ADAS

The Environmental Impacts of Pasture Improvement

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Submitted to:

Dr E. Genever
AHDB

Prepared by:

Kate Phillips
ADAS UK Ltd
ADAS Drayton
Alcester Rd
Stratford-upon-Avon
Warwickshire
CV37 9RQ

The ADAS team involved in this work included:

Owen Davies

Mair Morgan

Kate Phillips

Rachel Thorman

Sarah Wynn

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1.0 Introduction

Well managed grassland provides a cost-effective and high quality feed for cattle and sheep, and given the high cost of supplementary feeds, producers need to make maximum use of grazed grass to improve efficiency. The use of modern varieties of grass and clover and the benefits of reseeding in terms of improved animal performance have been well demonstrated, but the impact of reseeding on greenhouse gas emissions has not been well documented.

Agriculture accounts for 67% of the UK nitrous oxide (N_2O) emissions and 37% of methane (CH_4) emissions (86% from enteric fermentation in ruminants). Emissions of N_2O and CH_4 are particularly important, as their global warming potentials are 310 and 21 times greater than CO_2 respectively (IPCC, 2007).

Disturbance of permanent pasture by ploughing and other cultivations causes mineralisation of soil carbon and nitrogen and release of CO_2 and N_2O. N_2O is also released when the old sward decomposes after incorporation into the soil. Liming generates CO_2 and fertiliser (including manure) generates ammonia and N_2O, hence judicious use of chemical fertiliser and manures in line with recommendations in RB209 (Defra, 2003) will help to minimise emissions. Field operations, including ploughing, harrowing, etc., use fuel and hence generate CO_2.

However the emissions generated by reseeding are likely to be offset by significant improvements in animal performance (higher live-weight gain and shorter time to slaughter) when compared to animal weight gain on permanent pasture. Introduction of improved varieties of grass, like high sugar grasses, and clover will improve the efficiency of digestion, help to reduce nitrogen excretion and help to reduce CH_4 emissions per kg of meat produced (Lovett *et al.,* 2004 and 2006).

This work aims to:

1. Review literature on the advantages of reseeding on animal performance and forage yield that can be realised at a farm level, especially in relation to different species and mixtures.

2. Calculate the emissions generated from the various forms of reseeding in terms of energy used by machinery and land disturbance.

3. Produce information on the benefits in relation to GHG emissions from improved animal performance as a result of better quality pasture. The calculations will use permanent pasture as the control. The calculations will include information on predicted live-weight gain and days on farm for both lambs and finishing cattle.

2.0 Literature Review - The Environmental Impacts of Pasture Improvement

The three main greenhouse gases (GHGs) are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). GHG emissions from agriculture account for around 7% of total UK emissions (Defra 2008). In terms of agriculture N_2O and CH_4 are the most significant and have a global warming potential 310 and 21 times greater than CO_2 respectively. Hopkins & Lobley (2009) stated that total UK agricultural GHG emissions have decreased by 17% since 1990, and methane emissions have decreased by 52% through a combination of reduced livestock numbers and more efficient feeding. Pasture improvement through the use of new forage varieties with improved energy and protein characteristics, coupled with efficient utilisation through animals bred with high genetic potential for meat and milk production, is one practical and effective way of realising GHG reductions.

Newly sown grassland swards can deteriorate after just a few years, through ingress of weeds, soil compaction and poaching. Within three years, the proportion of sown grasses in a sward can drop by 30%, and by 10 years, sown species have virtually halved (Hopkins, 2000). When weeds become established in a sward, grass growth can be impaired and the overall digestibility and palatability is reduced. Many suggest that permanent grass leys should be considered for reseeding every 8-10 years.

2.1 Benefits of reseeding on ruminant performance

2.1.1 Reseeding grasslands

Pasture improvement is usually carried out when swards have been damaged through excessive poaching, when sown species have largely been replaced by weed grasses, or to introduce improved varieties of grass and clover. If weed species contribute more than 10% of sward dry matter, production is compromised. As an example, creeping thistle (*Cirsium arvense*) is a common weed of grazed pastures and a 10% infestation of thistles in a sward will reduce grass production by 1.1 tDM/ha (Connabeer, 2009). At 40% infestation, the loss rises to 4.4 tDM/ha. IGER research in the late 1990's showed that cattle and sheep tend to leave 30cm around each thistle plant reducing overall sward utilisation. Mechanical topping reduces seed production of creeping thistle but not root spread (Connabeer, 2009). Weed species are able to dominate over sown species under conditions of low pH, low phosphate or potash status, over or under grazing, or compaction, and their presence brings losses in terms of sward digestibility, soluble carbohydrate (sugar) content, metabolisable energy and dry matter yield.

Eblex (2008a) ('Improving pasture for better returns') states that new varieties can boost production from permanent pasture over five years by £2,000/ha after typical reseeding costs, and reseeding a five year old ley with improved varieties can produce an extra £1,235/ha of forage in the first year, 33% more yield than a typical five year old ley. Over the next four years, yields will be an average of 10% higher than the original sward.

Other reported advantages include higher digestibility, improved growth in early spring and late autumn, better quality silage and increased animal performance - higher milk yield, milk protein content and live-weight gain.

Costs

Records from an upland farm in Powys showed that reseeding old grassland with a mixed ley of ryegrasses, chicory and clover dramatically improved live-weight gain and improved subsequent beef returns by more than £100 a head (FWi 2009). and British Seed Houses (2008) calculated that reseeding costs at between £309 and £469/ha (Table 1) and highlighted that reseeding worn out grazing to best practice standards costs an extra £32/ha a year but yields a 7:1 return on investment. Reseeding to best practice costs £94/ha for each year of a 5 year ley.

Table 1 Typical reseeding costs

	Standard	Best practice
Seed (£/ha)	£86	£111
Fertiliser (£/ha)	£99	£124
Chemicals (£/ha)	£25	£62
Labour and machinery (£/ha)	£99	£148
Total establishment cost (£/ha a year)	£309	£469
Extra cost of best practice (£/ha a year)		£32

(Monsanto and British Seed Houses 2008)

Yields

Hopkins (2000) highlighted how basal yields, with no added fertiliser N, vary greatly depending on site conditions. Under a monthly cutting regime in the UK, the potential annual herbage production from unfertilised sown perennial ryegrass may exceed 6t DM/ha, but less than 1t DM/ha may be achieved under poor grass growing conditions.

The Grassland Management ‘Practice into Profit’ (GMPIP) report 99 (DARD, 1999) also highlights the variability of grass yield, due to numerous limiting factors, and quotes that maximum production on commercial farms seldom exceeds 10-13 tDM/ha, but that some hybrid ryegrass based swards can support high yields of herbage (over 16 tDM/ha in 4 cuts) as well as grazings into late summer and autumn. Growth plots at Greenmount, Ireland produced 11.7tDM/ha in 1999 and 12.4t DM/ha in 1998 (GMPIP report 99).

