maximum milking cows relative to dry cows will increase efficiency and decrease methane/litre of milk produced. Overall, it remains likely that both herd size and milk yield/cow will continue to increase in the UK.

Expectation from forage can be high with both approaches, and is an important contributor to controlling costs. Methane production will increase with dietary intake, and this will increase as the proportion of forage increases. Higher forage diets may therefore be criticised for higher methane emissions than higher concentrate diets. With good forage quality correctly supplemented a cost effective diet is achieved with a reduced methane production/litre of milk.

With grazing featuring in very many dairy systems, there is much scope for improved utilization of grass. Better access to grazing with appropriate paddock sizes allows better presentation of the grass. Monitoring grass growth so that grass is offered at the stage where it can contribute most effectively to milk production. Effective milk production using grass typically needs some supplementation, but constraining protein supply can often benefit nitrogen excretion.

Selection of grass varieties is done with several factors in mind. Varieties that have a higher sugar content, to some extent at the expense of protein, will be especially important on mainly grass farms. There is potential for better grass utilization in the rumen (less waste nitrogen), and for an improved crop for ensilage. High quality forage is typically sought. The desire to save on supplementary protein means that higher protein forage is necessary. Adopting strategies in silage making that result in reduced risk (from weather in particular) in achieving the quality of forage required; mainly give the diet greater consistency.

With less productive land/more traditional dairying this targeting of higher quality forage may not always be desirable or practical. With variable seasons it remains a challenge to produce enough forage, so that diet changes are minimized.

Both lucerne and clover (red and white) have the ability to provide high quality, high protein forages, with little or no nitrogen requirement. Where land is suitable these crops can make a good contribution to the diet. Clear management requirements need to be followed in relation to cutting/grazing and ensiling, if success is to be achieved.

Maize silage has the potential to decrease both methane production and nitrogen excretion, if mature crops can be grown. Earlier maturing/higher yielding varieties suitable for more marginal areas are offered each year. More varieties are also being trialled for use under plastic. If immature maize crops are harvested, not only will this detract from milking performance, it is unlikely to contribute to methane reduction. For a dairy farm to buy maize from an arable grower may be a preferred approach. Having a mature maize crop (with a good level of starch) to feed is more important than having a large proportion of maize in the diet. Farmers must be encouraged to allow adequate time after crops are ensiled, to achieve good grain utilization.

Cereal wholecrops have not been appraised for their ability to reduce methane, though it is likely to be beneficial. They are potentially useful in providing a lower protein forage leading to reduced nitrogen excretion. For success, the quality of the growing corn crop must be good, and with the greater risk of aerobic spoilage during storage, the management must be correct at all stages. Growing a proportion of the forage as maize/wholecrop will decrease the volume of grass silage to be made, generally decreasing the weather risk, and again allowing greater consistency of the diet.

Good quality diets enhance performance and decrease methane and nitrogen losses. Without information on the quality of forage, it is not possible to supplement effectively and accurately for the planned milk production. Routine analysis of all forages (including grazing) should be undertaken.

Precise and practical diet formulation is necessary, and needs to take into account the way the diet is managed. Nitrogen excretion is most easily controlled at this stage, by not supplying more protein (nitrogen) than necessary, and also ensuring that energy and protein are in balance. Decreasing protein supply will be gradual as producers gain confidence but monitoring milk urea nitrogen (MUN) as well as milking performance, will give a guide to the nitrogen balance of the diet.

Monitoring of feed and forage intake is poor on many farms and non existent on others. Knowing the intake achieved allows greater control in providing effective diets. It will also enable feed conversion to be calculated and improved, potentially to the benefit of methane emissions.

Matching compound feed or blends to the forage fed remains far from exact. Over or under feeding of supplement results, and nutrient supply is not balanced, When grazing, nitrogen in particular may be oversupplied.

Added fat has been shown to decrease methane production, but fat comes in various forms and must be handled with care. It is unlikely that the addition of the more popular ‘protected fats’ will decrease methane production or make little difference to nitrogen excretion. Combining a low amount of ‘unprotected’ fat in diets, largely from vegetable sources may have a small benefit in reducing methane, but this must not be at the expense of rumen function or milk fat percentage. For this reason the opportunities are very limited.