The Eblex booklet ‘Improving pasture for better returns’ quoted that well managed, correctly fertilised pasture containing productive grasses and clovers can produce 10-11 tDM/ha under grazing or 13-14tDM/ha when cut for silage.

Numerous studies have shown permanent pasture to be less productive than reseeded pasture, particularly with high fertiliser application. O'Donovan *et al* (2009) quoted that research at Moorpark has shown old permanent pasture to be on average 3t DM/ha lower in DM production compared to young perennial ryegrass swards and 25% lower in nutrient responsiveness. Fitzgerald (2008) quoted that reseeded silage swards give up to 20% higher yield than old permanent pastures in the first cut, but no yield advantage in the second cut.

Research at Moorpark has shown that well established, well managed new swards will deliver an average yield increase of 2.5 t DM/ha, saving on concentrates, allowing increased stocking rates or releasing land for other uses. Moreover the yield can increase even more in the second year.

Hopkins *et al* (1990) had a multi site trial to compare herbage production of permanent swards with *Lolium perenne* reseeded swards. This showed that responses to reseeding were considerable in the first harvest year, with a 30-40% increase in DM yield at the same fertiliser treatment. Another study by Hopkins *et al* (1992) on nine sites that were recorded for 7 years and received 300 kg N/ha/year found a mean increase in DM production of 6% from the reseeded swards, compared with permanent swards, during the 6 year period following the first harvest year.

Eblex stated (in 'Improving Pasture for Better Returns') that commercial trials using an overseeding machine, which harrows and sows seed, showed up to 40% more grass yield in the following year. Overseeding may need repeating or a full reseed may just be delayed, however, at around £175-200/ha it is cheaper than a full reseed using a plough. Slit aeration boosted grass production by 0.8t/ha.

Direct drilling is more expensive at £275-300/ha. Red clover research at Bronydd Mawr found that direct drilling gave 85% better establishment which translated into 46% higher annual yield than the control. Yields of 8.4 t/ha/annum were attained (Fothergill, 2003).

Species, variety and fertiliser application rate greatly affects yield. Herbage productivity is usually 12-15 tDM/ha from perennial ryegrass swards receiving maximum rates of fertiliser N on good grass growing sites. Hopkins (2000) quoted that although 25 tDM/ha could be produced from perennial ryegrass in the best grass-growing areas of Britain, in practice annual herbage production from newly sown perennial ryegrass swards receiving 250kg fertiliser N/ha has been shown to vary between 10 and 18t/ha.

Perennial ryegrasses give a good return for money spent on fertiliser. From one kilo of nitrogen, ryegrass can deliver 20-25 kgDM, while less productive grasses achieve only half that or even less. Hopkins (2000) quoted that fertiliser N rates on leys in England and Wales were c. 200 kgN/ha, whereas 40% of over 20 year old swards receive less than 50 kgN/ha. However average rates have decreased to 55 kgN/ha in 2008 (British Survey of Fertiliser Practice 2008).

Hopkins *et al* (1995) compared the productivity and nitrogen uptake of ageing sown leys (5-12 years old) with newly sown diploid perennial ryegrass at a range of N fertiliser rates (0, 125, 250, 375, and 500 kg N/ha) and with a diploid/tetraploid mixture of perennial ryegrasses. They found that mean annual DM yields at 500 kgN/ha were 12.3 t/ha for ageing swards and 13.2 t/ha for newly sown swards. They found differences between sites in the relative productivity of sward types, on some sites, particularly at low rates of N fertiliser, ageing leys gave greater production than newly sown swards.

Daly & Mackenzie (1984) carried out a similar study comparing permanent pasture and a reseeded swards at different nitrogen levels (0, 180, 360, 500 kg N/ha year). Permanent pasture responded to N rates up to 360 kgN/ha, and the resown plots only out-yielded the permanent pasture above this level. D values increased overall by 4 units in the permanent pasture between 0 and 360 kgN/ha/year, but did not increase in the resown plots. A 4 year liveweight production trial (at 360 kgN/ha/year) gave virtually no difference in lamb production between the permanent pasture and resown plots.

Clover

One reason for reseeding is to introduce clover into the sward and overseeding can be used to achieve this. Through nitrogen fixation clover can replace a large proportion of the artificial nitrogen used. Clovers produce a high protein and palatable crop, which often improves animal performance. Hopkins *et al* (1995) quoted typical production values for grass-white clover swards of 5-10 tDM/ha. They highlighted that the benefits of clover based pasture cannot be assessed in terms of DM productivity alone, it also has higher nutritive value. Advantages of using white clover include nitrogen fixation, higher protein, higher digestibility and mineral content as well as higher DM intake.

White clover can fix up to 280 kgN/ha, although more typically 150 kgN/ha. Hopkins (2000) quoted that production levels from grass/white clover swards without inputs of N fertiliser are similar to those of grass swards receiving up to 200 kgN/ha. Research at Bronydd Mawr has shown that good white clover/grass swards will fix about 150 kgN/ha in the uplands (Fothergill, 2003).

Moore & Moore (2006) describe clover as the nitrogen for the future. They quote that the use of clover based swards is compatible with maintaining a stock carrying capacity equivalent to grass swards receiving up to 200kg N/ha/yr. Clover will increase animal intake and can increase live-weight gain.

Incorporating clover into swards can reduce fertiliser use. White clover-based systems are capable of fixing the equivalent of 1 kgN/ha each day between May and September (McCalman, 2008). Clover can increase yields up to 15% depending on clover content and N inputs. The ABER Clover Management Guide advises that maintaining an optimum dry matter balance of 30% white clover to 70% grass is the key to grass/clover sward management.

Ribeiro Filho *et al* (2003) found that the nutritional advantage of introducing white clover into swards of perennial ryegrass was related to an increase in herbage intake and not to any improvement in the nutritive value of the sward.

Clover swards lose quality more slowly than grass, dropping about two units of digestible value (D value) each week and according to “Clover, Nitrogen for the future” (Mackey *et al,* 2006), this contributes to greater herbage intake and:

• up to 10% higher live-weight gain in cattle;

• 20% more milk from dairy cows;

• 25% higher live-weight gain in lambs.

Including clover also improves soil structure. The root structure of white clover can help to overcome problems of soil compaction and improve general movement of nutrients (ABER Clover Management Guide). Other sward constituents that improve soil nutrients are species such as chicory, bird's foot trefoil and plantain. They may also help to alleviate certain health problems and micronutrient deficiencies thus boosting productivity in grazing animals.

It has been suggested that on good clover leys, only one application of N is needed for spring grass. In fact to maintain clover content, N application should be limited to one 50 kg/ha application each spring.

To optimise yields from reseeds, other limiting factors need to be considered, particularly soil pH, P and K. In a review of five experiments, Skinner (1997) showed that mean herbage DM increased from about 6 t/ha at pH 4.5 to about 9 t/ha at pH 6.0-6.5. Optimum soil pH for grass and clover growth is between 6 and 6.5 and if soil pH is between 5 and 5.5, swards will yield 9% less than at pH 6-6.5. O'Donovan *et al* (2009) stated that the ideal pH for the establishment of a ryegrass sward is 6.2 to 6.7. Phosphate and potash recommendations are given in Table 2. Specific fertiliser recommendations can be found in RB209 (Defra 2003) and examples are given in **Error! Reference source not found.**.

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Table 2 Phosphate and Potash Recommendations for Reseeding (kg/ha)

Soil Index	0	1	2	3	Over 3
Phosphate	120	80	50	30	0
Potash	120	80	50	0	0

(RB209)

Table 3 Fertiliser requirements for maintaining a ryegrass/white clover sward (kg/ha)

Index	0	1	2	3
Grazing rate of nutrient/annum (kg/ha)				
P	60	40	20	nil
K	60	30	nil	nil
Conservation rate of nutrient/cut (kg/ha)				
P	100	80	50	40
K	120	100	60	30

Recent advances in grass breeding have led to the development of perennial ryegrass varieties that express high levels of water-soluble carbohydrates ('sugars'). The higher energy content of these grasses provides a better nutrient balance with the proteins in grass, allowing the animal to make more efficient use of plant nitrogen (Moorby, 2004).

2.1.2 Animal performance

Reseeding with improved varieties, introducing clover and reducing weeds all contribute to improved animal performance and reduced time to finish beef cattle and lambs.

Generally in the UK, finished lamb has a relatively short production cycle. Lambs are generally finished between 10 to 24 weeks of age off grass. Lamb growth rates can vary between 50 and 350 g/day (Table 4). Research at Bronydd Mawr found lambs to have growth rates between 209 and 234 g/day before weaning and 54-103 g/day post weaning (Davies, 2003). Earlier research showed the difference in DLWG on common grazing and inbye was 132 and 177g/day respectively.

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Table 4 Daily lamb growth rate (g/day) on grass/white clover and N-fertilized grass (200kg N/ha) pastures on upland and lowland sites (Davies & Munro 1988)

	Pre-weaning		Post weaning	
	Grass/clover	Grass	Grass/clover	Grass
Upland	201	186	112	86
Lowland	232	212	140	81

Good growth rates are often not achieved due to unsuitable grazing and lamb genetics. Davies *et al* (1998) found that lamb production from perennial ryegrass varieties differed by up to 20% and a similar level of difference was found in different varieties of white clover. Mackey *et a*l (2006) stated that in a three year investigation, Lleyn and Lleyn cross Texel lambs, gained 266g/day and averaged 21.6kg at slaughter on clover.

Weaned lambs sometimes graze red clover aftermath. Work from IGER has shown that lambs grazed on red clover produce 25% higher DLWG than lambs grazed on perennial ryegrass swards. This reduced time to finishing from 49 to 40 days (Mackey *et al*, 2006)

Grass produced beef in the UK is generally finished at 18-24 months of age. This is dependant on breed of animal and quality of forage. Growth rates of around 1 kg/day can be achieved under very good grazing conditions. Large-framed cattle turned out at 250-300kg on to good leys with a long grazing season can gain 200kg whilst small framed cattle on marginal grazing may gain just half this weight in the same period (Eblex, 2008b).

Table 5 Growth rate performance targets for grass beef

	kg/day
Birth-wean (suckled)	1.0 - 1.2
Wean-12months (dairy bred)	0.75 - 0.85
Winter (pre summer grazing)	0.65 - 0.75
Summer grazing	0.80 - 1.0
Finishing period	1.2 - 1.4

(Eblex - More profitable beef from grass)

A technical note on www.ruralni.gov.uk (2009) quoted that weight gains exceeding 1 kg/day can be achieved from good grass during April and May in store beef cattle. The authors also highlight that good performance during this part of the grazing season is crucial if the target weight gain of 200 kg per animal is to be achieved by housing.

Research at Bronydd Mawr has shown that growth of steers on Molinia dominant rough grazing can be of an acceptable level (around 0.8 kg/day) when steers on improved pasture had an average DLWG of 1.24kg/day during the grazing period (Davies, 2003). Earlier studies at Bronydd Mawr with yearling steers (325 kg live-weight at turnout) showed average DLWG (from May to October) of 0.94 and 0.76 kg on pasture grazed at 8-10 and 4-5cm height respectively (Davies).

Drennan & McGee (2008) found that increasing the level of fertiliser N application increased suckler cow live-weight gain at pasture by 24 kg, improved body condition score (BCS) by 0.36 units and prolonged the grazing season by 7 days. Similarly at a low level of fertiliser N, reducing the stocking rate (0.1 ha/cow) increased cow live-weight gain at pasture by 21 kg, improved BCS gain by 0.23 units and prolonged the grazing season by 7 days. At the low stocking rate all the winter silage requirements could be provided in one, as opposed to two harvests, thereby reducing the conservation area. However, delayed harvesting of silage resulted in lower silage digestibility and reduced calf performance in winter.

Records from an upland farm in Powys showed that live-weight gains increased by 100 kg/head as a result of a proactive grassland reseeding regime. A group of 90 store cattle were split and put on either old pasture or managed pasture (15% reseeded each year). The cattle on the managed pasture achieved an average live-weight gain of 150 -160 kg in comparison with the animals on the older sward that had only gained an average of 50 - 60kg. All the animals achieved the same conformation class at slaughter, but the group that had been grazed on recently reseeded land achieved a higher killing out percentage and the carcasses were also 40 kg heavier (www.fwi.co.uk 2009).

Hopkins (2000) quoted that daily gains of up to 1.25 kg in cattle and 300 g in lambs are theoretically achievable with high quality pasture. The ADAS Forage Manual (2003) also states that in good growing conditions on clover rich swards growth rates of 300 g/day for finishing twin lambs at stocking rates of 14 ewes + twin lambs per ha can be achieved. Finishing cattle can achieve weight gains of up to 1.0 kg/day at a stocking rate of 3.3 beasts/ha. These performance figures give outputs per ha equivalent to those that could be expected from a grass-only sward receiving between 150 to 200 kg/ha of nitrogen. High clover diets can increase live-weight gain by 0.2kg/day in beef cattle.

Hopkins & Lobley (2009) highlighted the fact that a shorter period from birth to slaughter can help reduce GHG emissions (particularly of enteric methane) per kg of meat produced, hence improved quality of grassland has its part to play in mitigation of GHG emissions.