Heated and expelled/extruded linseed products (with 25 – 50% oil) are claimed to contribute to methane reduction, but their relatively high price means they need to be beneficial in other ways.

Additives including plant extracts, should not be seen as a route to reduced methane production, and neither is it clear that nitrogen excretion will be reduced. The ability of some additives to influence rumen flora, may mean that small benefits might be seen.

Improving feed utilisation can be achieved in several ways. Feed (forage) waste is all too common, and must be minimized and eliminated. It is a direct loss of feed as well as a contaminant to the diet. Utilisation of the diet will benefit from good and consistent presentation. This means critical judgements are required on a daily basis, together with clear longer term plans especially for forage availability. Diets have suffered from considerable inconsistency in the past, and all farms can seek ways to minimise this. Presentation of a finely chopped diet may have the potential to increase intake, but this may increase costs and potentially impair rumen health. Similarly the place for chopped straw in the diet must be reasoned carefully. Although a possible aid to diet presentation and FCE, others will find it a high cost and of limited benefit to overall feed utilisation.

Feed utilisation improves with good health in cows. Success in transition from dry to milking remains the single main event that determines how cows perform over the subsequent lactation. Improved management at this time pays dividends in short and long term performance. Too many herds have a high degree of lameness and locomotion scoring has raised the importance of this issue and all farms need a programme for improvement.

In general, milk production will become more efficient as milk production increases relative to maintenance. Higher starch:fibre levels in the diet will decrease methane production, but, input costs must relate sensibly to the output achieved, and a more costly diet in terms of methane may still be judged more profitable to produce.

A high FCE reflects lower methane emissions/litre. Although a potentially valuable guide to increasing the efficiency of production, it is important that other factors do not constrain intakes or performance. To obtain an accurate FCE, reliable feed details including forage dry matter content are necessary.

9.2.2 Beef Systems

Most beef systems tend to be adjusted to match the resources available, the interest and ability of the farmer, and the perceived market demand.

Broadly speaking beef production systems can be divided into three main categories –

- Rearing of cattle that are produced as a by product of the dairy herd
- Rearing of suckled calves
- Finishing systems

9.2.2.1 Rearing Cattle from the Dairy Herd

Dairy bred purebred bull calves and crossbred male and female calves are reared artificially on reconstituted milk substitute to weaning at about 6 weeks of age. There is need for better growth rates in the milk feeding stage by more use of ad lib feeding and better intakes of starter feeds.

Once weaned the majority of cattle are fed diets of forage and concentrates until they are turned out onto grass at 6-8 months of age depending on month of birth. During the housed, post-weaning period there is a need to feed better quality forage by harvesting grass before 50% ear emergence and then adding straw to the ration to delay progress through the rumen and improve digestion. An increase in the number of beef units that include maize in rearing rations would enhance beef cattle performance but this is expensive to produce (£400/ha on seed, fertiliser and sprays and another £175/ha on harvesting, carting and clamping). Good yields are needed to justify costs but the outlay per tonne for a high quality product is reasonable when yields are high – e.g. 40 tonnes/ha. Care is always needed to prevent certain types of animals from becoming too fat when maize is included in the ration.

9.2.2.2 Rearing of Suckler Bred Cattle

There is need for producers to focus on calving heifers at an earlier age (two years) in order to reduce the number of unproductive stock on the farm. The longevity of breeding cows needs to be improved by genetics and better management. Better growth rates in suckled calves must be encouraged as FCE is highest in the relatively early stages of life. Creep feeding can generally lead to increases in growth rate of up to 30% but it is estimated that only about 50% of suckled calves in England are supplemented during the suckling phase. In the post-weaning phase there is a need for a better choice of feed ingredients e.g. feeding fermentable carbohydrate in the form of molasses and rolled cereals when offering feeds with rapidly available nitrogen (e.g. urea).

9.2.2.3 Finishing Systems

About 30% of clean cattle slaughtered in Britain are over 27 months of age. The feed conversion efficiency of 30 month old cattle is likely to be about 20:1. Reducing the age at slaughter would improve the carbon footprint of the beef industry and for most producer businesses increase profitability.

Cattle tend to be finished either at grass during the summer or indoors during the winter on diets of forage and concentrates. Grass is under utilised and it is estimated that 50% of what is grown is wasted. Cattle growth rates at grass are usually disappointing – 15-20% below potential, due to poor control of grass height, poor weather or poor sward composition. Grazing systems often do not permit grass to be managed in a way that prevents it losing digestibility as the season progresses and there is a poor understanding of the way that grass quality and feed value deteriorates. Better grazing management to maintain grass height can increase cattle growth rates by at least 20%. Turnout of cattle onto grass is often delayed which means that high quality forage is not being utilised early in the season. In order to make the best use of spring grazing, in certain circumstances producers should be prepared to turnout part of the herd rather than wait until conditions permit the whole herd to be turned out. Continued emphasis in KT on grazing management especially with regard to benefits of using tools (e.g. plate meter) to assess when cattle should be moved on to other pastures or supplemented on the existing area is very important if performance of cattle on grass is to be improved. Strategic use of high energy supplementary feeds to finishing cattle would enhance growth rates, reduce time to slaughter and often eliminate need to house for another winter. There is scope for more use of clover; although it is now included in the majority of new leys. Dry matter intakes can be 20-30% more on grass/white clover swards compared with grass only swards.

There is a need to adopt strategies in silage making that produce material that meets the requirements of the class of animal being fed. Efficiency of production would be improved in finishing systems by an increased use of crimped maize. Work by Harper Adams (2010) showed that compared with barley, crimped maize increased cattle growth rates from 1.34 kg/day to 1.51 kg/day and improved feed conversion ratio from 6.59 to 4.98.

There is a need to reduce feed wastage and storage. On many farms baled silage is often left unprotected and damaged, and waste bales are common. Feed presentation is also key and less feed could be wasted if more attention was paid to how the feed is presented to the animals to minimize forage being pulled into the bedding and contaminated.

9.2.3 Sheep Systems

EBLEX figures have shown that the top third farms in terms of financial performance are those that keep their costs down, with low concentrate inputs, high number of lambs reared and higher carcase weights. Higher carcase weight, reducing time to slaughter and higher number of lambs reared will increase efficiency and reduce methane emissions/kg of meat produced.

With the vast majority of nutritional requirements derived from grazed grass and forage crops emphasis for guidelines of best practice for mitigating GHG must focus on improved utilisation of these crops. Grassland management can be improved through monitoring grass growth, the use of a sward sticks and rotational grazing.

Grassland improvement (by slot seeding) can improve DLWG and reduce emissions. Selection of grass varieties is very important. Many commercial grass mixes now include high-sugar grasses which will increase DLWG and reduce methane. Most sheep farmers would use a grass mix with white clover to improve palatability, improve DLWG and reduce fertiliser requirements. Chicory is occasionally planted to increase DLWG and helps to reduce worm burdens. Red clover is planted to make high protein silage and to finish lambs in the autumn.

There is a need to adopt strategies in silage making that result in reduced risk (from weather in particular) in achieving the quality of forage required. There is scope for more farmers to get forage correctly analysed and to have winter feed rations properly formulated based on forage quality to meet the nutritional requirements of their sheep. Feeding a high quality ration and the use of co-products can reduce emissions. Low carbon sources of protein should be considered more frequently e.g. rapeseed meal rather than soya bean meal.

More efficient ways of presenting forage to ewes need to be developed to reduce feed wastage. A better appreciation of the cost of production of conserved forages would also help to focus attention on effective feed storage.

10 Dissemination of Guidelines of Best Practice

The following list of best practice guidelines has been developed in collaboration with stakeholders, DairyCo, Eblex and HCC. It is intended for wider dissemination to the livestock industry as a concise summary of this report.