Many new grass varieties have the bonus of high sugar that helps to improve animal performance by better nitrogen utilisation and hence reduced nitrate losses. Research has shown improvements of 18-35% in live-weight gain from fattening beef animals on grass with high sugar compared to those on grass with normal sugar levels. With lambs up to 20% higher live weight gain is achieved as well as 20% increase in stocking rates with HSG (Hanton, 2007).

Extra energy is provided to beef cattle by feeding HSG varieties, grass protein is used more efficiently and animal performance is enhanced. Dry matter intake of animals fed HSG increased by around 25% compared with those fed the control variety. Greater intakes were achieved due to the HSG variety being highly palatable. Some of the latest HSG varieties produced by plant breeders at IGER have grazing D values of over 4 units greater than the recommended varieties in the 80’s (Forage Matters 2007). The same article quoted that a one unit increase in D-value can increase animal performance by 5%.

Research at IGER found that animals grazing HSG recorded average daily live-weight gains of 1.0 kg/head per day, which was 20% higher than the gain of cattle on the control variety (Fennema, 0.78 kg/head per day), and consequently slaughter weights were reached quicker (BSH & IGER High Sugar Grass booklet).

Pendergrast (2008) quoted that an extra unit of D value will increase daily liveweight gain in fattening cattle by around 40 g/day and in fattening lambs by around 20 g/day. It is possible to increase D value by around 10 points by establishing a new sward.

2.2 Release of greenhouse gases

Between 1999 and 2005 atmospheric CH_4 concentrations levelled off while the world population of ruminants increased at an accelerated rate. Prior to 1999, the world ruminant population was increasing at the rate of 9.15 million head/year but since 1999 it has increased to 16.96 million head/year. It has been suggested that the reason for the levelling off in ruminant CH_4 emissions might be improvements in animal husbandry and feeding in the developed world (www-naweb.iaea.org).

Defra (2009) quote a fall in CH_4 emissions over the last 10 years (12%), and state that this is due to the general reduction in livestock numbers over this period. Hopkins & Lobley (2009) quoted that CH_4 emissions have decreased by 52 % since 1990, through a combination of reduced livestock numbers and more efficient feeding.

Lovett *et al* (2006) suggest that strategies exist to facilitate a reduction in CH_4 emissions. For example pasture management practices that promote increased dry matter (DM) intake, while maximising the nutritive value of the sward, could increase productivity, resulting in a decrease in CH_4 output per unit of animal product. They also found that the cultivar 'Kells' produced less CH_4 than 'Yatsyn I' (*in vitro*). The results suggest that differences exist between cultivars in how organic matter (OM) is partitioned following microbial fermentation. They suggest that in the course of time it may be possible to exploit these differences through cultivar selection and plant breeding programmes, and thereby reduce enteric CH_4 emissions within pastoral production systems. This is now being investigated in a Defra Link project at IBERS.

Clover (2007) referred to research at IGER Aberystwyth (now IBERS) on how to reduce CH_4 produced from a cow. Normally, the efficiency of a cow's stomach is very low with around 20% digested. Using a mixture which includes Birdsfoot trefoil (*Lotus corniculates)* in a planted mix of white clover and perennial ryegrass improved the efficiency of the cow's stomach at processing the nitrogen content of grass to around 34%.

IGER found that cows offered Aber high sugar grasses deposit 39% of nitrogen back in their dung compared with 42% for other grasses, and 26% of nitrogen in urine compared with 35% (Farmers Weekly, 30/05/2008).

Ramirez-Restrepo & Barry (2005) looked at the use of alternative temperate forages to improve the sustainable production of grazing ruminants. Of the forages reviewed, the herb chicory and the condensed tannin-containing legumes Birdsfoot trefoil (*Lotus corniculatus L. sulla)* offered the most advantages. Chicory and Birdsfoot trefoil promoted faster growth rates in young sheep and showed reduced CH_4 production in other studies. Cattle grazing on *Birdsfoot trefoil* were associated with increases in reproductive rate, milk production and reduced CH_4 production, effects that were mainly due to its content of condensed tannins.

Oliveira & Berchielli (2007) reviewed the potential of tannins in forage conservation and ruminant nutrition in Brazil. Positive effects are mainly related to a better use of the dietary protein and an increased efficiency of microbial protein synthesis in the rumen. They stated that the use of tannins to reduce ruminal CH_4 emissions has been the subject of current research, firmly indicating a decrease in ruminal methanogenesis.

John Wallace (Head of the Rowett's Microbial Biochemistry group) concluded that in lambs, fumaric acid inclusion in the diet reduced CH_4 production by 70% and increased feed conversion efficiency by 10%. (Farmer's Weekly 13/01/2006). The most natural way to depress CH_4 production is to manipulate the diet to give high rates of fermentation and/or passage through the rumen, affecting rumen volatile fatty acids (VFAs) (Hopkins & Lobley, 2009).

Livestock in upland and marginal areas may be associated with high CH_4 emissions per unit of output (due to relatively low quality forage) but low emissions per hectare. Many of these areas also have a role in CH_4 capture, and their management via low intensity beef and sheep grazing is also important in achieving wider agri-environmental objectives. However, it has been suggested that older swards, such as those aged more than 20 years, may no longer act as a carbon sink. (Hopkins & Lobley, 2009)

N_2O emissions have also decreased in recent years. The main agricultural source is from the oxidation of the nitrogen in fertilisers, accounting for 68% of all N_2O emissions. The rate of application has fallen by a third over the last 10 years (Defra, 2009). N_2O emissions can be reduced by increasing efficiency of nitrogen management in all agricultural systems by minimising residual nitrogen.

Hoekstra *et al* (2007) identified three pathways through which more efficient N utilisation by grazing can be achieved: (1) matching protein supply to animal requirements, (2) balancing and synchronising carbohydrate and N supply in the rumen, and (3) increasing the proportion of rumen undegradable protein. Matching the diet requirements of grazing bovines through herbage manipulation encompasses the manipulation of carbon (C) and nitrogen (N) contents of growing herbage. These C and N contents vary both spatially within the grass sward and over time. Under grazing conditions, grassland management tools, such as the length of the regrowth period, grazing intensity, fertiliser N application rate and herbage variety are the main pathways to manipulate C and N dynamics. Regrowth length, N application rate and high sugar varieties were shown to be the most promising grassland management tools with respect to manipulating herbage quality and subsequent bovine N efficiency.

Lovett *et al* (2004) investigated the effect of rate of inorganic (N) fertiliser (0, 80 or 160 kg N/ha per regrowth), season of harvest (regrowths 1, 2 and 3) and perennial ryegrass (*Lolium perenne* L.) cultivar [classified as having either a normal or elevated water soluble carbohydrate (WSC) concentration genotype] on in vitro gas production and digestibility. They found that increased fertiliser application significantly decreased total gas production, CH_4 production and organic matter digestibility. Season of harvest only significantly altered in vitro OMD and methane production at 8 hours. They concluded that cultivar effects on all measured *in vitro* parameters were not significant because the elevated WSC concentration trait was not expressed strongly in the study.

Andrews *et al* (2007) concluded that GHG emissions resulting from nitrogen fertiliser production could be avoided with the perennial ryegrass/white clover pasture. They highlighted that white clover can provide the N required by a pasture at a lower financial cost than that incurred by the application of N fertiliser. They suggest that nitrate, phosphorus and CH_4 losses from the system, and decreases in biodiversity relative to a grazed indigenous sward are likely to be similar for a perennial ryegrass/white clover pasture and a perennial ryegrass pasture receiving 200 kg N/ha/annum.

Bristow & Jarvis (1991) measured C and N in the soil microbial biomass under swards of perennial ryegrass receiving 210 or 420 kgN/ha per year or of ryegrass/white clover receiving no fertiliser N. Values for microbial C were not significantly different but were usually larger under grass/clover than under grass. Larger N values were again recorded under grass/clover but differences were not significant.

Davies *et al* (2001) tested the hypotheses that N mineralisation and losses following incorporation of grass clover swards are greater than from grass swards and the second hypotheses that N mineralisation and losses following incorporation of previously grazed swards are greater than previously cut swards. His results showed that there was a higher N release after ploughing from the grass-fallow treatment (449 kg N/ha) than from the grass-clover fallow treatment (244 kg N/ha) over 18 months. Results also showed that the net release of N after ploughing and reseeding, was about 85 kg/ha for the grass clover plots and 140 kg/ha for the grass only plots, over the following 18 months. Of this the net releases in the second cropping season after incorporation were 19 and 25 kg N/ha on the resown grass-clover and grass-only plots respectively. Davies *et al* (2001) also calculated that the net release of mineral N after ploughing in 1993/1994, when swards had not been grazed for over a year, was only about 40 kg/ha and no effect of the previous sward was evident. In the 7 weeks after the 1992 ploughing, there was a considerable short-term input of N_2O to the atmosphere (1.5 - 3.7 kg N/ha), due to the supply of readily available C. Leaving swards ungrazed and unfertilised over winter before ploughing in spring has the potential to reduce such emissions considerably. It was concluded that N release following cultivation of grazed swards is more a function of grazing intensity and history prior to ploughing rather than of sward composition.

Shepherd *et al* (2001) investigated nitrate leaching from reseeded pasture and found that nitrate-N leaching losses during the winter immediately following autumn reseeding ranged between 60 and 350 kgN/ha in 1995/96, depending on soil type, sward management history and rainfall. Losses were much less in the following winter when treatments were repeated (10 -107 kgN/ha). Reseeding in spring had little effect on soil mineral N content or leaching losses in the following autumn, compared with undisturbed pasture. Similarly, leaching losses from autumn reseeds in the second winter after cultivation were the same as undisturbed pasture (1-19 kgN/ha). They concluded the effect of ploughing grassland for reseeding was relatively short-term, in contrast to the effect of repeated annual cultivation associated with arable rotations.

2.3 Conclusions

CH_4, N_2O and CO_2 emissions from agriculture need to be reduced to help the UK achieve its target for GHG emissions nationally. Alterations to ruminant diets and increasing feed efficiency may reduce CH_4 emissions but could increase CO_2 emissions.

Improving pasture quality through reseeding with new, more productive varieties with a longer growing season can increase animal performance and consequently reduce CH_4 emissions. Liveweight gain of beef cattle can be up to 0.4 kg/day greater on improved pasture compared to permanent pasture. Hopkins (2000) quoted that daily gains of up to 1.25 kg from cattle and 300g from growing lambs are theoretically obtainable with high quality pasture.

Including nitrogen fixing crops/nitrogen efficient crop varieties will reduce the need for artificial nitrogen applications and consequently reduce N_2O emissions. Legumes have the potential to replace many N-fertilised grass swards and help reduce the need for purchased protein-rich feed. Lamb daily growth rates on a grass/clover ley can be up to 60 g/day greater than on a grass only ley.

A shorter period from birth to slaughter can reduce GHG emissions, particularly CH_4, per kg of meat produced. Longer lived, slower maturing animals will produce more CH_4 per tonne of production. Hopkins & Lobley (2009) highlighted how the longer the production cycle for beef and lamb the higher the CH_4 emissions. They referred to Williams *et al,* (2006) and quoted how CH_4 emissions were lowest from cereal finished beef and up to 50% higher when finishing at grass.

The main benefits of reseeding include: improved varieties of grass and clover, increased palatability, increased protein (from white and red clovers), improved response to nitrogen, reduced nitrogen requirement (with clover), opportunity to tackle weeds, and less disease. As quoted by Fitzgerald (2008), well managed reseeded swards will give higher total yields, will grow earlier and later in the year and will give silage of higher digestibility which is easier to preserve. However reseeding is questionable at low stocking rates (below 1.5 LU per ha).

Maintaining grassland as long term pastures enables increased soil C storage (Hopkins & Lobley 2009). However there is a potential trade-off between maintaining soil C in long-term grassland, and resowing with nutritionally superior grasses or other forages that might help reduce enteric CH_4 emissions compared with lower value forage. There is a need for further research to quantify the overall GHG balance of this choice on a site-specific basis.

3.0 Method

Process diagrams for grass land production were created in Excel, using the method and boundaries set out in PAS2050. A 5-year ley period was assessed, and where appropriate, this included the first year's emissions for establishment divided over the 5 years plus annual emissions. Emissions assessed included those from the production of raw materials (fertilisers, seed, pesticides), transport of raw materials, tractor operations (ploughing, harrowing, spraying, etc.), soil emissions from nitrogen fertiliser and lime applications and the incorporation of crop residues (where relevant), and any emissions from waste, such as packaging from raw materials.

Process diagrams for store cattle and finishing lambs were calculated based on the PAS2050 method, but this was adapted to remove all of the production processes involved in producing the 350 kg finishing cattle (cow, bull, feed, medicines etc) or the lambs (4.5 kg birth weight) (ram, ewe, fed etc). It was assumed that all animals entering the pasture were produced in the same way, and therefore would have the same emissions. The calculations look at the effects of the different emissions from grassland improvement and resultant growth rate differences on the kg CO_2e emissions per kg live weight gain. Emissions included were those from the grass, plus soil and animal emissions produced as a result of the animals grazing. The final figure is only related to the emissions produced during the grazing period and does not represent a carbon footprint of beef or lamb production.