Best Practice Guidelines for Cattle and Sheep Feeding

Forage Supply

- Good soil structure, soil fertility and liming are fundamental to maximising crop growth. Soil test regularly every 3-5 years
- Manage farm produced manures to retain nutrients. Maximise available nutrient supply by spreading the right amount at the right time when the crop can utilise it.
- Take account of soil nutrient supply and that from applied manures to establish fertiliser requirements using PLANET or Tried & Tested.
- Plan for sufficient forage to provide grazing and conserved forage to meet livestock requirements (e.g. guidelines from Eblex, DairyCo, HCC and Tried & Tested).

Grassland

- Control invasive weeds such as thistles, docks and nettles
- Encourage white clover to be 30% of DM of sward
- Re-seed when necessary using mixtures based on appropriate varieties selected from 'Recommended Grass and Clover Lists'
- Consider place for lucerne or red clover, as drought tolerant and high protein yields
- Assess grass growth, supply and demand regularly and match to stock needs – measure sward heights to ensure targets are met
- Develop better access to grazing e.g. lanes, multiple gates, so permitting more timely grazing

Grass Silage

- Target quality / cutting date for stock being fed, e.g. growing / lactating cattle vs dry cows
- Adopt the well established guidelines to reduce in field and in silo losses, such as those produced by Eblex, HCC and DairyCo.
- Consider the use of effective additives to improve fermentation, aerobic stability and dry matter intakes
- Wrap big bales well (enough layers of wrap (4-6) to ensure a good preservation)
- Store big bales carefully – on hard standing and aim to minimise bale damage by vermin or machinery.

Arable and Forage Crops - Maize, Whole Crop Silages, Root Crops and other Brassicas

- Recommended where they suit the farm, feeding system and crop rotation - and where economic yields can be achieved of appropriate quality
- Compare dry matter yields of different crops and ease of feeding/in situ grazing of root crops and other brassicas.
- If only an immature maize crop is possible, consider the potential of a cereal wholecrop.

Supplementation

- Evaluate nutrient supply from grazing or conserved forage in relation to required performance and nutrient intake and then choose amount and type of most effective supplementary feeds
- In part this involves an accurate assessment of forage quality and intakes
- Seek professional help for accurate ration formulation

Nutrient Requirements

- Choose and target requirements for breed, genetic potential, sex, production system and end product quality, e.g. high requirements for DLWG for finishing stock and lower requirements for store or dry stock
- For breeding stock take account of changes in body condition, fertility and health needs as well as milk/meat production, e.g. stage of lactation for dairy cows or weeks in lamb for ewes
- Seek professional guidance if in doubt

Nutrient Supply

- Plan forage provision and assess conserved forage stocks throughout feeding period
- Get winter forages analysed as a priority
- Use the latest laboratory analyses and tables of feed composition to accurately describe the nutrient supply and balance of available feeds
- Use the latest ration formulation software or seek professional help
- Maximise rumen microbial production by optimising balance between fermentable energy and rumen degradable protein in a uniform daily diet. In particular, investigate the opportunity to reduce protein in dairy and beef finishing diets
- Some dietary additives may have small benefits in decreasing methane or improving nitrogen utilization, but their inclusion must be in line with good milk or meat production

Feed Management

- Remove forage from clamps and present feed to animals in such a way as to minimise feed wastage
- Ensure sufficient trough space for all animals
- Ensure daily ration is fresh, palatable, and where appropriate, correctly mixed and chopped
- Where diet is fed ad libitum remove any uneaten feed daily
- Feed a consistent diet to maintain a stable rumen fermentation
- Give equal management attention to dry and lactating stock and youngstock
- Diet changes are inevitable, manage carefully at critical times by introducing new feeds gradually over a few days
- Take advantage of high growth potential of young animals. Review the age that replacement stock come in to dairy and suckler herds, and the age of finishing cattle
- Adopt good feed hygiene, particularly avoiding contamination
- Maintain a clean and adequate water supply

Planning, Monitoring. Recording, Reviewing.