The permanent pasture is assumed to be well managed in terms of grazing heights and that fertiliser inputs are set to maintain soil pH and P and K status at desirable levels for optimum production. Clover content is considered to be negligible. The grass seed mixture is assumed to be suitable as a 5-year ley containing modern varieties of hybrid grasses and white clover.

3.1 Reseeding methods:

Full reseed (FR): incorporation of the old sward into the ground by ploughing followed by discing (x2) and harrowing (x3), seed and fertiliser application and rolling.

Over-seed (OS): spraying off with glyphosate, harrowing (x3), fertiliser and seed broadcasting followed by rolling.

Rejuvenation (R): harrowing (x2), fertiliser and seed broadcasting, rolling.

Direct drill (DD): drilling seed, harrowing (x2), rolling.

CO_2 emissions from field cultivations were calculated from tractor work rates and fuel energy use multiplied by a carbon conversion factor of 0.069 (Defra, 2008)

Assumptions made for all swards:

- Soil has a moderate soil nitrogen supply (SNS)
- Crop is spring sown
- P index 2

- K index -2
- Grazed by beef or sheep at maximum stocking density
- Grass average growth class on medium soil
- Sulphur deficiency indicated

Table 6 shows all the crop inputs for the year of establishment and the subsequent four years of production.

Table 6 Assumed Crop Inputs

	PP	FR	OS	R	DD
Establishment **Year 1**					
Seed (kg/ha)	-	35	35	20	20
Nitrogen (kg/ha)	-	60	60	60	60
Phosphate (kg/ha)	-	50	50	50	50
Potash (kg/ha)	-	60	60	60	60
Annual inputs					
N (kg/ha) (1)	200	100	100	100	100
or N (kg/ha) (2)	150	50	50	50	50
P (kg/ha)	20	20	20	20	20
S (kg/ha)	33	33	33	33	33
Lime (kg/ha)*	860	860	860	860	860
Herbicides (kg/ha)	0.97	0.89	0.89	0.89	0.89
Fungicides (kg/ha)	-	0.19	0.19	0.19	0.19
Grass yield - years 1 and 2 (t/ha)	8	10	10	9	9

* equivalent to 4.3t/ha over 5 years.

3.2 Calculation of N_2O, CO_2 and CH_4 emissions

In order to register and account effectively for annual greenhouse gas (GHG) emissions from agriculture, the method used should be adequately accurate. The Intergovernmental Panel on Climate Change (IPCC) provide standard international guidelines on the methods to use, which may be one of three, *viz*: Tier 1, Tier 2 or Tier 3, which increase in their complexity, but also in their accuracy (IPCC, 1997; IPCC, 2006). The standard IPCC Tier 1 methodology is simple and generalised, due to its intended initial wide scope of application and uses IPCC equations and IPCC default parameter values (e.g. emission factors). The Tier 2 methodology can use the same methodological approach as Tier 1, but applies default parameter values that are based on country or region specific data. Tier 3 provides emission estimates of a greater accuracy than from the two lower Tiers through the use of higher order methods, including models and inventory management systems tailored to address national circumstances.

The current UK Agricultural GHG Emissions Inventory (Choudrie et al., 2008, inventory year 2006) is estimated using the standard Tier 1 IPCC revised 1996 methodology for all calculations of nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions (IPCC, 1997). Methane (CH_4) emissions are also calculated using the Tier 1 approach, with the exception of enteric fermentation and manure management emissions from the dairy cow herd, the beef herd and other cattle < 1 year old. For these emissions, the Tier 2 approach is used.

As a result of new global research and improved scientific understanding, the revised 1996 IPCC inventory methodology has recently been *updated* incorporating new default values and equations for some of the emission estimate calculations. We have used the updated 1996 IPCC methodology (i.e. IPCC 2006) to estimate agricultural N_2O, CH_4 and CO_2 emissions in this project. The IPCC 2006 method is also used in the PAS2050:2008, "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services"' for the calculation of carbon footprints. As indicated by the PAS 2050:2008 document, agricultural N_2O and CH_4 emissions should be calculated with "the highest tier approach set out in the IPCC (2006) Guidelines for National Greenhouse Gas Inventories or the highest tier approach employed by the country in which the emissions were produced". In this project, the 2006 IPCC method was followed using the same tier approach to that used to calculate the latest published UK Agricultural Greenhouse Gas Inventory for 2006 (Choudrie et al., 2008) with the exception of CH_4 emissions from sheep and lambs. In this project, as with the beef cattle, it was necessary to calculate sheep and lamb CH_4 emissions from enteric fermentation and from grazing using the Tier 2 approach, rather than the Tier 1 approach used in the 2006 GHG inventory, to take into account different grass quality/livestock weight gains between contrasting grassland types. The UK (country) specific data required for the Tier 2 approach was taken from the latest published UK Agricultural Greenhouse Gas Inventory for 2006 (Choudrie et al., 2008) or from expert opinion within ADAS (personal communications from Kate Phillips and Owen Davies).

It should be noted, however, that Defra has no immediate plans to use the IPCC 2006 methodology to calculate agricultural GHG emissions in the UK GHG inventory (personal communication, Laura Cardenas).

3.3 Carbon storage and associated nitrous oxide (N_2O) emissions

There is growing emphasis being placed on soil carbon (C) storage in the mitigation of climate change and various measures are being explored to determine how best soil organic C storage (SOC) levels can be increased (e.g. Defra, 2008).

Data from the National Soils Inventory (NSI) indicates that grassland top soils typically contain 4.2% SOC (1995/96 data), compared with 2.8% in arable/ley soils (Webb et al., 2001). In contrast, the conversion of tillage land to grassland can result in increased SOC storage in the range 1.1 to 7.0 t CO_2e/ha/year (Dawson & Smith, 2006). Permanent grassland pasture will increase SOC storage as soils are not annually cultivated, (since cultivation stimulates organic matter breakdown).

With all estimates of potential changes in SOC storage, it must be recognised that annual rates of accumulation (or depletion) change over time. After a change of management or land use, SOC content tends to move towards a new equilibrium value (after 100 years or more) that is characteristic of the soil type, land use and climate (Johnston & Poulton, 2005). Consequently, annual rates of SOC accumulation (or depletion) change over time and gradually decline as the new equilibrium is approached, when they become zero. The greatest rate of increase/decrease will therefore occur in the early years following change, with *c.*50% of the long-term (*c*.100 years) SOC accumulation occurring in the first 20 years (Johnston & Poulton, 2005). A result of this 'diminishing return' situation is that, whatever annual rate of SOC increase/decrease is estimated, it must not be assumed that it will continue indefinitely. Eventually (e.g. after a period of *c*.100 years) the annual rate of SOC increase/decrease will be zero.