- Farms should have a clear plan for profitable production

- Stock should be managed for optimum health at all times, working to a veterinary farm health plan
- Monitoring is essential for each enterprise and feeding system on the farm. Measuring weight gain will allow diets to be reformulated to help reach growth rate targets
- This should take place at several levels including monitoring feed supply and quality, animal performance (growth rate, milk yield etc), and key indicators of efficiency such as intake, dung quality, blood metabolites and product quality (milk and meat composition)

Information and Promotion

- Encourage uptake of existing best practice, and promote new development / research
- Demonstrating how improved feeding efficiency is compatible with both improved profitability and reduced greenhouse gas emissions

11 Conclusions and Recommendations

There is scope to improve feeding management on most livestock farms. This is the single most important factor that could help reduce the emissions of methane and nitrous oxide from livestock production.

Livestock farmers primarily aim to have a profitable enterprise, and do not have reduction of methane and nitrous oxide high on their list of priorities. But, improving feeding management is a key route to increased performance and profitability.

Techniques that improve feeding management are being adopted largely by dairy farmers and to a lesser extent by beef and sheep farmers. To a large degree this is because milk production is more closely monitored but monitoring is being applied on more progressive beef and sheep farms to good effect.

Improvement in forage production and management is known to be at the core of improved ruminant production. Feeding diets based on good quality forages to achieve enhanced milk and meat production, will be more important than relatively small manipulations to diets to achieve altered rumen fermentation.

There is greater appreciation of the need to decrease nitrogen excretion than methane emissions, partly as there is a more tangible cost saving. There has been gradual reduction in dietary protein, especially on dairy farms, though there is correctly reluctance to undersupply.

The use of higher starch forages and the present substantial rise in protein price has renewed interest in protein contribution from forages, especially legumes. Improved utilization of dietary nitrogen through better energy substrates is receiving increased attention.

Longer term feeding management that influences health and fertility of breeding stock is as important as immediate results – e.g. improved milk yield. If replacement rates can be reduced and longevity improved, then systems become more efficient and emissions decline per unit of output.

Recommendations

There is a need for increased adoption of current recommendations to improve feeding management on dairy, beef and sheep farms. This must be based around improving profitability, with the added benefit of reduced greenhouse gases.

Increasing human population will dictate that ruminants must use forage to a greater extent than at present, and more efficiently.

Improving all aspects of fresh and conserved forage production, to reduce risk and increase consistency of the product and to manage forage well, reducing waste and ensuring effective contribution to the diet.

We must encourage a continuing reduction in nitrogen use, and further the use of forage protein. In all systems we must look to improve understanding relating to efficient nitrogen capture.

To monitor developments relating to dietary additives influencing rumen activity, and be ready to take up desirable products where compatible with profitable production.

Consider how the monitoring of performance and improvements to grazing management can be further promoted, in more extensive beef and sheep systems.

Livestock farms should follow the ‘Feeding Management - Best Practice Guidelines’.

12 Projects Reviewed for this Report

Project number	Title
AC0219	Methane emissions by individual dairy cows under commercial conditions
AC0290	Ruminant nutrition regimes to reduce methane and nitrogen emissions
CC0201	To provide practical advice on measures of dietary management to reduce methane emissions from ruminants
CC0211	Literature review of dietary manipulation to reduce methane emissions
CC0223	Methane/novel feed additives
CC0239	Development of strategies to provide cost effective means for reducing methane emissions from dairy cows
CC0270	The implications of farm-scale mitigation measures for long-term national methane emissions.
CSA4320	Novel feed additives for decreasing methane emissions from ruminants
LK0615	Impact of novel forage characteristics on productive output and efficiency
LK0638	High sugar ryegrass for improved production efficiency of ruminant livestock and reduced environmental pollution
LK0954	The incorporation of important traits underlying sustainable development of the oat crop through combining 'conventional' phenotypic selection with molecular marker technologies (‘OatLink’)
LS3640	Reducing losses of nitrogen to the environment with diets based on red cover silage
LS3653	The potential of non-toxic tannins to improve the utilisation of nitrogen compounds in grass silage for ruminants
WQ0133	A review of the energy, protein and phosphorus requirements of beef cattle and sheep.
LS3656	Optimising nutrition to increase carbon and nitrogen capture in ruminant products

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