Soil carbon accumulation is also reversible, maintaining SOC at the new equilibrium level is then dependent on continuing the new management practice/land use indefinitely. Full re-seeding of a permanent grassland pasture and the associated soil cultivation will, therefore, result in a substantial loss of the accumulated SOC. Indeed, the conversion of grassland or permanent cropping to tillage cropping has been estimated to result in C losses in the range 2.2 to 6.2 t CO_2e/ha/year (Dawson & Smith, 2006), largely due to vegetation clearance, increased soil organic matter decomposition rates upon cultivation and losses of C through erosion (Freibauer *et al.,* 2004).

When considering the carbon storage potential of agricultural practices, including pasture renewal, the overall effect of the practice on all greenhouse gases (i.e. CO_2, N_2O and CH_4) needs to be considered, although, they have not always been extensively quantified, leading to further uncertainty.

The decomposition of organic matter, which occurs following cultivation of a permanent grassland pasture, does not only lose SOC as carbon dioxide, but soil organic nitrogen will also be lost as N_2O. Within this project, this was not calculated as, although the IPCC (2006) methodology includes a term for the calculation of N_2O emitted following soil nitrogen mineralisation (as a result of loss of soil C through a change in land use or management), the IPCC Tier 1 and Tier 2 methods for the calculation of carbon storage/depletion do not appear to completely account for a full re-seeding of grassland. Additionally, within the current UK GHG inventory no N_2O emissions have been calculated associated with SOC loss. It is believed that the IPCC method, i.e. to take the CO_2 emission due to a specific change and then use the C:N ratio for the soils being disturbed to estimate the N lost due to the mineralisation of organic matter, is not scientifically sound (Choudrie *et al.,* 2008). The inventory compilers have decided therefore to await an alternative approach to estimating N_2O emissions due to land use change before including any data in the inventory. The 2006 IPCC method is also based on the C:N ratio. On this basis, in this project, we have not included any N_2O emissions from this potential loss pathway, although it is part of the tier 1, 2006 IPCC approach.

3.4 Livestock Production

3.4.1 Cattle

The cattle are assumed to be 350 kg steers at the start of the grazing season in April. They stay at grass until the end of September and emissions are based on the average performance over this period only. Grazing is well managed throughout the season and grass heights maintained at ideal levels. The metabolisable energy of the grass has been assumed as 11.0 MJ/kgDM for permanent pasture and 11.5 MJ/kgDM for the full reseed and the over-seed and 11.25MJ/kgDM for the rejuvenated and direct drilled swards (with new varieties mixed with the original grasses). Grass growth has been assumed to decline as the reseeded pastures deteriorate over time, with R and DD showing greater decline than FR and OS.

Tables 7 and 8 show the performance parameters used in the process diagrams for calculation of emissions.

Table 7 Cattle performance assumptions year 1 and 2

	PP	FR	OS	R	DD
Growth rate (kg/day)	0.7	0.85	0.85	0.78	0.78
MJ/day *	80	89	89	84.5	84.5
Stocking rate steers/ha	5.5	6.5	6.5	6	6
Average weight (kg)	413	427	427	420	420
Wt at end of 180 days (kg)	476	503	503	489	489
Total wt gain per animal (kg)	126	153	153	139	139
Total wt gain (kg/ha)	693	995	995	834	834
Grass yield t/ha **	8	10	10	9	9

*AFRC 1995
** 90 % of the grass yield is assumed to be utilised.

Performance in the subsequent 3 years was based on the following grass yields and stocking rates:

ADAS

Table 8 Grass yields and stocking rates years 3, 4 and 5

	PP	**FR**	**OS**	**R**	**DD**
Year 3					
Grass yield (t/ha)	8	9.5	9.5	8.5	8.5
Steers/ha	5.5	6.1	6.1	5.6	5.6
Year 4					
Grass yield (t/ha)	8	9.25	9.25	8.25	8.25
Steers/ha	5.5	5.9	5.9	5.4	5.4
Year 5					
Grass yield (t/ha)	8	9	9	8	8
Steers/ha	5.5	5.7	5.7	5.2	5.2

3.4.2 Sheep

The sheep are assumed to be lowland ewes of 70 kg mature body weight, lambing in April and with twin lambs (4.5 kg birth weight). The ewes stay with the lambs until weaning at 16 weeks. Lambs are kept on the farm through the 180-day grazing period to the end of September but it is recognised that in practice many of the lambs on the reseeded pastures are likely to have been slaughtered by 22 weeks (150 days) of age. Emissions have only been calculated for the ewe and her twin lambs from April through to September. Energy requirements were taken from AFRC (1995) and included the ewe and her two lambs for the whole 180 days. Tables 9 and 10 show the performance parameters used in the calculation of emissions.

Table 9 Lamb performance – birth to 6 months of age

	PP	FR	OS	R	DD
Lamb wt gain (g/day) to 6 weeks	250	275	275	263	263
Lamb wt gain (g/day) 6 to 16 weeks	225	250	250	238	238
Lamb wt gain (g/day) post weaning	150	175	175	163	163
Days to reach 40 kg	**174**	**149**	**149**	**160**	**160**
Total wt gain to 180 days	36.75	41.3	41.3	39.1	39.1
Final wt at 180 days	41.25	45.8	45.8	43.6	43.6

Table 10 Grass yields and sheep stocking rates years 1 to 5

	PP	FR	OS	R	DD
Years 1 and 2					
Grass yield	8	10	10	9	9
Ewes (+lambs) per ha	14	17.5	17.5	15.7	15.7
Year 3					
Grass yield	8	9.5	9.5	8.5	8.5
Ewes (+lambs) per ha	14	16.4	16.4	14.7	14.7
Year 4					
Grass yield	8	9.25	9.25	8.25	8.25
Ewes (+ lambs per ha)	14	15.9	15.9	14.0	14.0
Year 5					
Grass yield	8	9	9	8	8
Ewes (+ lambs per ha)	14	15.4	15.4	13.5	13.5

4.0 Results

The CO_2 emissions from the field cultivations of reseeding are shown in Table 11. These clearly show the large difference in emissions related to the full reseed compared to the other methods which is largely related to the tractor power required for ploughing.

Table 11 CO_2 emissions from field cultivations

Reseeding method	Total CO_2 kg/ha
Full reseed	146.182
Over-seed	58.307
Rejuvenation	37.196
Direct drill	47.048

Assumptions:
1) The work rates chosen are the typical work rate for the machines in hours/ha
2) Embodied energy within machines has not been incorporated as per PAS2050 standard
3) Embodied energy in crop spray has not been included

4.1 Emissions from reseeding

The total emissions from establishment of pasture reseeds and annual maintenance in terms of fertiliser inputs and energy use are shown in Table 12.

Table 12 Grassland emissions

	PP	FR	OS	R	DD
Average total emissions *$kgCO_2e/ha$ @200kgN/ha on PP and 100 kgN/ha on other pastures	3260	2350	2340	2190	2190
Total establishment ** inputs ($kgCO_2e/ha$)		780	780	720	720
Total emissions from annual inputs *** ($kgCO_2e/ha$)	1620	920	920	920	920
Average energy use * ($kgCO_2e/ha$)	50	80	60	60	60
Average soil emissions * ($kgCO_2e/ha$)	1590	1200	1200	1070	1070

*All figures include one fifth of the establishment emissions plus annual inputs.
** Includes all fertiliser inputs and seed
*** Includes all fertiliser inputs and lime

The emissions from permanent pasture are much higher than from the reseeded pastures largely as a consequence of the much higher N application rate of 200 kg/ha compared to 100 kg/ha (reseeds with clover). There is little to choose between the methods of reseeding in terms of annual emissions but it would appear that over-seeding is likely to generate slightly lower emissions than a full reseed (with ploughing) through lower use of machinery.

At lower levels of N application emissions would be as shown in Table 13.

Table 13 Grassland emissions

	PP	FR	OS	R	DD
Average total emissions *$kgCO_2e/ha$ @150kgN/ha on pp and 50 kgN/ha on other pastures	2588	1692	1678	1534	1536
Total establishment ** inputs ($kgCO_2e/ha$)		720	720	710	710
Total emissions from annual inputs *** ($kgCO_2e/ha$)	1260	560	560	560	560
Average energy use * ($kgCO_2e/ha$)	40	70	60	50	50
Average soil emissions * ($kgCO_2e/ha$)	1280	890	890	760	760

* All figures include one fifth of the establishment emissions plus annual inputs.
** Includes all fertiliser inputs and seed
*** Includes all fertiliser inputs and lime

4.2 Animal Emissions

Animal performance data (live-weight gains and stocking rates) were used to calculate emissions per kg of live-weight gain. These are shown in Table 14 for cattle and Table 15 for lambs.

Table 14 Emissions per kg live-weight gain - steers

$kgCO_2e$/kg live-weight gain	PP	FR	OS	R	DD
Years 1 and 2		9.2	9.2	10	10
Year 3		9.8	9.8	10.7	10.7
Year 4		10.1	10.1	11.1	11.1
Year 5		10.5	10.5	11.5	11.5
Average over the five years (200 kgN/ha for PP and 100 kgN/ha for other pastures)	12.7	9.8	9.8	10.7	10.7
Average over the five years (150 kgN/ha for PP and 50 kgN/ha for other pastures)*	12.2	9.0	9.0	9.8	9.8

* Assumes the same level of DM yield and same animal performance.

Table 15 Emissions per kg live-weight gain - lambs

$kgCO_2e$/kg live-weight gain	PP	FR	OS	R	DD
Years 1 and 2		6.0	6.0	6.5	6.5
Year 3		6.1	6.1	6.5	6.5
Year 4		6.2	6.2	6.7	6.7
Year 5		6.3	6.3	6.8	6.8
Average over the five years (200 kgN/ha for pp and 100 kgN/ha for other pastures)	8.2	6.4	6.4	6.6	6.6
Average over the five years (150 kgN/ha for PP and 50 kgN/ha for other pastures)*	7.9	5.6	5.6	6.0	6.0

* Assumes the same level of DM yield and same animal performance for reseeded pastures, but 1 tonne less DM from PP.

Alternative levels of fertiliser application for PP were also investigated. The calculations assumed a response rate of 20 kgDM/kg N applied. The results are shown below in tables 16 and 17.

Table 16 Performance of cattle on permanent pasture at varying levels of N application

kgN/ha	Grass DM/ha	Stocking rate (steers/ha)	kg live-weight gain/ha	kgCO2e/kg live-weight gained
200	8	5.5	693	12.7
150	7	4.8	605	12.2
100	6	4.1	520	11.6
50	5	3.4	428	10.8
0	4	2.8	347	9.8

Table 17 Performance of sheep on permanent pasture at varying levels of N application

kgN/ha	Grass DM/ha	Stocking rate (ewes/ha)	kg Live-weight gain/ha	$kgCO_2e$/kg live-weight gained
200	8	14.0	1028.2	8.1
150	7	12.3	905	7.9
100	6	10.5	771	7.5
50	5	8.8	642	6.9
0	4	7.0	514	6.1

5.0 Conclusions

The improved performance of livestock on modern varieties of grass and clover has been well researched and is ongoing as new varieties are developed and marketed. This work aimed to evaluate whether the benefits in live-weight gain were adequate to offset the increased emissions of GHGs associated with reseeding. Table 18 summarises the main findings of this work.

Table 18 Summary of emissions from grassland production and cattle and sheep live-weight gain during the grazing season

	PP	FR	OS	R	DD
Emissions from grass production (over 5 years)					
Average total emissions *$kgCO_2e$/ha @200kgN/ha on PP and 100 kgN/ha on other pastures	3260	2370	2350	2220	2220
Average total emissions *$kgCO_2e$/ha @150kgN/ha on PP and 50 kgN/ha on other pastures	2588	1660	1650	1520	1520
Cattle - emissions $kgCO_2e$/kg live-weight gain					
Average over the five years (200 kgN/ha for PP and 100 kgN/ha for other pastures)	12.7	9.8	9.8	10.7	10.7
Average over the five years (150 kgN/ha for PP and 50 kgN/ha for other pastures)*	12.2	9.0	9.0	9.8	9.8

Sheep - emissions $kgCO_2e$/kg live-weight gain					
Average over the five years (200 kgN/ha for PP and 100 kgN/ha for other pastures)	8.2	6.4	6.4	6.6	6.6
Average over the five years (150 kgN/ha for PP and 50 kgN/ha for other pastures)*	7.9	5.6	5.6	6.0	6.0

The calculations were reworked using a significantly lower level of N application with all swards receiving only 50 kgN/ha. Even at this level of fertiliser on the PP, emissions per kg live-weight gain for both store cattle and growing lambs were lower on all reseeded pastures (10.8 $kgCO_2e$/kg live-weight gain in steers and 6.9 $kgCO_2e$/kg live-weight gain in lambs on PP with 50 kgN/ha).

It is clear from the calculations that emissions from permanent pasture using the chosen levels of N fertiliser are significantly higher than from reseeded pastures, despite the emissions generated by soil disturbance and machinery when reseeding by whichever method chosen. The increased animal performance achieved on improved pastures (with clover) further outweighs the emissions from reseeding giving consistently lower emissions per kg of live-weight gain for all reseeded pastures. Emissions per hectare of land are highly dependent on nitrogen fertiliser input, grass yield, nutritional value of the sward, utilisation and animal stocking rate and will vary very considerably from site to site. Further scenarios could be tested using the same methodology.

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